A-level chemistry students' conceptions and understandings of the nature of chemical reactions and approaches to the learning of chemistry content.

Boo, Hong Kwen

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A-LEVEL CHEMISTRY STUDENTS' CONCEPTIONS AND UNDERSTANDINGS OF THE NATURE OF CHEMICAL REACTIONS AND APPROACHES TO THE LEARNING OF CHEMISTRY CONTENT

HONG KWEN BOO

Thesis submitted in fulfilment of the requirements for the Ph.D. degree of the University of London

Centre for Educational Studies
King's College London
University of London
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Above all, I thank God, Father, Son and Holy Spirit, the ultimate Power and Source of all guidance, help, support and encouragement; Who is before all things, from Whom all Blessings flow and in Whom all things hold together.
ABSTRACT

This study is concerned with the development of insights into the kinds of conceptions and understandings that A-level students have with respect to the nature of chemical reactions. The interview-about-events technique was used to elicit students' ideas, explanatory models and theories about the nature of chemical reactions. Five main events, involving chemical phenomena familiar to the students, were used as foci for discussion during the interviews. Based on their knowledge of the properties of the common substances involved, students were asked to make predictions about the kinds of chemical reactions and energy changes involved. In addition, for each event, they were asked to provide detailed accounts of how they imagined the reaction taking place at the microscopic level and why they thought the reaction takes place.

The 48 students were each interviewed twice, using essentially the same interview schedule; once when they were in their lower sixth form, and second time when they were in the upper sixth form. This longitudinal approach enabled the investigation of students' progression in conception and understanding with increased exposure to formal chemistry instruction.

The consistency of students' ideas was examined by comparing students' conceptions and understandings across the five events.

The main study findings are that, whilst most students gave a good account of the reactants and products involved, they were less able in their explanations of the processes or energetics of chemical reaction. Contrary to expectations for A-level, few students were able to utilise the scientist's approach of using a single, consistent conceptual model or framework to explain a multiplicity of superficially different events. Rather, these students held a variety of task related alternative frameworks in much the same way as younger students in earlier studies.
CONTENTS

Acknowledgements
Abstract
Contents
List of tables
List of appendices
Glossary of terms
Nomenclatures used in this thesis

1 INTRODUCTION
1.1 Background and rationale for the study
1.2 Design of the study
1.3 Aims of the study
1.4 Procedural summary
1.5 Structure of the thesis

2 REVIEW OF THE RELATED LITERATURE
2.1 Concepts and conceptualisation
2.2 View of learning and teaching
2.3 Students' conceptions and difficulties in learning science/chemistry
   2.3.1 How students' alternative conceptions (ACs) arise
   2.3.2 Issues relating to consistency of ACs (or stability of ACs) across task context
   2.3.3 Issues relating to stability of ACs over time (or persistence of ACs)
2.4 Overview on studies in chemistry
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4.1</td>
<td>Students' conceptions and understandings of chemical and physical changes</td>
</tr>
<tr>
<td>2.4.2</td>
<td>Students' understandings about the particulate nature of matter</td>
</tr>
<tr>
<td>2.4.3</td>
<td>Chemists' understanding of chemical reactions</td>
</tr>
<tr>
<td>2.4.4</td>
<td>Students' conceptions of the nature of chemical reactions</td>
</tr>
<tr>
<td>2.4.4.1</td>
<td>The 'what', the 'how' and the 'why' of chemical change</td>
</tr>
<tr>
<td>2.4.4.2</td>
<td>On different types of reactions</td>
</tr>
</tbody>
</table>

**3** RESEARCH METHODS AND PROCEDURES

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Theoretical framework of research</td>
</tr>
<tr>
<td>3.2</td>
<td>Research questions</td>
</tr>
<tr>
<td>3.3</td>
<td>Research design</td>
</tr>
<tr>
<td>3.4</td>
<td>The sample</td>
</tr>
<tr>
<td>3.5</td>
<td>Data collection</td>
</tr>
<tr>
<td>3.5.1</td>
<td>The interview-about-events</td>
</tr>
<tr>
<td>3.5.2</td>
<td>The interview mode and style</td>
</tr>
<tr>
<td>3.5.3</td>
<td>Events/tasks used and rationale for choosing them</td>
</tr>
<tr>
<td>3.5.4</td>
<td>The interview procedure</td>
</tr>
<tr>
<td>3.5.5</td>
<td>Validity and reliability of the interview method</td>
</tr>
<tr>
<td>3.5.6</td>
<td>Supplementary data collected</td>
</tr>
<tr>
<td>3.6</td>
<td>Data analysis</td>
</tr>
<tr>
<td>3.7</td>
<td>Summary of chapter</td>
</tr>
</tbody>
</table>
4 STUDENTS' UNDERSTANDINGS AND ALTERNATIVE CONCEPTIONS WITH RESPECT TO ASPECT A, TYPE OF CHANGE PREDICTED

4.0 Overview

4.1 Analysis of students' responses on aspect A over all 5 events

4.2 Analysis of students' responses on aspect A by event by school

4.3 Analysis of students' responses on aspect A by event by sex

4.4 Students' alternative conceptions associated with aspect A, prediction about type of change (in terms of reactants and products)

4.5 Summary of chapter

5 STUDENTS' UNDERSTANDINGS AND ALTERNATIVE CONCEPTIONS WITH RESPECT TO ASPECT B, TYPE OF CHANGE PREDICTED

5.0 Overview

5.1 Analysis of students' responses on aspect B over all 5 events

5.2 Analysis of students' responses on aspect B by event by school

5.3 Students' alternative conceptions associated mainly with aspect B, prediction on overall energy change

5.4 Summary of chapter

6 STUDENTS' UNDERSTANDINGS AND ALTERNATIVE CONCEPTIONS WITH RESPECT TO ASPECT C, HOW THE REACTION TAKES PLACE

6.0 Overview

6.1 Analysis of students' responses on aspect C over 5 main events

6.2 Analysis of students' responses on aspect C by event by school

6.3 Alternative conceptions associated mainly with aspect C, how the reaction takes place

6.4 Summary of chapter
STUDENTS' UNDERSTANDINGS AND ALTERNATIVE CONCEPTIONS WITH RESPECT TO ASPECT D, HOW THE REACTION TAKES PLACE

Overview

Analysis of students' responses on aspect D over all 5 events

Analysis of students' responses on aspect D by event by school

Alternative conceptions associated mainly with aspect D, driving force or why the reaction takes place

Summary of chapter

DISCUSSION AND CATEGORISATION OF STUDENTS' UNDERSTANDINGS AND ALTERNATIVE CONCEPTIONS OF THE NATURE OF CHEMICAL REACTIONS

Introduction

Summary of students' scores over the four aspects

Summary of students' attainment by school by event

Students understandings across events

8.3.1 Summary of students' ACs by event type

8.3.2 Discussion of students' understanding of the events

Students' understandings across the four aspects

8.4.1 Summary of students' ACs regarding the process of chemical reaction

8.4.2 Discussion of student understanding of the process of chemical reaction

Categorisation of alternative conceptions

8.5.1 Category 1: ACs associated with naive chemistry

8.5.2 Category 2: ACs associated with the process of bonding and the nature of bonds

8.5.3 Category 3: ACs associated with driving force

Students' understanding of chemical versus physical change

Summary of chapter
9 PROGRESSION AND NON-PROGRESSION AMONG STUDENTS IN THE STUDY

9.0 Overview

9.1 Forms and patterns of progression

9.2 Relationship between KE and AC scores
   9.2.1 Procedural issues
   9.2.2 Results obtained

9.3 Persistence of ACs at U6

9.4 Delineation and general description of the top and bottom group of students

9.5 Pattern of progression among the top and bottom group students - similarities and differences

9.6 Some possible reasons why top group progress more than the bottom group

9.7 Discussion regarding possible reasons for increase in ACs between interviews

9.8 Relationship between chemistry understanding at A-level and science subjects studied at GCSE

9.9 Summary of chapter

10 CONSISTENCY AND INCONSISTENCY OF STUDENTS' VIEWS ACROSS EVENTS

10.0 Introduction

10.1 Consistency or inconsistency in responses on aspect B, overall energy change

10.2 Consistency or inconsistency related to aspect D, why the reaction was thought to have taken place

10.3 Summary of chapter

11 STUDENTS' LEARNING APPROACHES

12 CASE STUDY
13 CONCLUSIONS OF STUDY

13.1 Discussion of the study results

13.1.1 Overview of the study results
13.1.2 Progression and non-progression in students' conceptions
13.1.3 Consistency and inconsistency of students' conceptions
13.1.4 Categorisation of students' understandings
13.1.5 Why chemistry learning is so difficult (including sources and causes of ACs)

13.1.5.1 Basic difficulties
13.1.5.2 Inconsistencies within chemistry and between science subjects
13.1.5.3 Discrepancies between school science and actual science (and everyday life)
13.1.5.4 Discontinuity between chemistry learned at lower levels and at A-level

13.2 Review of research methodology
13.3 Significance of the findings and implications for science education
13.4 Areas for further study
13.5 Concluding remarks

Appendix A 287
Appendix B 289
Appendix C 294
Appendix D 303
Appendix E 319
Appendix F 323
Appendix G 324
Appendix H 332
Appendix I 338
Appendix J 341
Appendix K 343
Appendix L 352
Appendix M 393
Appendix N 428
Bibliography 465
Appendix O 488
Appendix P 489
<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Profile of study schools and sample</td>
<td>66</td>
</tr>
<tr>
<td>4.1</td>
<td>Mean U6, L6 and progression scores on aspect A by school</td>
<td>83</td>
</tr>
<tr>
<td>4.2</td>
<td>Mean U6, L6 and progression scores on aspect A by sex</td>
<td>83</td>
</tr>
<tr>
<td>4.3</td>
<td>Mean U6 and L6 scores on aspect A by event by school</td>
<td>84</td>
</tr>
<tr>
<td>4.4</td>
<td>Mean U6 and L6 scores on aspect A by event by sex</td>
<td>86</td>
</tr>
<tr>
<td>4.5</td>
<td>Students subscribing to AC A1a</td>
<td>89</td>
</tr>
<tr>
<td>4.6</td>
<td>Students subscribing to AC A1b</td>
<td>93</td>
</tr>
<tr>
<td>4.7</td>
<td>Students subscribing to AC A1d</td>
<td>99</td>
</tr>
<tr>
<td>5.1</td>
<td>Mean U6, U6 and progression scores on aspect B by school</td>
<td>109</td>
</tr>
<tr>
<td>5.2</td>
<td>Mean U6, L6 and progression scores on aspect B by sex</td>
<td>109</td>
</tr>
<tr>
<td>5.3</td>
<td>Mean U6 and L6 scores on aspect B by event by school</td>
<td>110</td>
</tr>
<tr>
<td>5.4</td>
<td>Mean U6 and L6 scores on aspect B by event by sex</td>
<td>111</td>
</tr>
<tr>
<td>5.5</td>
<td>Students subscribing to AC B1a</td>
<td>112</td>
</tr>
<tr>
<td>5.6</td>
<td>Students subscribing to AC B2a</td>
<td>113</td>
</tr>
<tr>
<td>5.7</td>
<td>Students subscribing to AC B3a</td>
<td>116</td>
</tr>
<tr>
<td>6.1</td>
<td>Mean U6, L6 and progression scores on aspect C by school</td>
<td>122</td>
</tr>
<tr>
<td>6.2</td>
<td>Mean U6, L6 and progression scores on aspect C by sex</td>
<td>122</td>
</tr>
<tr>
<td>6.3</td>
<td>Mean U6 and L6 scores on aspect C by event by school</td>
<td>123</td>
</tr>
<tr>
<td>6.4</td>
<td>Mean U6 and L6 scores on aspect C by event by sex</td>
<td>124</td>
</tr>
<tr>
<td>6.5</td>
<td>Students subscribing to AC C1a</td>
<td>126</td>
</tr>
<tr>
<td>6.6</td>
<td>Students subscribing to AC C2a</td>
<td>128</td>
</tr>
<tr>
<td>6.7</td>
<td>Students subscribing to AC C3a</td>
<td>129</td>
</tr>
<tr>
<td>6.8</td>
<td>Students subscribing to AC C3b</td>
<td>130</td>
</tr>
<tr>
<td>6.9</td>
<td>Students subscribing to AC C3a</td>
<td>131</td>
</tr>
<tr>
<td>6.10</td>
<td>Students subscribing to AC C3d</td>
<td>131</td>
</tr>
</tbody>
</table>
7.1 Mean U6, L6 and progression scores on aspect D by school 144
7.2 Mean U6, L6 and progression scores on aspect D by sex 144
7.3 Mean U6 and L6 scores on aspect D by event by school 145
7.4 Mean scores on aspect D by event by sex 145
7.5 Students subscribing to AC D1a 147
7.6 Students subscribing to AC D1b 150
7.7 Students subscribing to AC D2a 153
8.1 Aspects A to D: percentage of key elements included in the average student's responses (over all students irrespective of school) in the U6 and L6 interviews 157
8.2 Correlation between U6 scores on aspects A, B, C and D 158
8.3 Mean U6 and L6 scores across aspects by event by school and the average overall scores by event 159
9.1 Aspects A to D: percentage of key elements included in the average student's responses (over all students irrespective of school) in the U6 and L6 interviews and the difference in scores between the 2 interviews 197
9.2 Mean progression scores (U-L) by aspect by school 198
9.3 Mean progression (U-L) scores by event 198
9.4 Correlation between different measures related to progression 202
9.5 Correlation between various measures, PRO-KE, TOT-L-KE and PRO-AC 203
9.6 Correlation coefficients among KE and AC measures at U6 and L6 204
9.7 Partial correlations on TOT-KE and TOT-AC scores at U6 and L6 207
9.8 AC groups and their persistence 208
9.9 Total KEs scored at U6 and L6 interviews, and improvement in these scores for top group students 210
9.10 No. of ACs, U6 and L6, and No. and types of ACs abandoned by top group students 211
9.11 Total KEs scored at U6 and L6 interviews, and difference in these scores for bottom group students 212
9.12 Number of ACs, U6 and L6, and No. and types of ACs abandoned by bottom group students 212
9.13 Progression (U6-L6) scores in terms of number of KEs by event for top group students

9.14 Progression (U6-L6) scores by event for bottom group students

9.15 Progression (U6-L6) scores in terms of number of KEs by aspect for top group students

9.16 Progression (U6-L6) scores in terms of number of KEs by aspect for bottom group students

9.17 Incidence of common persistent ACs in top and bottom groups and instances of abandonment

9.18 Actual number of ACs held by top and bottom groups at U6 and L6

9.19 Top and bottom groups: GCSE science subjects and grades

9.20 Relationship between ACs in each category at U6 and L6 by science subject taken at GCSE

9.21 Mean total U6 and L6 and progression scores in terms of KEs

10.1 Summary of categories and criteria used for consistency analysis for aspect B

10.2 Consistency on aspect B: distribution of students by event and by category

10.3 Consistency of students using ideas associated with aspect B across the set of combustion reactions and reactions in solutions

10.4 Students' frameworks on aspect D by event

10.5 Students' frameworks by event groups

12.1 ACs revealed by student R7

A.1 Comparative data on public examination results and absentee rates of study schools

A.2 A-level examination syllabuses and chemistry curriculum time

G.1 U6 and L6 KE scores and progression scores (U-L) for aspect A across events for each student

G.2 U6 and L6 KE scores and progression scores (U-L) for aspect B across events for each student

G.3 U6 and L6 KE scores and progression scores (U-L) for aspect C across events for each student
G.4 U6 and L6 KE scores and progression scores (U-L) for aspect D across events for each student

H.1 Frequencies of ACs

I Number of ACs by student by school by interview counted according to procedure given in section 9.2, chapter 9 (ie limited to maximum of 9 per student)

J Means scores of ACs counted by procedure in section 9.2, chapter 2 by AC category and by school

L.1 Motive and strategy in approaches to learning and studying

L.2 Computation of sub-scales on the Biggs' LPQ

L.4.1 Mean scores on each learning motive-strategy-approach subscales by school

L.4.2 Mean scores on scores Q37-Q50 by school

L.6.1 GCSE subjects and grades; A-level chemistry grades predicted by students themselves and their teacher: school C

L.6.2 GCSE subjects and grades; A-level chemistry grades predicted by students themselves and their teacher: school R

L.6.3 GCSE subjects and grades; A-level chemistry grades predicted by students themselves and their teacher: school P

L.6.4 GCSE subjects and grades; A-level chemistry grades predicted by students themselves and their teacher: school E

L.6.5 GCSE subjects and grades; A-level chemistry grades predicted by students themselves and their teacher: school S
LIST OF APPENDICES

A. Some comparative data on the study schools 287
B. The interview schedule 289
C. Key elements in the expected responses in each of the aspects A-D 294
D. Verbatim transcript for student R7 illustrating the scoring of KEs and ACs 303
E. Record sheets
   E.1 Record sheet showing which KEs and ACs are counted 319
   E.2 Record sheet showing which KEs and ACs are counted for Case I, student R7 321
F. Record sheet showing number of KEs and ACs counted 323
G. Tables G.1, G.2, G.3, G.4 324-331
H. Categorisation of ACs, their descriptions and frequencies 332
I. Table: Number of ACs by student by school by interview, counted according to procedure given in section 9.2, chapter 9 (ie limited to maximum of 9 per student 338
J. Table: Mean scores of ACs counted by procedure in section 9.2, chapter 9 by AC category and by school 341
K. Scatter Plots
   K.1. Plot of TOT-U-KE versus TOT-L-KE 343
   K.2. Plot of T-PRO-KE versus TOT-L-KE 344
   K.3. Plot of T-PRO-AC versus TOT-L-KE 345
   K.4. Plot of T-PRO-AC versus T-PRO-KE 346
   K.5. Plot of T-PRO-KE versus TOT-L-KE for School C 347
   K.8. Plot of T-PRO-KE versus TOT-L-KE for School E 350
INVESTIGATION OF LEARNING APPROACHES OF THE STUDY SAMPLE

L.1 Review of studies on students’ learning approaches with particular emphasis on Biggs’ learning process questionnaire

L.2 Method of the Learning Process Questionnaire

L.3 The Learning Process Questionnaire with covering letter to the respondent

L.4 Findings based on the Learning Process Questionnaire

L.5 Analyses of the Learning Process Questionaire

L.6 Profiles of study schools

L.7 Summary

M. Further case studies

M.1 Student E1 (Case II)

M.2 Student P4 (Case III)

M.3 Student C10 (Case IV)

N. Students’ drawings

N.1.1 L6 Drawings by student R7 (Case I)

N.1.2 U6 Drawings by student R7

N.2.1 L6 Drawings by student E1 (Case II)

N.2.2 U6 Drawings by student E1

N.3.1 L6 Drawings by student P4 (Case III)

N.3.2 U6 Drawings by student P4

N.4.1 L6 Drawings by student C10 (Case IV)

N.4.2 U6 Drawings by student C10

Bibliography

O Reliability of interview data

P Derivation and significance of p-values
GLOSSARY OF TERMS

AA Achieving Approach
AC Alternative Conception
AM Achieving Motive
AS Achieving Strategy
DA Deep Approach
DM Deep Motive
DS Deep Strategy
GCSE General Certificate of Secondary Education
KE Key Element
LPQ Learning Process Questionnaire
L6 Lower sixth form (same as L)
SA Surface Approach
SM Surface Motive
SS Surface Strategy

ULEAC: University of London Examinations and Assessment Council

U6 Upper sixth form (same as U)

The following variable names used in the Minitab software program are used in the body of the text with the following meanings:

A-L-KE KE score on aspect A at L6
A-PRO-KE KE progression score on aspect A
A-U-KE KE score on aspect A at U6
AC-1-L Number of ACs in category 1 revealed at L6
AC1-PRO Progression in ACs in category 1
AC-1-U Number of ACs in category 1 revealed at U6
AC-2-L Number of ACs in category 2 revealed at L6
<table>
<thead>
<tr>
<th>AC2-PRO</th>
<th>Progression in ACs in category 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC-2-U</td>
<td>Number of ACs in category 2 revealed at U6</td>
</tr>
<tr>
<td>AC-3-L</td>
<td>Number of ACs in category 3 revealed at L6</td>
</tr>
<tr>
<td>AC3-PRO</td>
<td>Progression in ACs in category 3</td>
</tr>
<tr>
<td>AC-3-U</td>
<td>Number of ACs in category 3 revealed at U6</td>
</tr>
<tr>
<td>A1-L-KE</td>
<td>KE score on aspect A event 1 at L6</td>
</tr>
<tr>
<td>A1-U-KE</td>
<td>KE score on aspect A event 1 at U6</td>
</tr>
<tr>
<td>A2-L-KE</td>
<td>KE score on aspect A event 2 at L6</td>
</tr>
<tr>
<td>A2-U-KE</td>
<td>KE score on aspect A event 2 at U6</td>
</tr>
<tr>
<td>A3-L-KE</td>
<td>KE score on aspect A event 3 at L6</td>
</tr>
<tr>
<td>A3-U-KE</td>
<td>KE score on aspect A event 3 at U6</td>
</tr>
<tr>
<td>A4-L-KE</td>
<td>KE score on aspect A event 4 at L6</td>
</tr>
<tr>
<td>A4-U-KE</td>
<td>KE score on aspect A event 4 at U6</td>
</tr>
<tr>
<td>A5-L-KE</td>
<td>KE score on aspect A event 5 at L6</td>
</tr>
<tr>
<td>A5-U-KE</td>
<td>KE score on aspect A event 5 at U6</td>
</tr>
<tr>
<td>B-L-KE</td>
<td>KE score on aspect B at L6</td>
</tr>
<tr>
<td>B-PRO-KE</td>
<td>KE progression score on aspect B</td>
</tr>
<tr>
<td>B-U-KE</td>
<td>KE score on aspect B at U6</td>
</tr>
<tr>
<td>B1-L-KE</td>
<td>KE score on aspect B event 1 at L6</td>
</tr>
<tr>
<td>B1-U-KE</td>
<td>KE score on aspect B event 1 at U6</td>
</tr>
<tr>
<td>B2-L-KE</td>
<td>KE score on aspect B event 2 at L6</td>
</tr>
<tr>
<td>B2-U-KE</td>
<td>KE score on aspect B event 2 at U6</td>
</tr>
<tr>
<td>B3-L-KE</td>
<td>KE score on aspect B event 3 at L6</td>
</tr>
<tr>
<td>B3-U-KE</td>
<td>KE score on aspect B event 3 at U6</td>
</tr>
<tr>
<td>B4-L-KE</td>
<td>KE score on aspect B event 4 at L6</td>
</tr>
<tr>
<td>B4-U-KE</td>
<td>KE score on aspect B event 4 at U6</td>
</tr>
<tr>
<td>B5-L-KE</td>
<td>KE score on aspect B event 5 at L6</td>
</tr>
</tbody>
</table>
B5-U-KE KE score on aspect B event 5 at U6
C-L-KE KE score on aspect C at L6
C-PRO-KE KE progression score on aspect C
C-U-KE KE score on aspect C at U6
C1-L-KE KE score on aspect C event 1 at L6
C1-U-KE KE score on aspect C event 1 at U6
C2-L-KE KE score on aspect C event 2 at L6
C2-U-KE KE score on aspect C event 2 at U6
C3-L-KE KE score on aspect C event 3 at L6
C3-U-KE KE score on aspect C event 3 at U6
C4-L-KE KE score on aspect C event 4 at L6
C4-U-KE KE score on aspect C event 4 at U6
C5-L-KE KE score on aspect C event 5 at L6
C5-U-KE KE score on aspect C event 5 at U6
D-L-KE KE score on aspect D at L6
D-PRO-KE KE progression score on aspect D
D-U-KE KE score on aspect D at U6
D1-L-KE KE score on aspect D event 1 at L6
D1-U-KE KE score on aspect D event 1 at U6
D2-L-KE KE score on aspect D event 2 at L6
D2-U-KE KE score on aspect D event 2 at U6
D3-L-KE KE score on aspect D event 3 at L6
D3-U-KE KE score on aspect D event 3 at U6
D4-L-KE KE score on aspect D event 4 at L6
D4-U-KE KE score on aspect D event 4 at U6
D5-L-KE KE score on aspect D event 5 at L6
D5-U-KE KE score on aspect D event 5 at U6
E1-L-KE KE score on event 1 at L6
E1-PROG KE progression score on event 1
E1-U-KE KE score on event 1 at U6
E2-L-KE KE score on event 2 at L6
E2-PROG KE progression score on event 2
E2-U-KE KE score on event 2 at U6
E3-L-KE KE score on event 3 at L6
E3-PROG KE progression score on event 3
E3-U-KE KE score on event 3 at U6
E4-L-KE KE score on event 4 at L6
E4-PROG KE progression score on event 4
E5-U-KE KE score on event 5 at U6
E5-L-KE KE score on event 5 at L6
E5-PROG KE progression score on event 5
TOT-L-KE Total KE score at L6
TOT-PRO-KE Total KE progression score
TOT-PROG Total KE progression score (same as TOT-PRO-KE)
TOT-U-KE Total KE score at U6
T-PRO-KE Total KE progression score (same as TOT-PRO-KE)
NOMENCLATURES USED IN THIS THESIS

A number of referencing nomenclatures are used in this thesis. These are defined below:

1. **SCHOOL REFERENCES**

   Schools are identified by a single alphabetic character from the following list: C, E, P, F, S.

2. **STUDENT REFERENCES**

   Students are identified by an alphanumeric code as follows:

   Ann

   where
   - A is the student’s school code
   - nn is the number of the student within a particular school
     - nn = (odd number) for male student
     - nn = (even number) for female student

3. **INTERVIEW REFERENCES**

   Interviews are identified by an alphanumeric code as follows:

   Ann.m

   where
   - Ann refers to the student identity
   - m is the interview number for a student
     - m = 1 = Lower Sixth Interview
     - m = 2 = Upper Sixth Interview

   If reference is made to both interviews attended by a particular student then the form Ann.nn.1,2 is used.

   A reference Ann.m is used interchangeably according to context to refer to either a specific interview or student Ann at interview m.

4. **ALTERNATIVE CONCEPTIONS (ACs)**

   Alternative Conceptions are identified by an alphanumeric code as follows:

   X.n.x

   where
   - X refers to the aspect (A, B, C, or D) against which the AC is identified
   - n identifies the group within X to which the AC is allocated
   - x identifies the alphabetic sequence within X.n

5. **USE OF ITALICS: FORMAT OF INTERVIEW TEXTS**

   Students' verbatim responses are in italics.
CHAPTER 1

INTRODUCTION

1.1 BACKGROUND AND RATIONALE FOR THE STUDY

Chemical reactions occur within us and round about us all the time. The various life processes such as respiration and digestion all involve chemical reactions. Cooking, heating of houses, heating of steam to produce electricity, transport, manufacturing, all involve chemical reactions; more specifically, combustion reactions, directly or indirectly. Not only are chemical reactions ubiquitous in our everyday life, they are also central in the domain of chemistry.

The concept of chemical reaction is fundamental to the study of chemistry. According to a definition from Underwood and Webster (1981), chemistry is "the study of the properties of the matter that makes up the earth and the rest of the universe. The chemist is particularly concerned with the ways in which different substances react together, and with the ways in which some substances are made up from other simpler ones."

Substances are identified and distinguished by both their chemical and physical properties. Chemical properties, however, can only be ascertained by the use of chemical reactions. Thus, the concept of chemical reactions is not only at the core and foundation of chemistry study but also permeates its entire structure.

In secondary school curricula, students are introduced to the concept of chemical reactions very early in their school career, during which time, chemical reactions are either carried out by students themselves or demonstrated to them.

While there is literature documenting students' conceptions of chemical reactions, much of this refers to pupils who have not yet received a significant amount of formal science education and is primarily concerned with documenting younger pupils' pre-formal or naive concepts. What evidence there is appears to show that students of all ages and levels have great difficulties in grasping the scientist's view of the concept of chemical reaction.
A survey of the literature reveals a general lack of science education research involving older students, particularly those who are in a transitional phase between the secondary school and university, that is, sixth formers or A-level students. Within this dearth of material, chemistry students may be judged to be under-represented. This may reflect a perceived view within education that such student's, having chosen to study the subject at an advanced level and who have some long term commitment to science, are unlikely to provide new or generalised insights into science education.

When the search is further focused on sixth formers' or A-level chemistry students' conceptions and understandings of the nature of chemical reactions, the need for studies in this area is evident; there is lack of information and insights about how these students view and explain common chemical phenomena and reactions.

As chemistry is generally regarded as a difficult subject, the insights into the specific nature of the difficulties confronting learners would be useful to classroom teachers as well as curriculum developers in their tasks of helping learners grasp this most basic, most enveloping concept in the study of chemistry.

Among the few studies which have involved students at this level, that is, aged between 17-19 years, not many have employed the labour-intensive technique of interview-about-events, which was used in the present study. One of the features of studies hitherto carried out which employed written tests or paper-pencil methods was that there were limitations to what could be exposed and explored if students involved were not interviewed to allow for clarifications and probings of meanings of terms and labels used by both researcher and the students involved. Among the handful of studies which did involve the use of interview-about-events as a data gathering device, the coverage and emphasis were very different from the present study.

This present study is aimed at addressing some of the needs and gaps highlighted in the preceding paragraphs. It is unique in its comprehensive and in-depth coverage of students' understandings in the key conceptual area of chemical reactions, especially with respect to understandings of chemical bonding and the dynamics of chemical reaction which is key to the process of prediction. Using a flexible yet structured interview format, it allows students to reveal not only their conceptions and theories of the nature of chemical
reactions in the context of some familiar chemical phenomena, but also their reasoning processes.

The study is also a longitudinal one, in the sense that the students' understandings are examined at two points, one in the lower sixth form and the other in the upper sixth form, i.e., separated by a period of formal chemistry instruction and learning.

It allows for investigation into the development and progression in conceptions and understandings of students as individuals. It also facilitates the evaluation of the consistency or inconsistency of students' ideas by evaluating their understandings over a range of five main events or tasks. Additional checks on students' understandings are also provided for in the form of two other events which are directly linked and parallel to two of the five main events, so that in effect, seven events are used as foci for discussion in the interviews. The size of the sample enables analysis of common misconceptions and reasoning processes within the group and by drawing the sample from a range of schools gives some insights into different learning environments.

The study also looks at students' motives and strategies in learning, as well as their perceptions of chemistry classes, and the possible effects these have on students' conceptions and understandings. It is to be acknowledged that besides these two variables, there are a multitude of other variables (such as those associated with the teacher and his/her interaction with the individual students, the students' prior achievements and homegrounds and so forth) which influence students' learning.

The study, which employs the interview-about-events as a main data collection device, enjoys an advantage by having as its specific focus sixth formers or A-level students, who are inevitably a more select, motivated, mature and also perhaps generally more reflective, vocal and expressive group compared to younger students, having had the benefit of more time to consolidate and integrate their scientific ideas and having greater maturity to be able to express them.

As noted earlier, this category of students has generally been eschewed by researchers in the past since questions of educational returns have inevitably led researchers to be concerned with issues of generalisability of findings over the population as a whole.
whereas 'A'-level students can be seen as being focused and non-representative, being the top 10-15% of each cohort.

This has contributed, at least in part, to an imbalance in current science education research where the need is now for more insights into the conceptions and understandings of older students in particular disciplines rather than for more generalisations of student populations as a whole.

1.2 DESIGN OF THE STUDY

The study sample of 48 sixth formers was drawn from 5 schools; 3 are secondary schools and 2 sixth form colleges, roughly 10 students per school.

The interview-about-events technique (Osborne and Gilbert, 1980; Gilbert, Watts and Osborne, 1985) was chosen as a method for gathering data on students' conceptions and understandings after examining the methods of previous studies.

The detailed learning experiences which students had encountered in class were not monitored. However, it had been ascertained by examination of the work schemes and informal discussions with the teachers concerned that the students had covered the basic concepts investigated in this study.

The choice of events, interview questions, and the framework for analysis interview data were based essentially on the epistemology of the subject.

Additionally, a paper and pencil questionnaire of 50 items was used to determine students' approaches to the learning of subject content and their perceptions of chemistry classes. The first 36 items on the questionnaire which were about students' motives and strategies in learning, were adopted from Biggs' Learning Process Questionnaire (Biggs, 1987), with minor changes in the wording of a small number of items. The rest of the 14 items which relate to students' perceptions of their chemistry lessons were constructed by this researcher and validated by two experts in the field.
Both qualitative and quantitative methods were employed in analysing the gathered data.

1.3 AIMS OF THE STUDY

The main aims of this study are:

(a) to develop comprehensive insights into A-level students' understandings of the nature of some familiar, well-known chemical reactions;

(b) to examine consistencies and inconsistencies in these understandings over different events;

(c) to investigate how these understandings develop or change with increasing exposure to formal chemistry instruction;

(d) to investigate the students' learning approaches (in terms of learning motives and strategies) and perceptions of chemistry classes; and the possible effects these have on students' understandings.

1.4 PROCEDURAL SUMMARY

In May 1992, a pilot study was carried out by this researcher at two schools in the London area. The purpose was to gain experiences in conducting student interviews and to refine the interview structure.

The first round of interviews for the main study was carried out when the students were in the second and third terms of their lower sixth form, i.e., from November to May 1993.

Then followed a second round of interviews lasting from September to December 1993, involving essentially the same subjects (with the exception of those who had dropped chemistry in the interim period between the 2 interviews), who were then in the upper sixth form.
Each upper sixth interviewee also completed the 50-item learning process questionnaire. Supplementary data about the school and classroom environment were also gleaned from informal, unobtrusive observations as well as from informal discussions with teachers. Such data were used to understand the different learning approaches adopted by students.

1.5 STRUCTURE OF THE THESIS

This thesis is divided into three main parts.

Chapters 1 and 2 provide background to the research through this introduction and the review of related literature respectively.

Chapter 3 describes the research methods and procedures.

Chapters 4 to 13 describe research findings and discuss interpretations.

The study is based on students' understandings of four key aspects of chemical reactions measured over five events. The five events were:

1. hot copper in air;
2. the burning candle;
3. the bunsen flame;
4. addition of magnesium to dilute hydrochloric acid;
5. addition of aqueous lead nitrate to aqueous sodium chloride.

The four aspects were:

A. the type of change predicted;
B. the overall energy change predicted;
C. how the process of change is conceived or imagined;
D. what the students conceived of as the driving force for the change or the students' explanation for why they thought the change took place.
In this study the data is examined by school, gender and event for the following reasons:

a) This researcher has designed and arranged the 5 events in what is hypothesised/conceptualised to be a hierarchy of increasing difficulty or complexity. It is thus pertinent throughout the study to examine students' responses by event to test this hypothesis.

b) One of the aims in this study was to examine the consistency or inconsistency in students' understandings and conceptions across different tasks or events.

c) Although school and gender effects were not the main focus of this study, it became pertinent to examine them because the data showed that there are significant differences in students' understandings and conceptions of some aspects between schools and genders.

Chapters 4 to 7 each discuss students' understandings of a separate aspect, A to D, associated with the nature of chemical reactions across five separate events.

Chapter 8 discusses and categorises students' understandings and alternative conceptions of the nature of chemical reactions based on findings revealed in Chapters 4 to 7.

Chapter 9 is concerned with the issues of progression and non-progression.

Chapter 10 is concerned with the issues of consistency and inconsistency of students' conceptions across events.

Chapter 11 is concerned with students' learning approaches and perceptions of chemistry classes; and the possible effects these have on students' understandings.

Chapter 12 presents an individual student case study (further illustrative case studies are at Appendix M).

Chapter 13 summarises the findings, discusses interpretations, implications, and significance of the study; and makes recommendations for further research.
CHAPTER 2

REVIEW OF THE RELATED LITERATURE

The purpose of this chapter is to provide a review of the literature that is related to this study.

Section 2.1 provides an introductory background to the development and study of concept theory as a basis for the more detailed review sections that follow.

Section 2.2 provides a synthesis of a current view of learning as a process of conceptual development which is subscribed to by this researcher.

Section 2.3 deals with the nature of students' alternative conceptions in science thinking in terms of their possible origins and causes, consistency and persistence.

Section 2.4 deals more specifically with students' conceptions and difficulties in the learning of chemistry topics, with particular emphasis on the nature of chemical reactions.

Section 2.5 deals with some of the techniques which have been used to elicit data on students' conceptions.

Section 2.6 summarises the literature review as a platform for this particular study.

(For a review of the literature which relates to learning approaches with specific reference to the Biggs' Learning Process Questionnaire, LPQ, see Appendix L.)

2.1 CONCEPTS AND CONCEPTUALISATION

Since students' conceptualisations in the area of chemical reaction represent a key aspect of this study, it is, first of all, important to review some of the literature to determine acceptable definitions and meanings with respect to concepts and the mental processes
Not only is conceptualisation key to this work but, if a broader view is taken, conceptualisation lies at the heart of scientific understanding and scientific enquiry. The role of the scientist may be considered as the building of conceptual models to endeavour to explain "how" and "why" things happen in complex real-world events. The usefulness of the conceptual model can be judged by the degree of accuracy of the model in its construction and detail as compared to the real world. A detailed and accurate model will correctly reflect the real world and enable "what if" or "how about" questions to be asked by the suitable manipulation of the model itself rather than the equivalent manipulation of the real world; an important consideration in such diverse areas as developing a jet engine or predicting the path of a comet through space. The conceptual model is, in fact, the basis of prediction which is one of the main aims of science.

As stated by Hurd (1970), concepts have the most potential for interpreting, generalising, inferring and providing many opportunities for the development of cognitive skills and logical thinking which characterise learning in any discipline, and in particular, science. Concepts can also be used to build other more powerful concepts and principles within science and provide linkages with the conceptual structure of other disciplines.

According to Hurd (1970) a concept may be defined as follows:

A concept is a synthesis or logical relationship given to relevant information by the student; it is a product of his/her own imagination, insight or reasoned judgement. A concept is more than a collection of organised facts. Facts are essentially bits of information, concepts are mental constructs resulting from the class identity given to the facts by the learner (p. 57).

Rothenberg (1985) gives another definition of the term concept from a slightly different stance:

In philosophical terms a concept is an idea that includes everything characteristically associated with or suggested by a class of logical species. For the psychologist, a concept is knowledge not directly perceived through the senses, but
which results from the manipulation of sensory impressions (p. 500).

Yet another definition of a concept is given by Fieldman (1987):

A concept is a categorisation of objects, events or people that share common properties. Through the use of concepts we are able to distil the complexities of the world into more simplified and therefore more easily usable cognitive categories. Concepts allow us to classify newly encountered objects into a form that is understandable in terms of our past experience (p. 210).

These three definitions, with their differing emphases on structure and process, lead into considerations of the ways in which concepts are developed, the nature of conceptualisation and thence onto questions of how new knowledge is learned and new ideas generated.

Gilbert and Watts (1983) in discussing the development of a new realist approach to science education to replace the earlier allegiance to empirical inductivism, identify three views of concept:

A 'classical' view in which essentially all instances of a concept share common properties; properties which are necessary and sufficient to define the concept. Gilbert and Watts describe this view as "too simplistic" and "remote from the concept forming activity in both subject-oriented terms and as well as in everyday life", referring to work by Johnson-Laird and Wason (1977).

An 'actional' view, in which conceptualising is a "kind of doing" (Neisser, 1976) and concepts are seen as active, constructive and intentional, being "ways of organising our experiences" (Freyberg and Osborne, 1981) so that new experiences always result in some amount of reorganisation of existing concepts.

A 'relational' view of concept which represents the middle-ground between the classical and actional views. In the relational view, the all-or-nothing syllogistic nature of concept has given way to some flexibility and includes borderline cases or degrees of membership. It represents a composite view of concepts comprising
probabilistic as well as exemplar components. This means that instances can be evaluated against two terms: in terms of their degree of membership of a particular concept (i.e., their 'probability' of membership) and in terms of their linkages to other concepts. An example of where this 'relational' view of concept is applied is the work on 'fuzzy sets' (Zadeh, 1965, discussed in Pope and Keen, 1981). This view represents an improvement on the classical view in the sense that it allows for a mixture of forms of concepts and shifts towards a more naturalistic consideration of concept development.

Returning to the earlier definitions of concept quoted above, the last two definitions (Rothenberg, 1985; Fieldman, 1987) reflect essentially the 'classical' view of concept; the definition by Hurd (1970) appears closer to the 'actional' view discussed, because of the emphasis it gives to the action on the part of the individual student in concept formation. Hurd's definition by placing the task on concept formation on the student is reflective of the activist view of concept espoused by Lakatos (1970), who maintains it is we who create our own conceptual frames, and therefore "we can also, critically, demolish them".

As mentioned by Gilbert and Watts (1983), it is not likely that a tight division can be maintained between the three views of concept. In this present study, for example, the classical view is applied where judgment is made on whether a particular view expressed by a student is an "alternative conception" (AC); also whenever the term "misconception" is used with respect to the view(s) expressed by an individual or group of students, it implies that the student's view has been judged against the accepted scientific concept, in its classical sense.

However, the actional view is also implied, in that the term "alternative conception" is used in this study mainly in the sense suggested by Driver and Easley (1978), which is to focus on the "alternative interpretations" of natural phenomena by learners which are the "product of pupils' imaginative efforts to explain events and abstract commonalities they see between them". This meaning of the term "alternative conception (AC)" also includes the meaning suggested by Gilbert and Watts (1983), where the focus is again on the "personalised theorising and hypothesising of individuals". In the main, the term "AC" used in this study refer to ideas which are at variance with currently accepted scientific ideas and these include students' ideas which arise as a result of confusion or of non-
formal thinking or 'one factor only' type reasoning. In this present thesis, the term "misconceptions" and "alternative conceptions" are used rather interchangeably. When an idea or AC is used with consistency over more than one context or event, then it is referred to as an "alternative framework" as used in Driver and Easley (1978).

2.2 VIEW OF LEARNING AND TEACHING

This researcher subscribes to the general view of learning as conceptual development or change rather than piecemeal accretion of new information. In particular, the constructivist-generative learning model propounded by a number of researchers (Kelly, 1955; Wittrock, 1974 a,b, 1984; Osborne and Wittrock, 1985; Driver, 1986; Pines and West, 1986) is adopted. In this view, the route to the learner's construction of meaning from incoming experiences do not begin with that experience. It begins with selective attention of that experience, which is governed by a variety of aspects of long-term memory and cognitive processes. Attention involves both attending to the unexpected and sustaining an interest in the experience, which requires voluntarily controlled effort. The natural consequence of selective attention is selective perception. To construct meanings from sensory information, the learner needs to generate links to what are perceived to be relevant aspects of information in the long-term memory. In other words, learning with understanding is a generative process of constructing meaning from one's memories, knowledge, experience and inputs.

In other words, it means that knowledge is not simply absorbed from a book or a lecture. Instead, each learner constructs his/her own version of each concept, and the construction is informed at every stage by the learner's overall conceptual model or worldview (Brown, 1979).

The learner's worldview influences the way s/he sees himself/herself and the way s/he interprets the world around, permitting him/her to make judgments about whether and how components fit together (Boulding, 1956). One's worldview includes (but is not limited to) one's six-fold image: one's ideal self; one's perception of one's actual self; one's ideal world; one's perception of the actual world; how one wants to be seen by others; and how one thinks one is seen by others. This means in effect that learning, including learning in
science, cannot be seen as merely involving the learner's cognitive capacity and engagement, but also the entire human person, with the involvement of affect and emotions. From this, it can be seen why a learner's worldview influences his/her confidence in learning science.

A learner's worldview also includes beliefs which are personally intrinsic and which greatly influence cognitive responses to an idea. If a concept that is being taught is in conflict with the student's beliefs, whether it involves his/her self-image, value system, perception of the world, perceptions of other people's expectations, then the learner is likely to have difficulty learning the concept. Conversely, if the new concept fits easily into his/her worldview, then learning may be relatively easy. (Fisher and Lipson, 1986; Hewson, 1981).

This view of learning poses a tremendous challenge to the teacher. It means not only must the teacher be aware of the learner's cognitive knowledge and capacity, but s/he must also be mindful of the learner's psychological-emotional state, beliefs and value system. This is important in the process of helping the learner to construct meaning from incoming new concepts, and to transfer appropriate ideas from long-term memory to the comprehending of the new information, the teacher needs to provide retrieval cues that will take into consideration not just the learner's pre-existing ideas but also his/her emotional and psychological states and belief system.

2.3 STUDENTS' CONCEPTIONS AND DIFFICULTIES IN LEARNING SCIENCE/CHEMISTRY

Studies in students' alternative conceptions (ACs) in science have a long history, being traceable back to Piaget's early work on children's views of natural phenomena (Piaget, 1929, 1930). There is now a substantial body of literature documenting the various types of alternative conceptions or preconceptions held by students in various conceptual areas (Driver and Oldham., 1985; Pfund and Duit, 1991; Carmichael et al, 1991). However, the vast majority of these studies involved science learning up to age 16.

In the literature are also various studies on strategies that have been devised to promote
conceptual change in learners. These strategies generally fall into two broad categories. The first category of strategies are based essentially upon cognitive conflict and the resolution of conflicting perspectives (e.g., Nussbaum and Novick, 1982; Posner et al., 1982; Champagne, Gunstone and Klopfer, 1985). The second category of strategies comprise those which build on learners' existing ideas and extend them (Clement et al., 1987; Clement, Brown and Zietsman, 1989; Niedderer, 1987).

2.3.1 HOW STUDENTS' ALTERNATIVE CONCEPTIONS (ACs) ARISE

The origin of ACs have been examined by many researchers. Among the sources of ACs suggested are the following, some of which overlap:

* From everyday experience and observation (Claxton, 1982; di Sessa, 1982; Strauss, 1981; and Viennot, 1979). Young children, for example, learn much from their environment through kinaesthetic experiences such as the handling of objects, in Bruner's terms, the enactive mode of learning, or in Piagetian terms, the sensorimotor stage. From such experiences, ideas such as an object will only move as long as a force is applied are likely to develop. Further childhood experience will tend to reinforce these intuitive ideas until more scientific views are encountered in school, which could then lead to confusion and learning difficulties. From such experience, non-Newtonian ideas such as 'an object will only move if a force is applied, and as soon as the force is removed, it stops' will develop.

* From the use of perceptual thinking, which is related to the previous source, and is seen in a number of studies where students' explanations of scientific phenomena are dominated by what is immediately perceptible. In the field of mechanics for example, Gilbert, Watts and Osborne (1982) found that pupils who were shown a picture of a golf ball free falling towards the ground denied that there is a force acting on it. In the study on state changes such as evaporation (Stavy, 1989) and dissolving (Piaget and Inhelder, 1974), combustion (Driver, 1985 and BouJaoude, 1991) the use of perceptually dominated thinking leads students to infer disappearance of material.
From confusion about analogies (Shipstone, 1984). Much explanation in science involves the use of analogies. The use of spontaneous analogies in problem-solving by scientifically trained subjects have been described by Clement (1981). The fact that there is no perfect congruence between an analogy and the idea or concept which is being explained can often lead to confusion and alternative conceptions as the analogy becomes over-extended in the students' minds.

From the use of metaphors. While the use of analogies can be consciously and purposefully introduced by teachers, the negative influence of metaphors can be unnoticed by teachers because of their prevalence in everyday language. A number of researchers (such as Black, 1962; Ortony, 1979; Sutton, 1982; Eaton et al., 1983; Head and Sutton, 1985) have suggested that metaphors are central in our thinking which result in metaphorical speech in our verbal communication. For example, in the case of studies on electricity, words such as 'current' and 'flow' may suggest a comparison with the movement of water even if the analogy has not been made by the teacher. Such confusion would seem almost inevitable since there is so much overlap between words used in science and in everyday language.

From diagrams or statements in textbooks - errors or inconsistencies in textbooks may contribute to students' misconceptions since they are a major source of information (Blosser, 1987). For example, Baird (1986) found the discussion of the nature of chemical bonding in many textbooks to be so simplified that many scientifically incorrect statements are made. Cho, Kahle and Nordland (1985) examined what they considered to be three most widely used high school biology textbooks (BSCS green, BSCS yellow, and Modern Biology); four possible sources of misconceptions and learning difficulties were identified: conceptual organisation, particularly sequencing of topics; conceptual relationships; use of terms; and mathematical elements.

From students' lack of formal operational thought or relevant cognitive processing characteristics. Some researchers have suggested that formal operational thought is implicit in much of science education (Shayer and Adey, 1981; Lawson and Wollman, 1976). More specifically, it has also been suggested that some science concepts require students to be operating at the highest Piagetian level of thinking.
in order to develop complete understanding. Partial understanding was thought to be a reflection of the students' understanding of some concrete aspects of the whole concept (Shepherd and Renner, 1982). From this mismatch between cognitive demand of the concept and the operational stage of the student, misconceptions can arise (Gabel, 1989). For example, to handle stoichiometric calculations successfully, students must relate three variables: the mass, the molar mass and the number of moles. Many students simplify their calculations by considering only two variables and end up with incorrect answers (Schmidt, 1987).

From lack of an adequate conceptual framework. As discussed by Krajcik (1991) the fact that chemistry students often learn isolated facts without integrating them into appropriate frameworks mean that misconceptions often arise from misapplication of facts in wrong contexts. Studies by McDermott (1988), Gorodetsky and Gussarsky (1987) and Cachapuz and Martins (1987), demonstrate the existence of these kinds of ACs (see section 2.4.4.1 B).

From concept interference. As mentioned in the preceding section, the context in which a concept is embedded provides a parameter for understanding by the student. The fact of students holding isolated fragments of ideas or holding ideas in a wrong context means that according to a constructivist view of learning, more ACs or misconceptions are likely to be generated as incoming formal science/chemistry ideas are assimilated or subsumed into the wrong cognitive structure. "Concept interference is a situation that occurs when the correct application of a concept by a student is hindered because of his/her misuse of another concept" (McDermott, 1988 p. 539).

From teachers and student teachers - Friedler, Amir and Tamir (1985) found that serious misconceptions exist among student teachers with respect to basic concepts such as solutions, solubility, particulate nature of matter and molecular movement; in spite of the fact that these teachers reported that they had studied, and had achieved a high level of understanding of all these concepts. Gabel et al. (1987) reported on the lack of high level understanding of the particulate model of matter among 90 prospective teachers' (54 or 60% had completed a course in high school or college chemistry). That misconceptions could arise as a result of instruction
has also been suggested by other researchers (e.g. Osborne and Cosgrove, 1983; Fisher, 1985; Bar, 1990; Bar and Travis, 1991; Griffiths and Preston, 1992).

As suggested by Nisbett and Ross, 1980, another source of ACs is what is termed the "vividness criterion". This is the tendency to try and apply recently discussed ideas to the presently discussed idea because they are fresh in our minds. This type of ACs are more likely to arise when the student cannot develop or recall a conception which could explain the phenomenon presented. Faced with the task of having to provide an explanation, the student uses one available in the short term memory.

Thus, ACs or misconceptions generate more mistakes because they are incorrect representations of conceptual relationships (Strike, 1983). This means that a student's preconceptions or existing ACs hinder effective concept learning in the future. This has been shown in a number of studies (e.g., Cachapuz and Martins, 1987; Schultz et al. 1987).

According to Pines and West (1986), the sum total of ACs and frameworks developed and used by learners to help them make sense of the world could be termed "personal knowledge" or "spontaneous knowledge"; as opposed to "scientific knowledge" or "formal knowledge". Parents, friends, teachers, books, television, movies, and cultural norms and mores all contribute to the construction of personal knowledge. Most students learn scientific knowledge distinct from their personal knowledge and, as a result fail to develop integrated conceptual understandings of fundamental scientific concepts, and develop instead, various ACs.

### 2.3.2 ISSUES RELATING TO CONSISTENCY OF ACs (OR STABILITY OF ACs) ACROSS TASK CONTEXT

The problem of student inconsistencies is also well-known to teachers who often complain that their students' performance on mathematical and scientific tasks seems to be inconsistent. That is to say, a student may succeed in a given task, but fail completely in another very similar task. The consequences of this is that simple diagnosis of
Performances in connection with one task only does not provide clear-cut adequate information of students' difficulties and, hence, cannot lead to effective remediation (Eylon, Ben-Zvi and Silberstein, 1987).

Mishler (1979), Linn (1983) and White (1985, 1988) emphasised the importance of context in psychological and educational research. The issue of apparent inconsistencies in performance has been raised in various domains of research involving human cognition. Examples of science education research which suggest that students' performance on a task or problem is influenced by the context or phenomenal setting are Jungwirth & Dreyduss (1979), Foxman et al (1980), Kerslake (1986), Clough, Driver and Wood-Robinson, (1987) and Schofield et al (1989), Song and Black (1991); this last named study, found that childrens' skills of interpretation and application are not transferable across different contexts.

The dependency of thinking skills on the context of the tasks has provided a powerful argument for those who questioned the usefulness of Piagetian stage theory as a model for learning (Brown and Desforges, 1977; Driver, 1978).

At the same time, there are researchers such as Pascual Leone et al (1978) who have argued that many of the apparent inconsistencies can be accounted for by careful analysis of the various tasks involved, and taking into consideration such aspects as short term memory load, field factors, etc. Another example is provided in the series of investigations by Brown and Burton (1978) and Burton (1981) who sought to explain mistakes made by children in addition and subtraction tasks in terms of relatively simple 'bugs' (structural errors) in children's procedures.

In the area of misconceptions, the issue of consistency had also been raised (Engel, 1982; Driver, 1985; Solomon and Black, 1985). For example, Engel (1982) in an attempt to examine whether a particular response is being activated by some idiosyncratic feature of the task context or whether it reflects a more global framework, has examined the consistency with which responses are given across a set of equivalent tasks. She found that the proportion of students using various frameworks across the set of equivalent tasks on heat and pressure was relatively stable, indicating that the ways in which a group of students of a certain age may conceptualise a type of problems are predictable to some
extent. There was also evidence for consistency in the use of scientists' views as well as alternative frameworks at the individual level; although the consistency in the use of alternative frameworks were more evident in phenomena where there were a limited number of alternative frameworks and where these were intuitive in nature.

Solomon and Black (1985) in a study on pupils' conceptions about electricity, showed that pupils' ideas are based on their everyday experience, and that these ideas are diverse, and often contradictory. Leach et al (1992) found that many pupils do not apply ideas consistently in different contexts; for example, some pupils thought that nutrition for grass and nutrition for trees different. BouJoaude (1991) reported that students' ideas about burning were fragmented and inconsistent. Palmer (1993) found that most students were unable to consistently apply either their own alternative conceptions or the correct scientific response. He reported, as did Clough and Driver (1986), that students appeared to have a general problem in recognising similarities between contexts, even when the contexts were closely related.

Vosniadou and Brewer (1989) reported that the majority of the children studied by them were rather consistent in the way they used their conceptions. Prieto, Watson and Dillion (1993) suggest that many apparent inconsistencies in pupils' thinking disappear when their ideas are categorised in multiple dimensions and that most pupils are consistent in applying their alternative frameworks.

As suggested by Driver (1989), it is still an open question whether students' ACs are genuinely "theory-like", i.e., having a coherent internal structure and being used consistently in different contexts.

Furthermore, researchers like Bar and Travis (1991) have shown that the format of testing can also affect the consistency or otherwise of students' ACs. They showed that when multiple-choice items are used to determine students' conceptions, and when one or more of the distracters seem 'scientific' i.e., contain physical and chemical terms, then the distracters tend to be more frequently selected. However, if the multiple-choice test is replaced by more open questions, then different responses are given by students. For example, they found that 75% of their subjects said that water vapour is made of water in an open-ended oral test whereas the percentage dropped significantly in a multiple-
choice test, where distracters such as 'water is changed to hydrogen and oxygen' tend to be selected.

2.3.3 ISSUES RELATING TO STABILITY OF ACs OVER TIME (OR PERSISTENCE OF ACs)

There is evidence that some ACs are resistant to instruction even when the teaching has been specifically restructured to address them (Nussbaum and Novick, 1982; Gunstone, Champagne and Klopfer, 1981; Champagne et al., 1981; Moreira, 1987).

A number of different reasons have been suggested for the persistence of ACs. These include:

* Positive feelings and low cost of holding on to ACs - as suggested by Gowin (1983); one of the reasons why ACs are persistent might be that students feel comfortable with them and that there is low cost involved in holding on to them.

* Functionality or usefulness to the student - A misconception or AC can persist because it represents functional meaning for the person who holds it (Novak and Gowin, 1984; Moreira, 1987). Although this meaning is a contextually unacceptable interpretation of the concept, it allows the learner to make sense of new knowledge in his/her own way or cognitive framework, thus minimising cognitive dissonance (Novak and Gowin, 1984; Posner, 1983).

* Gilbert, Watts and Osborne (1982), and Osborne and Cosgrove (1983) suggest that among other reasons, one reason why scientific views seem not to prevail over students' naive views is because scientific views are not relatable to everyday experience. They report that older students can hold very similar views to younger ones, in spite of their greater exposure to formal science instruction, because they utilised the additional science knowledge to support their naive views. For example, the particulate model for many students implied that liquids would be less dense than solids, yet the only example of a liquid/solid change with which they are familiar defies the implication.
Coexistence with orthodox scientific views - As described by Head and Sutton (1985), and Pines and West (1986), some of the reasons why ACs persist in spite of formal science instruction is that the scientific views could be seen as irrelevant or useless and are rejected by students; in cases where formal science is perceived to be useful in the classroom contexts and for passing tests and examinations, formal science knowledge is rote-compartmentalised so that it coexist with students' preconceptions or ACs. The coexistence of conflicting scientific views and intuitive views has been reported by Gilbert, Osborne and Fensham, 1982) and also demonstrated by Gunstone and White (1981) with physics students who were able to solve physics problems using algorithms based on theories which clashed with the students' own naive theories. Gunstone and Vvbite also describe how, in the same sample of first year university physics students, a majority of students predicted that if two balls of unequal weight were held in front of them and released instantaneously then the heavier ball would reach the ground first because "heavier things have a bigger force".

In chemistry, similar findings are revealed in studies such as Carter and Bodner (1987) where many students were found to "believe that chemistry is handed down by authorities and that they are not capable of understanding or discovering this knowledge" (p. 70). Under such situations, students begin to accept algorithms presented to them at face value, without attempting to understand the underlying meanings and their links to other related concepts. Instead, they "view chemical knowledge as a series of rules without reason" (p. 70). This means that students who use some particular knowledge or strategy in one context will not necessarily use it in another related context since they fail to recognise the connection or lack the underlying understanding. The result is persistence of ACs in spite of formal instruction.

2.4 OVERVIEW OF STUDIES IN CHEMISTRY

Compared to studies in physics and biology, there are fewer studies on students' conceptions in chemistry reported in the literature. From the bibliographies of Pfundt and Duit (1991) and of Carmichael et al (1991) it appears that within chemistry, besides the particulate model and its related topics such as states of matter including solutions and
suspensions, (which are of interest to this study and are discussed in section 2.4.2 below),
the major areas of research have been concerned with the mole concept (e.g., Anamuah-
Graham (1983), Griffiths et al. (1988)) and chemical equilibrium and kinetics (e.g., Batt
and Cachapuz (1988), Olney (1988), Gussarsky and Gorodetsky (1990), Kozma and
Johnstone (1990), Banerjee (1991)).

2.4.1 STUDENTS' CONCEPTIONS AND UNDERSTANDINGS OF THE
DIFFERENCES BETWEEN CHEMICAL AND PHYSICAL CHANGES

Pella and Voelker (1967) in a study which investigated the effectiveness of two methods
of teaching the concepts of physical and chemical change to elementary school children,
report among other things, that the concepts of physical and chemical change should not
be included in the elementary curriculum below grade 6.

Stavridou and Solomonidou (1989) in a study involving 15 Greek students, aged 8-17
years (among whom are one 16 year old and one 17 year old), report, among other things,
that students were not able to distinguish between physical and chemical change. They
report that some students consider chemical changes as irreversible, while physical
changes are reversible. Among other things, the authors infer that the concept of substance
(or compound) has not been grasped by the students since none of them use identity
conservation or change of identity of substance as a criterion to distinguish physical and
chemical changes. One problem with this study is the wide age range covered and the
small number of students aged 16-19 involved, which renders it very difficult to make any
reasonable inference.

That secondary school students (aged up to 15) have difficulties appreciating that in a
chemical reaction, the properties of the starting substance(s) are not conserved has been
report by De Vos and Verdonk (1985a,b; 1987a,b), Briggs and Holding (1985), and

In addition, there are many studies which report that students often confuse physical
changes (such as boiling, evaporation, condensation and melting, expansion on heating) with chemical changes (Osborne and Cosgrove, 1983; Driver, 1985; Mehuet et al., 1985; Stavey and Stachel, 1985; Andersson, 1986a; Donnelly, 1988; Bar, 1990; Bar and Travis, 1991).

Some of these studies further suggest that these kinds of students' confusions could be the result of formal instruction (eg Osborne and Cosgrove, 1983; Bar, 1990; Bar and Travis, 1991).

Ribeiro et al. (1990) report that fourth year university chemistry students tend to use the everyday understanding of the term "reaction" instead of the chemist's understanding. This indicate that everyday usage of terms could be a source of problems to students' learning about chemical changes.

### 2.4.2 STUDENTS' UNDERSTANDINGS ABOUT THE PARTICULATE NATURE OF MATTER

The atomic model or the particulate model of matter provides a necessary foundation for understanding other chemistry concepts, including that of chemical reaction. Indeed, an understanding of the particulate model is fundamental to understanding the mechanism of chemical reaction. To explain and predict chemical reactions, phase changes, the Gas Laws, the nature of dissolving and solutions as well as numerous other chemistry concepts, students must have an integrated understanding of the model.

A number of studies indicate that students at all levels have difficulties understanding the model, some of which suggest that lack of formal reasoning ability could be a contributing factor (eg Gabel, 1989; Samuel and Hunn, 1987; Shepherd and Renner, 1982).

Studies on primary school children (eg Pella and Carey, 1967; Doran, 1972) show that pupils have a continuous view of matter even in spite of specific instruction.

Other studies (eg Novick and Nussbaum, 1978; Kirscher, 1981; Selley, 1981; Prieto et al., 1989; Abraham et al., 1992) report on the difficulties that early secondary school pupils
(aged 11-14) have in grasping the particulate model when it is specifically taught to them.

The persistence of the continuous view of matter among older secondary school students (up to age 15-16) and the tendency of students to treat the microscopic world as merely an extension of the macroscopic world have been reported in numerous studies (eg Brook, Briggs and Driver, 1983; Andersson, 1986a, 1990; Ben-Zvi, Eylon and Silberstein, 1986a,b; Renstrom, 1988; Krajcik, 1989; Andersson, 1966a, 1990).

That students who have even more formal science instruction, ie senior high school and university students, also have difficulties with various aspects of the particulate model of matter have also been reported (Novick and Nussbaum, 1981; Griffiths and Preston, 1992; Hesse and Andersson, 1992; Nakhleh, 1992).

Similar links have been made between the difficulties many students have in understanding the nature of chemical reactions and their lack of understanding and/or misconceptions about various aspects of the particulate model of matter (eg Andersson, 1986a, 1990; Ben-Zvi, Eylon, Silberstein, 1986a, 1987; Abraham et al. 1992; Hesse and Anderson, 1992).

Vogelezang (1987) identifies both the need to introduce pupils early to the nature of substances in terms of atoms and molecules, and the problems of early introduction based on too simplistic models which then leads to confusion later when revised models are introduced which superficially conflict with the earlier ones.

2.4.3 CHEMISTS' UNDERSTANDING OF CHEMICAL REACTIONS

Chemists' understanding of chemical reactions are embedded in a conceptual framework which has been constructed through their active differentiation, integration and structuring of concepts about the nature of substances and chemical change over time via a variety of experiences.

To the chemist, a chemical equation, which is a symbolic representation of a chemical
reaction, does not just consist of symbols written on paper or chalkboard. Rather, it represents a wealth of integrated understanding that includes mental models and physical phenomena.

Ben-Zvi et al. (1987) present a task analysis depicting the wealth of integrated understanding needed in order to make proper sense of a relatively simple equation such as \(2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{g})\). When a chemist sees the equation for the combustion of hydrogen, the following understanding would probably be triggered:

* The structural aspects of a chemical reaction.

The chemist's understanding that the chemical symbols represent molecular species is activated. In the given example, the symbols \(\text{O}_2\) and \(\text{H}_2\) each represent a molecule of two specific elements, each with two atoms of the same element chemically bonded together. The formula 'H\(_2\)O' represents a molecule of a compound with two O-H bonds. To the chemist, the symbol '(g)' means that the elements and the molecular compound are in the gaseous state and consists of many particles in constant random motion.

* The interactive aspects of a chemical reaction.

The chemist understanding that a chemical reaction is a process of bond breaking and bond making is triggered. In the given reaction, the bonds in each molecule of \(\text{H}_2\) and \(\text{O}_2\) must break and new bonds between the O and H atoms must form.

* The dynamic aspects of a chemical reaction.

The chemist's understanding that a chemical reaction is a time-dependent process involving a dynamic interaction of many particles is activated.

* The quantitative aspects of a chemical reaction.

The chemist's understanding of the quantitative aspects of a chemical reaction is activated. In the given reaction, two moles of \(\text{H}_2\) react with one mole of \(\text{O}_2\) to form
two moles of $\text{H}_2\text{O}$.

In addition, a chemist's understanding of the energy aspects of the reaction would probably be triggered. Hydrogen ($\text{H}_2$) and oxygen ($\text{O}_2$) are at a higher energy level and will release energy when the atoms recombine to form water ($\text{H}_2\text{O}$). Some chemists would probably also visualise the kinetic aspects of the reaction. The physical properties of the reactants and products are also integrated into the chemist's understanding of the reaction (Krajcik, 1991).

### 2.4.4 STUDENTS' CONCEPTIONS OF THE NATURE OF CHEMICAL REACTIONS

#### 2.4.4.1 THE 'WHAT', THE 'HOW' AND THE 'WHY' OF CHEMICAL CHANGE

(A) **THE 'WHAT' ASPECTS OF CHEMICAL CHANGE**

Studies (e.g., Frazer, 1982; Gabel et al., 1983; Lythcott, 1990; Gabel, 1989) show that students can produce correct answers (to various kinds of problems such as those involving chemical stoichiometry) but their understanding of the underlying chemical concepts are lacking. This indicate that students could appear successful without achieving real understanding.

(B) **ENERGY CHANGES ASSOCIATED WITH CHEMICAL CHANGE**

Cros et al. (1986) report that the majority of the first year university students studied by them have poor understanding of the energy changes associated with neutralisation reactions.

De Vos and Verdonk (1986) reported on the difficulties students have in classifying chemical reactions as exothermic or endothermic. They found that some students incorrectly referred to the burning of candle as endothermic since heat was needed to light
it. They suggested that to define burning as exothermic requires a semi-quantitative approach in which the amount of heat needed for lighting is compared with the amount of heat produced by the candle as it burns. They found that not all students could make that comparison. Also, the constant temperature of the burning candle misled them into thinking that no heat was produced because they confused heat with temperature. These students also inferred that the burning of copper is endothermic because the oxide was formed only when copper was heated.

Cachapuz and Martins (1987) found that many of the students studied by them held ACs about energy changes. Among these, was the view that chemical change simply involves a transfer of energy existing between the water molecules, the "non-bonding" energy to the bonds being formed in the solution and the resulting temperature of the water depended on the amount of "non-bonding" energy left. Thus, it appeared that the students had applied the principle of conservation of energy which they learned in a physics class to an inappropriate contexts; and they had not appreciated the energy changes which occur at the microscopic level.

Cohen and Ben-Zvi (1992) suggest that misconceptions can develop among high school students learning the concepts of chemical energy as a result of problems associated with understanding the meaning of the relatively huge number of abstract concepts such as heat, energy, temperature and bond energy. They also suggest that the molecular-level explanation needed to understand these concepts as well as the other formal concepts such as standard conditions, standard heat of formation are not easy for most students.

(C) THE PROCESS ASPECTS OF CHEMICAL CHANGE

The study by Novick and Nussbaum (1978), mentioned earlier suggests that one reason why many grade 8 Israeli students studied, have difficulty in grasping the concept of chemical reaction, is that in spite of specific instruction, they have not abandoned the continuous view of matter or have adopted a distorted particulate view of matter, such as a static view of particles.

Research by Ben-Zvi and her colleagues (1982, 1987) show that students (aged 15 years),
have difficulties appreciating many particles and the dynamic aspects of chemical reactions. Their view of chemical reaction seems to be an additive rather than an interactive one, ie they visualised chemical reactions as a process of addition or gluing, of reactants to form products, rather than as a process of bond breaking and bond making involving many particles. Thus a molecule of a compound is not viewed as a new entity but rather as a mixture of its constituents. For example, when H₂ reacts with O₂, the H₂ adds to the O₂. Bond breaking in H₂ does not occur.

Research by Yarroch (1985) supports the findings of Ben-Zvi and her colleagues. He found that although all the students could successfully balance the equations, many show little understanding of what they were doing.

Thus it appear that while chemical equations trigger integrated understanding in chemists, they do not have the same effect on students, not even on those who seemed to have mastered the competence to manipulate them. This leads researchers like Krajcik (1991) to deduce that some students visualise the chemical equation as a mathematical puzzle rather than symbolising a dynamic and interactive process.

That students have difficulties understanding chemical bonds and bonding have also been reported. Peterson, Treagust and Garnett (1986) report, among other things, that students (grades 11 and 12) have the misconception that intramolecular covalent bonds (instead of intermolecular bonds) are broken when a substance changes phase. This confusion between intra- and inter- molecular bonds is also found among Thai first year university students (Kiokaew, 1989).

Butts and Smith (1987) report that students are confused between ionic and covalent bonding and structures. Ten of the 26 students (year 12) students studied by them refer to molecules in solid sodium chloride; some also conceptualise the sodium and chlorine atoms as being held together by covalent bonds. Only 4 students are reported to demonstrate a clear understanding of the three dimensional lattice structure of sodium chloride.

Similar confusions are reported by Taber (1994), of students at the beginning of an A-level course. He summarises the students' alternative frameworks in the form of 3
conjectures that students make:

* The valency conjecture:

The atomic electronic configuration determines the number of ionic bonds formed. E.g., a sodium atom can only form an ionic bond to one chlorine atom.

* The history conjecture:

Bonds are only formed between atoms that donate/accept electrons. E.g., in sodium chloride a chloride ion is bonded to the specific sodium that donated an electron to that particular anion, and vice versa.

* The just forces conjecture:

Ions interact with the counter-ions around them, but for those not ionically bonded these interactions are just forces. E.g., in sodium chloride, a chloride ion is bonded to one sodium ion, and attracted to a further five sodium ions, but just by forces, not bonds.

Cros et al. (1986) on a study involving first year university students report that students have poor understanding of the interactions of atoms and molecules, as well as aspects related to structure of crystals.

(D) DRIVING FORCE OF CHEMICAL CHANGE

That 8th grade students have difficulties appreciating that chemical reactions are not caused by external interventions such as heating has been reported by Novick and Nussbaum (1978). The findings of the study by Barral et al. (1992) also show that some of the students (aged 15-16) had the same belief. Brosnan (1992) also suggests that students often view chemical change differently to the chemist. While the chemist views chemical change as the result of interaction between equal partners, students often view it as being caused by an active agent acting on passive substances. Andersson (1986b)
further suggests that this view of an active causal agent is related to the students' everyday life - the experiential gestalt of causation (EGC).

That older students (aged 16-18) who have had more formal chemistry also have difficulties understanding the thermodynamics of chemical reactions has been reported by Johnstone, MacDonald and Webb (1977). They report that these students have the misconception that endothermic reactions cannot be spontaneous; and that all reactions which occur naturally (i.e., without overt application of heat) are exothermic.

That yet older students (fourth year university chemistry level) also have problems appreciating the thermodynamics of chemical reactions has been reported by Ribeiro et al. (1990). They report that these students do not use concepts of free energy when discussing issues related to the spontaneity of some common chemical reactions. Instead, everyday notions are used. This study highlights the dominance of perceptual thinking among students who have had so many years of background and training in chemistry.

2.4.4.2 ON DIFFERENT TYPES OF REACTIONS

(A) COMBUSTION REACTIONS

Up till now most of the studies on students' conceptions of chemical reactions revolve around this specific type of reaction - combustion. Among the studies which examined the students' conceptions of combustion, before and after instruction, are Knox (1985), and Mehuet, Saltiel and Tiberghien (1985); both involving 11-12 year olds. Prior to instruction, the majority of students in both studies have what Driver (1985) deemed as 'prototypic' ideas about burning, i.e., burning involves a flame; products are smoke and an incombustible material known as the ash; the change is irreversible; and oxygen/air is needed, but its role is unclear or unknown.

After specific instruction which includes the concept of interaction between oxygen and the combustible material, both studies report that students are still unable to grasp the role of oxygen in combining chemically with the combustible material. Instead, they still show
evidence of the use of perceptual thinking instead of conceptual thinking.

Further evidence of the use of perceptually dominated thinking in interpreting combustion reactions is reported by BouJaoude (1991) and Abraham et al. (1992); where the majority of the students studied see candle wax as merely melting and not burning.

Hesse and Anderson (1992) in a post-instruction study on older students (aged 16-19) report that the majority of the students use everyday or prototypic notions about burning instead of the scientific concepts.

Most of the studies on combustion include a concern with ideas of conservation of mass. This concept of conservation of mass is related to students' understandings of the concept of interaction between particles of reactants.

A written question about the burning of iron wool was given to the students in the Knox (1985) study mentioned earlier as well as to a group of 15-year-olds (n=765) as part of the APU survey (Driver et al., 1984). Results showed that only about 25% of both age groups predicted that the iron wool would become heavier after heating in air, and of these only a few gave the acceptable reason that oxygen from the air has combined with the iron. In the same survey with respect to a question about the rusting of iron, only about a third of the 15-year-old students predicted that the weight would increase, of whom only a minority give the correct reason that oxygen from the air has combined with the nails to form the iron oxide or rust.

Likewise, 9 out of the 11 students (aged 15-17) in the Hesse and Anderson (1992) study also reached incorrect conclusions about the mass of the products of rusting, burning of copper and burning of a wood splint because they failed to understand the nature of the chemical interaction and hence the conservation of mass involved. Instead they used reasoning that is more appropriate for physical changes (such as regarding rusting as a sort of "change of state" of the iron; nothing was lost and nothing was gained.)

Lack of understanding of chemical interaction and conservation of mass were also reported among university chemistry students. Bodner (1991) in a questionnaire study on chemistry graduate students reported that about 10% of the respondents thought that when
an iron bar rusts, its weight decreases for reasons other than loss of rust. 6% think that the weight would remain unchanged, while 81% reason correctly that the weight would increase as long as the rust was not scrapped off the bar.

Similar problems among teachers are reported by Lawrenz (1986). The instrument used is a written test, comprising 31 multiple choice items on various topics in physics and chemistry. Only 36% of the 333 elementary school teachers think that when iron combines with oxygen to form rust, the rust would weigh more than the iron it came from.

Ross (1991) reported a survey of people's views about burning in which no specific details were given of the nature of instrument used or the context or the sample involved other than that it included various groups of people such as firemen and people with strong science backgrounds. He reported that burning is often seen either as destructive or similar to evaporation and that oxygen, if mentioned at all, is usually seen as a "helper" rather than as a reactant and flames are seen as the active agent of destruction. It was a pity that no mention was made in the report on the nature of the context of the study and the composition and size of the study sample so that more useful inferences could be derived.

(B) REACTIONS IN SOLUTION - REDOX AND PRECIPITATION

Studies by Prieto et al. (1989) and Ribeiro et al. (1990) show that both younger students, aged 11-14, and older university fourth year students respectively do not appreciate the role of solvent (water) in chemical solutions. They report that students tend to ignore the presence of water or to assume a "passive" role for it.

Schollum (1982b) reports an interview study (40 pupils, aged 10-19) where solutions of sodium chloride and lead nitrate were mixed together to form the precipitate of lead chloride. Only 5 students (aged 16-19) included the word 'precipitate' in their responses when asked what they considered had happened. She also reported that 10 students saw the precipitate as a new substance, but only 1 (form 7) held the scientist's view of the mechanism involved. The rest of the students either saw the lead nitrate and sodium chloride a having simply settled out of the water separately without interacting in any way
or as having joined together in some way and settled out without forming any new products.

In a similar study, Nusirjan and Fensham (1987) reported that although most of the 30 senior secondary school Indonesian students interviewed by them predicted that a chemical reaction would occur if aqueous barium nitrate is mixed with aqueous sodium sulphate, only 8 identified the products in chemist’s terms. None of them referred to the concept of particles when probed on the process involved.

In another study, Butts and Smith (1987) report that the 26 chemistry students (year 12) studied by them generally had a better conception of the structure of a solid than they did of the corresponding aqueous solution, especially in the case of sodium chloride. They also report that the belief that all ionic compounds are soluble is prevalent; and that the actual process of dissolving, the role of the polar water molecule, seems to be poorly understood. In the same study, students were asked to account for the formation of a precipitate when aqueous sodium chloride was added to aqueous to silver nitrate. Only 2 of the students were found to relate the formation of the precipitate to the low solubility product of silver chloride. The researchers infer that precipitation from a mixture of ionic compounds is a phenomenon students found difficult to explain.

Garnett and Treaguest (1992), in an interview study which includes probing the understandings that 32 students (grade 12), report, among other things, that a number of the students held misconceptions about oxidation numbers, and also about redox reactions such as thinking that oxidation and reduction reactions can occur independently of each other or in isolation.

(C) STUDENTS’ EXPLANATORY MODELS OF CHEMICAL REACTIONS

Pfundt (1981) reports on the results of interviewing students (grades 2-7, aged 8-13 years, n=10) on their pre-instructional conceptions of the nature of chemical reactions. She suggests the following categories of conceptions:

* The conception of an irreversible destruction of substances
* The conception of an irreversible changing of properties of lasting substances

* The conception of a reversible changing of properties of lasting substances

* The conception that substances with all their properties continue to exist, that they are merely distributed or mixed or separated.

Another different set of categories on students' conceptions of the nature of chemical reactions has been suggested by Schollum (1982b), after interviewing 40 secondary school students, the majority of whom are in form 4 and below (with only six form 6 students):

* The conglomerate conception. All substances that react collect together like needles to a magnet.

* The conception of 'favourable circumstances' (or 'the bear in the cave'). The products of chemical reactions have been there all the time, though hidden, but when the conditions are right they appear.

* Magic. Anything can happen in chemistry.

Mehuet, Saltiel and Tiberghien (1985) after studying students' (aged 11-12 years) conceptions of the nature of a specific type of chemical reaction, namely, combustion suggest that there are 2 basic conceptions:

* The conception of combustion as involving a temporary (and reversible) change, i.e. the combustible material has merely undergone some change of properties and the product of combustion is the same as the combustible material.

* The conception of combustion as involving a permanent and irreversible change, i.e. the product is different from the combustible material.
Given that the pupils studied by Pfundt (1981) and Mehuet et al. (1985) had little formal chemistry instruction, it seemed hardly surprising that their conceptions of chemical change were so contrary to the chemist's view. In the Schollum study, because there were only six form 6 students involved, it was difficult to derive a reasonable view of how these students' conceptualise chemical change.

Andersson (1986a) in a review-cum-synthesis of studies carried out to-date on students' explanations of chemical reactions which is regarded by many researchers as a landmark study in the area of perception of chemical reaction comments on the paucity of research in this area at that time. Of the few studies that had been done, the focus is on the conceptions of students (aged 10-15 years), during which period these students meet chemistry for the first time. Based on the findings of studies that have hitherto been carried out, viz. Andersson and Renstrom (1981), Schollum (1982b), Pfundt (1981), Mehuet, Saltiel, Tiberghien (1985) he suggests a scheme for categorising the variety of pupils' explanations of chemical reactions. He has developed his scheme based on those proposed by Pfundt (1981), Schollum (1982b) and Mehuet et al (1985). His 5 categories are:

(A) It is just like that
(B) Displacement
(C) Modification
(D) Transmutation
(E) Chemical interaction

The first category, which Andersson (1990) renamed as 'Disappearance', is no explanation. Displacement means that a substance appears at a given place simply because it has been displaced, such as the paint on the wall coming from a pot. Happs (1983) after studying New Zealand students reports that "children believe matter can disappear in chemical reactions". Modification means that what appears to be a new substance is in actual fact the same substance as before, albeit in a modified form, such as saw-dust is wood modified by sawing. Transmutation means that a given substance is transformed into a new one, such as iron changing into carbon.

Andersson (1986a, 1990) also suggests that this scheme of categories are applicable to
students' conceptualisations of the microscopic world of atoms and molecules, since students do not regard the microscopic world as different from the macroscopic world.

Prieto, Watson and Dillon (1993) conducted a questionnaire survey of 300 English and Spanish students (aged 14-15 years) and produced, among other things, results which have led them to refine Andersson's scheme of 5 categories. In their scheme, category (A) 'Disappearance' in Andersson's scheme is regarded as a limiting form of category (D) 'Transmutation' where the substance is transmuted to nothing. Category (B) 'Displacement' is omitted based on the fact it does not fit any of their data. A new category 'Description' (D) is added to capture the lowest level of students' responses, which are mere descriptions and offer no explanations. Thus, their model comprises four categories/levels of understandings, namely, 'Description', Modification' (M), 'Transmutation' (T) and 'Chemical reaction' (C).

The work of Andersson (1986b, 1990) and Prieto, Watson and Dillion (1993) did not, however, reveal how the effect of further formal chemistry instruction at an Advanced level would have on the conceptions about chemical reactions/combustion of students aged 16 and below. Moreover, the categories delineated by them would not, in this researcher's view be adequate in representing the conceptions of A-level students which would generally be in the highest category.

CONCLUSION OF THIS SECTION

The overall picture presented by studies in this section is that there is a variety of alternative conceptions about the nature of chemical reactions among students (aged 11-16), and that the majority of these are at variance with the scientists' notion of interaction between particles of reacting substances. The review also shows that the vast majority of the studies conducted thus far pertain to students aged 16 and below. Some of the difficulties faced by these students include problems in grasping the particulate model of matter and the nature of substances, as well as understanding the interaction of particles of substances during chemical reactions.

Some pertinent questions are, 'Do A-level students, ie. those who have undergone a
reasonable level of chemistry instruction and who have chosen to specialise in the subject also face similar difficulties in conceptualising the nature of chemical reactions? If so, can anything be done to address these difficulties? There seems little research, especially of the ethnographic or phenomenographic type, which is focused on the understandings that students at this particular level have, in relation to the bond breaking and bond making processes, and driving forces involved in chemical reactions.

Thus this present study is precipitated by the fact that there is as yet insufficient insight available in the literature on the range and nature of students' (especially at A-level or equivalent grade) difficulties and misconceptions about a fundamental area in chemistry - that of the nature of chemical reactions, what they involve, how and why they arise.

2.5 METHODS OF ELICITING STUDENTS' CONCEPTIONS IN SCIENCE/CHEMISTRY

Any instrument used to measure students' conceptions needs to be valid, reliable, sensitive and sensible or practical according to the resources and constraints of the research programme in which it is used.

The main techniques used to elicit data in studies on students' conceptions are:

* **The Individual Interview Method:** The method first used by Piaget in his embryonic studies with young children, and refined by several researchers (Pines et al., 1978; Osborne and Gilbert, 1980; Watts, 1981) is flexible and sensitive but time-consuming, hard to standardise and score, and requires substantial training (Fensham, Garrard, West, 1981).

* **Written Test:** This is time efficient but has inherent concept label/concept experience problems. There are variations of this; some have a multiple-choice format (Linke and Venz, 1978, 1979; Helm, 1980; Trembath, 1984; Halloun and Hestenes, 1985) and others comprise a two-tier type structure (Treagust, 1988) whilst Prieto et al (1989) describe 'free-writing'. The work by Tamir (1971) was among the first of its kind in incorporating as distracters in multiple-choice items
students' misconceptions found through essay and other open-ended questions.

A good example of the two-tier type written test is that reported in Treagust (1988) which is constructed to assess content knowledge and rationale. The first part of each item is a multiple choice content question with two to four choices. The second part consisting of a set of four possible reasons for the answer given to the first part, was developed from students' responses previously elicited through interviews or from information in the literature. This instrument however, also suffers from concept label and language problems.

* **Concept Maps**: This technique has its origin in research concerned with investigating changes in students' understanding of science concepts over a 122-year span of schooling (Novak and Musonda, 1991) and since then has been used for various purposes, including the investigation of conceptual development of learners (Novak, 1990). A study by Edwards and Fraser (1983) show that 'concept maps were as accurate as interviews for revealing student comprehension of concepts'. They also pointed to the 'contrast between the high equivalence of information revealed by concept maps and interviews, and the low equivalence between information revealed by written answers and interviews'. Examples of studies which have used concept maps successfully are Arnaudin and Mintzes (1985); Wallace and Mintzes (1990).

* **Word Sorting or Word Association Tests**: These tests have been developed by using stimuli embedded in sentences and allowing multi-word responses. An example is the study by Maskill and Cachapuz (1989) which used word association tests to follow the concepts of chemical equilibrium being learned by 30 students (14 years old). The stimulus word 'equilibrium' was found to reveal interfering concepts that were hindering learning. In this study, individual students' ideas were explored using the word association tests as well as retrospective reports obtained by asking students what their responses meant. It was reported that through this method, the idiosyncratic ideas of students were revealed and were related to individual learning difficulties.
Small Group Discussion Method (Brosnan and Hann, 1992): In this approach, groups of individuals are engaged on tasks involving mutual assimilation of, learning from, and re-formulation of scientific information through discussion and argument in a context which the researchers believed is "in fact close to that through which much of the scientific understanding they currently possess was actually forged." Moreover, the approach is believed to be non-threatening and is able to reduce the level of perceived threat likely to be produced by 'testing scientific knowledge', providing also a context in which knowledge can be elicited naturally, without the need for intensive individual questioning.

CONCLUSION FROM THIS SECTION

The various techniques for eliciting data on students' ideas vary in their feasibility and effectiveness in collecting a relatively objective, undistorted corpus of data. The choice of any one method or combination of methods in a particular study depends on the specific purpose(s) of the study itself. For the purpose of developing insights into students' conceptions in the present study, the individual interview method has been selected (see section 3.5.1, chapter 3).

2.6 OVERALL CONCLUSION FROM THE LITERATURE REVIEW

This review has shown that there are as yet comparatively few studies which are aimed at developing comprehensive insights into the understandings that a particular group of students (students aged 16-19 years, with significant background in the subject and generally with aspirations for further scientific study beyond A-level) have about the vital conceptual area of chemical reactions. The very small number of studies which concern more or less the same group and same area of chemical reactions (such as Hesse and Anderson, 1992) and use the same interview technique are generally of too narrow a scope and shallow in terms of the aspects (for example, they does not cover aspects such as energy change and driving force of chemical change) and number of parallel tasks covered.
The studies on combustion point to difficulties that learners of various ages have in conceptualising the nature of this very common type of chemical reaction. However, they also indicate that most of the information obtained from the older groups of learners, i.e. grade 10, and beyond are obtained through the use of written tests/questions. This means that the information obtained is limited in range and depth; also there is little information on how A-level students understand chemical reactions, including combustion reactions, in terms of driving force and of the bond breaking and bond making processes involved. This has led to the inclusion of three different combustion reactions in different contexts in the present study, which used, not a written test, but an interview-about-events technique as its main data collection instrument.

While the work of researchers such as Andersson (1986a, 1990), Driver (1985), Mehuet et al. (1985), Pfundt (1982), Ben-Zvi et al. (1982, 1986, 1987), BouJaoude (1991), and Prieto, Watson and Dillion (1993) are highly commendable in their attempts to examine students' understandings of chemical reactions in a systematic way, the students studied by them are generally in secondary schools, aged 16 and below.

Thus, this present study aims to fill in the gaps and take the research further by examining the understandings of older students, i.e., those who have proven to be successful in school leaving examinations and who have voluntarily opted to specialise in the study of chemistry. Obviously this group of students are expected to fall into Andersson's (1986, 1990)'s category (E) in his scheme of classification on students' models of chemical reactions; the other four categories, Disappearance, Displacement, Modification, and Transmutation should not apply. Thus, this study hopes to 'fill in the gaps' and uncover the variation of ideas that are covered by Andersson's category (E) 'chemical reaction'.

The literature on the consistency of students' ideas seems equivocal; it seems that quite often a student is seen as inconsistent based on their beliefs and views elicited in connection to their performance on a given task, but not across multiple tasks. This suggestion, together with the need to examine if A-level students are able to generalise across tasks, has resulted in the inclusion of a comprehensive range of contexts in this present study.
CHAPTER 3

RESEARCH METHODS AND PROCEDURES

3.1 THEORETICAL FRAMEWORK OF RESEARCH

The design of this study was guided by a constructivist-generative view of learning and teaching described in section 2.2 of chapter 2. According to this view, the learner is actively involved in constructing and reconstructing conceptual schemes or mental representations of the world around him/her.

Thus, the study set out to discover (or uncover) the kinds of conceptions or understandings that A-level chemistry students have about some common chemical phenomena, and to examine how these change with increased exposure to formal chemistry instruction. It also examined students' learning approaches and their perceptions of chemistry classes, and their possible effects on students' understandings.

3.2 RESEARCH QUESTIONS

a. What kinds of conceptions do A-level chemistry students have with respect to some familiar chemical phenomena? Do they have comprehensive and consistent explanations for chemical reactions?

* How do these students perceive the process of chemical change, at the microscopic level?

* What kinds of conceptions do these students have with respect to the energy changes involved?

* What kinds of conceptions do these students have with respect to the driving force of chemical reactions. In other words, what explanations do these students have with respect to why chemical reactions take place?

61
How do students' conceptions and understandings change with increased exposure to formal chemistry instruction?

How consistent or inconsistent are students' conceptions across the events or tasks?

What kinds of learning approaches do students have?

What kinds of perceptions do these students have of their chemistry classes?

What possible effects do students' learning approaches and perceptions of chemistry classes have on their understandings?

Answers to all but the last three of these research questions, were obtained from analysis and interpretation of the data obtained through the process of interview-about-events. Answers to the last three questions, d, e and f, were derived from analysis of data obtained from the learning process questionnaire as well as from the interview-about-events.

3.3 RESEARCH DESIGN

This study, which employed the interview-about-events technique as its main data collection device, was founded on the expectation that sixth formers, having been exposed to formal chemistry instruction for three to four years, would have learned enough basic chemistry about the macroscopic and microscopic properties of substances, the nature of change involving chemical interaction of particles and energy exchange between the chemical system and its surroundings to make sense of familiar chemical phenomena.

Thus, given some familiar substances such as metallic copper and hot air, it was expected that these students would be able to construct explanatory models or theories of the chemical reactions involved based on their knowledge of the properties of these substances and the nature of chemical interaction.

In setting out to develop insights into the students' mental world, it appeared preferable
to begin where the students were, i.e., to explore the students' conceptions on their own terms, without biasing the findings by imposing scientists' frameworks. Examples of this 'direct' approach are the proposal of the "naive physics manifesto" by Hayes (1979) and the work of Bliss, Ogborn and Whitelock (1989) on "common sense understanding".

However, the direct approach (in its purest sense) was not used in the present research in that although relatively common events/tasks were presented to students, the questions presented and the analysis of responses was based firmly on a scientist's framework. Some tempering of the scientist's framework, however, was achieved by way of flexibility in the structured interview process adopted which enabled detailed exploration of the students' own perspectives.

During the interview, the introduction of scientific terms by the interviewer was avoided wherever possible, and responses elicited were very much given in the interviewees' own terms. Where scientific terms were introduced by the interviewee, their meanings were probed. To a significant extent, whilst the interview was conducted against a prepared schedule, each interview progressed according to the responses given by the interviewee as his/her ideas were further probed for insights into his/her idiosyncratic world-view. As evident in later chapters, the students' responses subsumed many interesting and unusual statements, which revealed many features of the students' mental worlds.

In order to examine the issue of consistency and inconsistency of students' ideas and their ability to generalise across events, a set of 5 main events were used as foci for discussion.

Data gathering was carried out in two stages: stage 1, when the students were in the lower sixth form (abbreviated L6), and stage 2, when they were in the upper sixth form (abbreviated U6). At both stages, based on the same interview technique and schedule, data on students' conceptions and understandings were collected, so that the effects of intervening learning could be examined. In addition, at stage 2, the learning process questionnaire, was used to collect data on students' learning approaches and perceptions of chemistry classes so that some aspects of the nature of the intervening learning could also be examined.
3.4 THE SAMPLE

It was decided at the outset, that between 30 to 60 students from 3 to 5 schools (averaging 6 to 20 students per school), would be included in the study. To include more than 60 students would render the research unmanageable within the constraints of time, energy and other resources needed. To include less than 30 would limit the usefulness of the study in terms of representativeness of A-level students as a group and also limit the secondary objective of seeking some degree of generalisability. The initial higher number of 60 was chosen to allow for drop-outs or other contingencies.

At stage 1 (i.e., during the L6 interviews) the study sample comprised 60 students, drawn from 5 schools. However, at stage 2 (i.e., during the U6 interviews) 12 students were not available for the follow-up interviews for various reasons (such as having dropped out of the chemistry class or repeated failure to turn up at the appointed time) and were therefore excluded from this study. This means that the effective (final) sample size was 48.

Since the developing of insights into sixth formers' understandings, and not generalisations across the nation's schools, was the primary concern in this study, randomised sampling was not carried out. Randomised sampling would not in any case be feasible, given the limited resources available. Instead, schools were selected based on three main considerations.

Firstly, in order to sample as broad a range of students' conceptions as possible, and to achieve some, albeit small, measure of representativeness in the types of schools sampled, it was also decided to include students from three different types of schools, ranging from very good to good, and average, in terms of academic achievement.

The second consideration was the geographical location of the schools. In this case, they were all situated within the greater London area, which meant that they were reasonably accessible to the researcher.

The third consideration was the willingness of the schools and students to co-operate, particularly during the data collection stage which involved the students' participation in two interview sessions and completion of the 50-item learning process questionnaire.
Since this researcher was a foreigner to this country, and had no contacts with the schools in the field to begin with, she had to rely on the goodwill of lecturers in the Centre for Educational Studies at King's College London, to make recommendations and introduce her to relevant teachers in the study schools. Thus, judgement as to which of three categories (very good, good and average) the study schools fit into were based chiefly on views of the lecturers who made the recommendations and introductions to the study schools.

Although two of the educational institutions involved were sixth form colleges, for simplicity, all five institutions are referred to as schools in this thesis. Within each school, the teachers concerned (typically the head of chemistry) were requested to provide students from across a range of ability in chemistry. In one of the schools (school P), there were only 12 L6 students in total doing chemistry, hence the entire enrolment was included in the interviews. (However, at the U6, 2 of the students dropped chemistry, so that the number of school P students reported in this thesis is 10.)

The following table 3.1 sets out a brief profile of each of the study schools and its sample, including the composition by sex and the relevant science subject taken at GCSE, whether it is chemistry as a single subject or coordinated science.
### TABLE 3.1

**PROFILE OF STUDY SCHOOLS AND SAMPLE**

<table>
<thead>
<tr>
<th>School</th>
<th>Type</th>
<th>Sex</th>
<th>Age range</th>
<th>No. boys</th>
<th>No. girls</th>
<th>No. GCSE chem</th>
<th>No. GCSE co-ord science</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>voluntary-aided comprehensive</td>
<td>all-girls</td>
<td>11-18</td>
<td>0</td>
<td>9</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>E</td>
<td>county, comprehensive</td>
<td>mixed</td>
<td>11-18</td>
<td>7</td>
<td>3</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>P</td>
<td>independent, selective</td>
<td>all-girls</td>
<td>5-18</td>
<td>0</td>
<td>10</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>R</td>
<td>6th form college county, comprehensive</td>
<td>mixed</td>
<td>16-19</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>S</td>
<td>6th form college voluntary-aided comprehensive</td>
<td>mixed</td>
<td>16-19</td>
<td>3</td>
<td>10</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>13</td>
<td>35</td>
<td>17</td>
<td>31</td>
</tr>
</tbody>
</table>

Some comparative data on the schools in terms of public examination results and syllabuses and so forth are at Appendix A. Other relevant information on the study schools and sample are at Appendix L.

### 3.5 DATA COLLECTION

The primary data collection device used in this study is the interview-about-events.

A secondary objective of the study had been to measure students' learning approaches and to investigate relationships between these and the primary findings on student's understandings. The results obtained were inconclusive but are presented at Appendix L for completeness.

66
The decision to use a specific data elicitation technique was influenced by a number of factors. Among these were the aims and objectives of the study, the nature of the data required, the nature of the experimental tasks, the characteristics of the individual subjects, the feasibility of the analysis and the time allocated for gathering and analysing the data.

In this study, the individual interview was selected as being the most appropriate to the nature and purpose of the investigation. It had been used in many studies, and the data, thus obtained, had been found to be valid and reliable with respect to students' knowledge of specific content domains (Nussbaum and Novak, 1976; Baskhar and Simon, 1977; Clement, 1979; Erickson, 1979; Osborne and Gilbert, 1980; Posner and Gertzog, 1982; Stewart, 1983; Finley, 1984b; Gilbert, Watts and Osborne, 1985).

Many previous studies on students' conceptions employed written tests or paper-pencil methods including concept maps, word sorting, word association. These were considered as unsuitable for the present study for the following reasons.

* Each individual person has his/her own unique world-view and meanings, and paper-pencil methods generally do not allow for both parties concerned (researcher and the study subject), to seek clarification and elaboration of terms and labels used. This means that paper-pencil methods are subject to possible mis-match of interpretation of terms and meanings between researcher and study subject.

* Moreover, it is also well-documented (eg Gunstone & White, 1981) that sometimes, students can answer written examination questions correctly without really understanding the underlying principles. The interview situation would provide for in-depth probing on understandings.

* Paper-pencil methods suffer from not having a means to ensure that students provide adequate details in their answers. (While it must be admitted that in the interview situation there are also no fool-proof means of ensuring that students would provide adequate details in their responses, it must be recognised that in the
personal, one to one interactive situation of the interview, depending on the expertise, interpersonal skills and sensitivity of the interviewer, students are less likely to get away with superficial or perfunctory responses.)

* Paper-pencil methods while being time efficient could also suffer from the problems of pre-determination of questions and coverage which might reflect the researcher's bias.

* As pointed out by Schuster (1983) paper-pencil methods are particularly susceptible to the danger of premature and over-general conclusions and categorisations. (Interview methods are also not free from this danger, such as when initial responses are accepted at face value and not probed to sufficient depth. The course of the in-depth interviews carried out in the present study had also revealed the danger of premature conclusions; students' ideas, in particular, the initial ones, were found to be rather fragile, fluid and volatile as they modify and change.)

While the small group discussion method used by Brosnan and Hann (1992) was interactive and therefore avoided some of the potential problems of paper-pencil methods (such as mismatch in the understandings of terms and expressions between researcher and study subject), it was not seen as appropriate in this study for many reasons. Among these were practical problems of arranging for such group sessions; the difficulties of monitoring the interaction; and the recording of data.

While the individual interview situation might be seen as threatening by some interviewees (a problem which was said to be arrested by the use of small group discussion method), this could be alleviated by reassurance - particularly with respect to the use of the output by the researcher - that the interview would be confidential and not linked to any in-school assessment procedures.. Also the fact that this researcher was a foreigner and not associated with the local education scene might also alleviate any problem of perceived threat from the "testing of scientific knowledge". Moreover, it was much easier for rapport to be established in a one-to-one situation; students were less likely to be side-tracked, distracted, or confused, or suffer having their trains of thought interrupted by others.
Thus, the interview method because of its interactive nature could be used in such a way that the weaknesses of paper-pencil methods could be avoided or minimised; e.g., by using specific phenomena as foci for discussion and by asking general questions; and at the same time, minimising the introduction of scientific terms, and allowing the interviewee to introduce these terms and then probing their meanings. It allowed both interviewer and interviewee to ask questions to clarify perceived or actual ambiguities.

However, this method, was demanding, not only in terms of time, but also in terms of the expertise and interpersonal intelligence of the interviewer. Its success depended on the extent to which students were able to articulate their understandings, which in turn depended on the extent to which they were made to feel free to express their views without feeling that these would be immediately assessed against an externally defined standard.

It must be admitted that the interview method could also suffer from dangers arising from the interviewer's theory and expectations of the interview situations, which could bias the collection and analysis of the interview data. (See section 3.5.1.4 "Issues of validity and reliability" on how the perceived weaknesses of the interview method have been minimised in this study).

Having weighed the pros and cons of various techniques, it seemed that the balance was clearly in favour of the interview method for the specific purpose of this study, which was mainly to develop insights into students' understandings. As suggested by researchers such as Swanson et al. (1981), except for the rare cases where some conceptions or notions might be unknown to the interviewees themselves at the point of the interview, or where there are deliberate dishonesty or sharing of false views, the fact remains that over a wide range of conditions and situations people, students included, are reasonably good at telling what they conceive and how they think.

Pines et al. (1978), arguing in respect of the individual interview method pointed out that this "less quantifiable, less reliable approach is defended in terms of the inherent and irreducible complexities of the phenomena of education and psychology".
Above all else, in this researcher's view, the fact that each learner is an unique individual and has his/her unique world view merits the use of the individual interactive interview method.

3.5.2 THE INTERVIEW MODE AND STYLE

The choice of events and broad, open questions used in the interview schedule have, of necessity, been based on a scientist's analysis of the conceptual area of chemical reactions.

Throughout the interview process, a very delicate balance had to be maintained between the need to cover common ground in the intra- and inter- individual interviews for comparison purposes and the need to allow each interviewee to express his/her own unique conceptions and reasoning processes.

For the interviewees to engage in thinking, and to verbalise their thoughts properly, there was a need to maintain sufficient wait time for each question. Again a sensitive balance had to be maintained between the need for good wait time and the need to cover the range of events and the various aspects involved in the time available for each interview.

Each student was interviewed twice, once in the lower sixth form, then again in the upper sixth form. The same interview schedule, hence the same events or tasks, were used in both interview sessions, which were conducted on a one to one basis by the researcher, audio-taped and then subsequently transcribed. During each interview, students were not only asked to verbalise conceptions and theories about various aspects of the conceptual area of chemical reactions, but were also asked to make drawings to illustrate their conceptions and explanations. Hence, drawings as well as verbal reports were used as data in this study.

Each interview session lasted an average of one hour; in some cases, it went on for one-and-a-half to two hours. The variation in the duration of the interviews was a result of several factors:
Some time slots were more convenient than others, that is, some students had successive free periods and were available and willing to talk for longer periods of time than others.

Some students were, by nature, more willing to talk for longer periods than others.

Some students found that the interview sessions were useful learning situations in themselves, in that it helped them to articulate their ideas, and clarify them in the process (in spite of having no feedback from the interviewer). Others saw the interviews as practice or training sessions, either for pending examinations and/or for university admission interviews. Hence, these students were most willing to discuss and test their ideas and reasoning processes with the researcher.

On the whole, most of the students were very co-operative and responded readily and freely to the various interview tasks, and the interviewer enjoyed the interactions with them. At the end of the upper sixth interviews, the interviewer also spent as much time as was possible (typically 30 to 60 minutes) giving feedback on an individual basis to students who requested feedback on their strengths and weaknesses.

3.5.3 EVENTS/TASKS USED AND RATIONALE FOR CHOOSING THEM

The basic content of the two interview sessions for each of the students was essentially the same; since the same events and the same interview schedule were used. The five events which were used as foci for discussion in the interview sessions were used to establish a set of different but related contexts for students to use as reference in their theorising about how and why chemical reactions take place.

The five main events used were:

1. hot copper in air;
2. the burning candle;
3. the bunsen flame;
4. addition of magnesium to dilute hydrochloric acid;
addition of aqueous lead nitrate to aqueous sodium chloride.

The choice of the specific events/tasks as foci for discussion during the interviews, was based on the following considerations.

(a) The events should be fairly simple ones and familiar to students, so that misunderstandings were minimised, and so that students would be at ease talking about them. Hence practically all the 5 events chosen were those that the interviewees had met with at a very early stage of their science curriculum.

(b) Some of the events should involve combustion since combustion reactions are so much a part of our everyday life. In fact, almost everything that happens around us, cooking, heating, lighting, transport, manufacturing and so forth involves combustion reactions, either directly or indirectly. And of course the respiration and food digestion processes in human beings and in animals also involve combustion reactions, albeit very slow ones. Additionally, combustion reactions are among the first groups of reactions introduced to students, often in connection with the study of oxygen and air in our environment.

(c) Having decided to include combustion reactions, the next question was, 'How many of these reactions should be chosen and which ones?' In order to examine the consistency of students' ideas across the class of combustion reactions, 3 different combustion reactions were chosen. Among these, a familiar dry reaction (without the complication of solvents) involving a common substance (a metal) and air/oxygen, and a perceptible solid product (a metal oxide), was chosen as the first event for discussion. A metal such as copper was seen to be an obvious choice since metals were, after all, one of the most common and important classes of materials that students were introduced to during their early school years, and copper is one of the most common metals found in schools.

(d) The burning candle was chosen for its familiarity to students in their everyday life (e.g., birthday candles) and the bunsen flame for its ubiquity in school laboratories. The thinking was that most students would have been instructed on the chemical reactions occurring in a bunsen flame (in most cases during their early secondary
school years); it would thus provide a good focus for discussion. The inclusion of 
the burning candle would also provide the opportunity for evaluating the students' 
ability to transfer school knowledge about the bunsen flame to the candle flame.

(e) Besides the combustion reactions, some of the reactions should include solutions 
because, among other things, solutions and their reactions are of great significance in analytical procedures.

(f) Among the reactions in solutions, are metal-acid reactions which are also very much a part of the secondary science curriculum, where students learn that all elements could be categorised essentially into 3 groups: metals, non-metals and semi- or weak metals. They learn too that metals are characterised by their reactions with acids to form salts and hydrogen gas, and that corrosion of metals in their environment is often related to this metal-acid reaction. In addition, students also learn that metals are characterised by their reaction with air/oxygen to form oxides (e.g., in event 1) which are basic in nature and which would also react with acids to form salt and water.

The decision to include an event of this type was also arrived at based on the fact that a metal-acid reaction could also be grouped with the 3 combustion reactions in that all 4 reactions are redox reactions, i.e. involving electron transfer or a change in the oxidation numbers of substances involved. Magnesium ribbon and dilute hydrochloric acid were reasonable choices because both materials were familiar to students (In fact the interviews revealed that the majority of students had even carried out this particular experiment before); also both the progress of the reaction and the energy changes involved are clearly perceptible.

(g) The last event was chosen as it typifies precipitation reactions, another class of reactions with which secondary school students are very familiar, especially in relation to their practical work on qualitative analysis of elements, mixtures and compounds. It also involves the ubiquitous sodium chloride and shares one commonality, among others, with the preceding event, in that it involves the role of water as a solvent in chemical reactions occurring in the aqueous medium.
(h) For events 4 and 5, where time permitted, a related event (addition of copper foil to dilute HCl; and addition of aqueous copper sulphate to aqueous sodium chloride respectively) was also discussed. The rationale for including these discussions was to probe at a deeper level students' understandings of the nature of the chemical reactions involved.

The events were chosen in such a way as to reflect, not only the various common types of chemical reactions but also to reflect a gradation or progression, of difficulty in terms of perceptual cues. Event 1 involving copper metal and hot air was perhaps the simplest chemical reaction. Here both the starting substance and the subsequent product were solids, perceptible and were clearly different in appearance, even though the second reactant, hot air, was not. This was followed by event 2 which, like event 1, involved a well-known material, the candle, but which had the added complication of the wax giving the wrong perceptual cues. The wax was clearly seen to be melting and not 'burning' in the everyday sense of the term. However, the fact that the candle wax decreased in volume was also a clear perceptual cue that some change was involved. Event 3 was clearly more demanding than event 2, since not only were products imperceptible gases, both reactants were imperceptible gases as well. Thus, there was a hierarchy of difficulties associated with the three combustion reactions involved in events 1 to 3.

Events 4 and 5 formed another group of similar reactions, in that they both involved a solvent which was essential in the reactions (the solvation effect of water in the production of free or mobile ions, which subsequently interacted leading to formation of new products) but whose role was not obvious nor reflected in the chemical equation. This posed additional difficulty compared to events 1 to 3. Specifically, event 4 involved a perceptible solid (Mg) reacting with an imperceptible solution (dilute HCl) to produce a perceptible gas and a imperceptible aqueous product. Event 5 involved two imperceptible solutions reacting to produce a perceptible solid product and an imperceptible aqueous product. Thus, this second group of reactions was not only more difficulty than the group of combustion reactions, but within it, there was an increasing complexity or difficulty.
3.5.4 THE INTERVIEW PROCEDURE

There were essentially three main stages to the interview:

Stage 1: The initiation stage

This was the 'ice-breaking' or 'setting the stage' step, and involved a self-introduction by the interviewer and getting acquainted with the interviewee. The purpose of the interview was explained. The interviewee was told that the purpose was to develop insights into his/her thought processes as well as views about the events considered. S/he was assured of the confidentiality of interview data, and of the fact that the interview situation was not a test or judgemental situation; the interviewer would not comment on the 'rightness' or 'wrongness' of his/her views but might seek clarification on views or ideas offered.

This stage was omitted during the second round of interviews, that is, when the students were in their upper sixth form, because in virtually all cases, immediate rapport was established; the interviewees appeared to be completely at ease. It was also during this second interview that students were asked about the grades they scored for the science subjects they took during the GCSE examinations. They were also asked to make predictions on the grade they expected to score for chemistry in the coming A-level examinations. (These data are presented in Appendix L)

Stage 2: The elicitation stage

In this stage, the attention of the interviewee was focused in turn on each of the events; and were asked to respond on four main aspects of the chemical reactions involved, namely,

(A) make predictions on the type of chemical change expected

(B) make predictions on the overall energy change involved
(C) give a detailed account of how s/he imagined the change taking place at the microscopic level

(D) explain the driving force behind the change, that is, give an explanation as to why s/he thinks the change takes place

For Events 4 and 5 which involved chemical reactions occurring in the aqueous medium, the interviewee was asked to speculate on the role of water and was asked to predict the consequence of not having water present, that is, adding magnesium ribbon to a sample of pure gaseous hydrogen chloride (Event 2) and adding solid lead nitrate to solid sodium chloride.

(See Appendix B: The Interview Schedule)

Stage 3: The closing stage

The interviewee was thanked wholeheartedly for his/her contribution to the research; and in particular for his/her ideas and time invested.

Following each interview, field observations and notes were made on various aspects of the interview situation and interviewee, including his/her nonverbal communication such as his/her attitude, the extent of his/her involvement and engagement, as well as the interviewer's evaluation of her own style and approach, and any other additional information which might help establish a context for interpreting and making sense out of the interview.

3.5.5 VALIDITY AND RELIABILITY OF THE INTERVIEW METHOD

The main issues of validity of the interview method relate to questions such as those raised by McClelland (1984): "To what extent do data thus elicited represent students' true views, and are not merely expedient or transient solutions invented in an interview where an answer of some kind is a social imperative?"
It can be argued that the same questions could also be raised with regard to paper-pencil methods. In fact, the advantage of the flexible, interactive interview method used in this study over paper-pencil methods was that it allowed probing of responses so that superficial or false views could be detected.

Allowing for the fact that students' ideas may be fluid and fragile and that initial responses could be misleading, in this present study the interviewees' conceptions were elicited across four related aspects and five main events or tasks. This meant that numerous statements were made on the same aspect and conceptual area thus providing various opportunities (i.e., at different stages in the interview) for the interviewee to articulate his/her understandings of a particular aspect. It also allowed for misunderstandings, misinterpretations or errors in verbalisation to be checked. Furthermore, drawings and illustrations were used throughout to supplement and to cross-check verbal data wherever possible.

The main issues of reliability relate to interviewer bias and learning by the respondent through the interview process, which are pertinent in the data collection stage; and the data coding and categorising stage of the study.

The question of interview bias with respect to framing and design of the interview events and questions is also relevant to paper-pencil methods. In the case of this study, this specific issue of interviewer bias had been addressed by a process of developing and refining of the interview method and schedule involving pilot testing and back-and-forth discussion and validation with two experts in the field.

Also instead of depending on interviewer's notes of the discussion as a record of the interview, this study utilised transcripts (mostly transcribed verbatim from audiocassette recording) of the interview for analysis.

Like any instrument, the interview must have some effect on those on whom it was used. In this case, it must have an effect on the learning of the students, so that perfect consistency or reliability would probably not be attainable. However, the present study has gone some way in attaining reliability in data collection, by fixing the interview structure and schedule, which was used in all interviews. Thus, all interviews essentially covered
the same contents, in terms of the fixed events and aspects.

In the present study, the issues of reliability across interviews were further addressed by having the verbatim transcripts of the interviews read by two experts in the field, who then provided feedback on reliability.

In the present study, internal consistency between interviews with the same student was provided for by having the same fixed interview schedule (hence the same questions) at both interviews and by maintaining a common analytical structure.

The second aspect of reliability pertains to coding and categorising of students' responses. For this purpose, a structured scheme of 'model answers' comprising specific key elements for each of the aspects A to D across the 5 events was drawn up (see Appendix C: Key Elements in the Expected Responses in Each of the Aspects A-D). This was then used to code students' interview transcripts. The coding scheme, together with samples of coded transcripts were made available to two experts, who cross-checked both the coding scheme and the coding process. Consistency of coding between the researcher and experts was taken as an indication of reliability of the method of coding and analysis applied to the interview data.

Some researchers (e.g., Spector, 1984) have suggested that interview reliability could be checked by summarising interpretations which have been made and then presenting them to respondents for verification. Such checks were considered infeasible in this case because the respondents would probably not remember their previous conceptions or what they had said to be their conceptions.

3.5.6 SUPPLEMENTARY DATA COLLECTED

Supplementary data about the students' GCSE grades for science subject(s) and classroom environment were also gleaned from informal unobtrusive observations as well as from informal discussions with teachers. Such data were used to understand the different learning approaches adopted by students.

1. See Appendix O
3.6 DATA ANALYSIS

In this study, qualitative analysis of interview data was combined with the use of statistical techniques using the Minitab software, release 7.1 which was also used in analysing the data from the learning process questionnaire described fully in Appendix L.

In the initial stage of data analysis, interviews were transcribed verbatim. From the transcripts, 'telegrammes' capturing essential and relevant bits of students' responses to each event were written.

In the second stage of data analysis, interviews were no longer transcribed verbatim, owing to the constraints of time and because 'telegrammatic' transcripts were adequate for the purposes of coding of interview data.

Thus, the next stage of the analysis involved making explicit, that is, on paper, a scientist's views of the kinds of responses expected from students at this stage and level of their chemistry learning. This compilation was done with reference to the syllabuses and textbooks which were used by the students, as well as with input from some of the teachers (i.e., teachers who were helpful and available to this researcher) via informal discussions.

This structured scheme of blueprint or 'model answers' as it were, was set out in the form of a number of specific key elements for each of the four aspects A to D, and for each of the five events (see Appendix C).

Each transcript was then scrutinised for the number of key elements (abbreviated 'KEs') in the expected response under each aspect and each event which was contained in it, as well as for alternative conceptions (abbreviated 'ACs'). (See Appendix D for an example of a verbatim transcript which also illustrates the scoring of KEs and ACs). The specific KEs on each transcript which matched those on the 'model answers' were coded on the transcript as well as recorded on a first summary sheet (Form X) for each student (see Appendix E: Record of Specific KEs and ACs Across Events and Aspects).
A master list of ACs was compiled. At the same time, each AC as it occurred, was coded on the transcript as well as on the summary sheet X for each student. The number of KEs and ACs for each aspect and event counted for each student was then recorded on a second summary sheet (labelled form Y, see Appendix F: Record of Number of KEs and ACs Across Events and Aspects).

In the counting procedure, for every key element included, '1KE' was assigned. Where a significant part of a key element was included, half a key element, '0.5KE' was assigned.

In discussing students' understandings under each aspect across the 5 events (chapters 4 to 7), for each interviewee, the sum total number of KEs was obtained by adding the numbers scored in each of the 5 events and rounding off to the nearest whole number.

In discussing students' understandings across aspects for each event, for each interviewee, the sum total of KEs was obtained by adding the numbers scored in each of the aspects A to D, and rounding off to the nearest whole numbers.

While being aware that researchers like Goldberg and McDermott (1983) had suggested an operational definition of 'holding' a conception as being the consistent application of the same idea throughout an interview, and also through a range of situations, this was considered unsuitable for the purpose of this study. This is because the consistency or inconsistency of students' conceptions was in itself, a targeted area of the study. Thus, in the present study, for each of the four aspects A to D focused on, the final responses of the interviewee made in the context of each event was taken as the valid response in that situation; and any conceptions which were at variance with scientists' views were noted as alternative conceptions (ACs).

3.7 SUMMARY OF CHAPTER

The main aim of developing insights into students' conceptions was thought most appropriately achieved through the interactive interview method, after a deliberation of possible methods to use. Like all other methods, this method suffers from inherent
weaknesses or limitations. These weaknesses had been alleviated by various measures or precautions throughout the study process, the design of the interview events and schedule, the interview situation and the coding and categorising of responses.
CHAPTER 4

STUDENTS' UNDERSTANDINGS AND ALTERNATIVE CONCEPTIONS WITH RESPECT TO ASPECT A, TYPE OF CHANGE PREDICTED

4.0 OVERVIEW

This chapter examines the students' responses under aspect A, prediction about the type of change (in terms of reactants and products) to determine students' understanding and range of ACs held.

Section 4.1 examines students' total scores on aspect A across events by school and by sex.

Section 4.2 examines students' scores on aspect A by event by school and by sex.

Section 4.3 examines students' alternative conceptions (ACs) associated with aspect A.

For aspect A, responses revolved around knowing that a chemical change was involved, and being able to identify the reactants and products involved. A total of two key elements (2KEs) in the expected response was defined (see Appendix C). Hence the maximum number of KEs defined across the 5 events are 2x5 or 10KEs.

4.1 ANALYSIS OF STUDENTS' RESPONSES ON ASPECT A OVER ALL 5 EVENTS

To examine the difference between schools in terms of the U6 and L6 KE scores; and in terms of progression i.e., (U-L) scores, on aspect A across events, mean scores are set out in the following table 4.1.
Table 4.1 shows that differences between schools on Aspect A became more significant at U6 compared to L6 indicating differential added educational input between the schools. Also it can be seen that except for school E which showed regression, the other 4 schools showed progression on aspect A scores across events.

The difference between U6 and L6 appears to be most significant between schools P and E, with school P making the greatest progression and school E the least on aspect A.

To examine the difference between the sexes in terms of the U6 and L6 KE scores; and in terms of progression, i.e., (U-L) scores, on aspect A across events, mean scores are set out in the following table 4.2.
From the results in table 4.2 it can be seen that while the male students did significantly better (p<0.05) than the female students on aspect A at the L6, the girls made significantly more progression (p<0.05), so that by U6, there was no more significant difference between the sexes.

**4.2 ANALYSIS OF STUDENTS' RESPONSES ON ASPECT A BY EVENT BY SCHOOL**

To examine the difference between the schools in terms of the U6 and L6 KE scores on aspect A by event, mean scores are set out in the following table 4.3.

<table>
<thead>
<tr>
<th>Sc</th>
<th>A1U</th>
<th>A1L</th>
<th>A2U</th>
<th>A2L</th>
<th>A3U</th>
<th>A3L</th>
<th>A4U</th>
<th>A4L</th>
<th>A5U</th>
<th>A5L</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>2.0</td>
<td>1.9</td>
<td>0.5</td>
<td>0.4</td>
<td>1.7</td>
<td>1.4</td>
<td>1.8</td>
<td>1.9</td>
<td>1.8</td>
<td>1.3</td>
</tr>
<tr>
<td>R</td>
<td>1.7</td>
<td>2.0</td>
<td>1.5</td>
<td>1.1</td>
<td>1.8</td>
<td>1.6</td>
<td>1.7</td>
<td>2.0</td>
<td>1.5</td>
<td>1.2</td>
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<tr>
<td>P</td>
<td>2.0</td>
<td>2.0</td>
<td>1.6</td>
<td>0.9</td>
<td>2.0</td>
<td>1.9</td>
<td>2.0</td>
<td>1.8</td>
<td>1.9</td>
<td>1.0</td>
</tr>
<tr>
<td>E</td>
<td>1.2</td>
<td>1.4</td>
<td>1.9</td>
<td>1.8</td>
<td>1.9</td>
<td>2.0</td>
<td>1.7</td>
<td>1.7</td>
<td>1.1</td>
<td>1.4</td>
</tr>
<tr>
<td>S</td>
<td>2.0</td>
<td>2.0</td>
<td>1.3</td>
<td>0.8</td>
<td>1.7</td>
<td>1.5</td>
<td>1.9</td>
<td>1.9</td>
<td>1.5</td>
<td>1.6</td>
</tr>
<tr>
<td>Av.</td>
<td>1.78</td>
<td>1.86</td>
<td>1.36</td>
<td>1.00</td>
<td>1.82</td>
<td>1.68</td>
<td>1.82</td>
<td>1.86</td>
<td>1.56</td>
<td>1.30</td>
</tr>
<tr>
<td>p</td>
<td>.006</td>
<td>.025</td>
<td>.001</td>
<td>.001</td>
<td>.324</td>
<td>.130</td>
<td>.259</td>
<td>.617</td>
<td>.112</td>
<td>.475</td>
</tr>
</tbody>
</table>

From table 4.3, comparing U6 and L6 scores (with the possible exception of event 3) the decreasing p values suggest that, with increased formal instruction, the school effect became greater.

At the L6, on aspect A, event 1, school E's score was significantly lower than those in the other 4 schools while at the U6, school R seemed to have regressed a little, so that the differences seemed to be between schools C, P and S (which had the full scores) on one hand and schools E (and R to a smaller extent) on the other hand.
At the L6, on aspect A, event 2, it seemed to be the reverse to event 1: the schools C, S and P which had proportionately more females did worse (scoring less than 1KE) than the schools who had more male students, schools E and R (scoring more than 1KE). At the U6 schools P and S progressed and joined the other 2 schools by scoring more than 1KE, leaving school C behind (which showed hardly any progression).

It is interesting to note that generally the schools which had proportionately more females did better on event 1 and worse on event 2.

One interesting observation was that while proportionately more female students were able to predict that copper in event 1 would undergo oxidation when heated in the bunsen flame, at the same time, in event 2, the burning candle, they were not able to conceptualise the candle wax as being burned or involved in any chemical reactions. More specifically 27 girls, 11 at the L6; and 16 at both U6 and L6 levels, conceptualised the wax in the burning candle as merely melting and not being involved in burning (see section 4.3).

This appeared to be a contrast to the male students, who had no problems whatsoever in conceptualising the burning of wax in the candle flame; yet among whom a significant proportion predicted that copper would only melt and not burn when heated in the bunsen flame (see section 4.3).

The data in Table 4.3 also shows that for events 3 and 4, the students, even at the L6 interview generally knew what chemical reactions were taking place, at least, in terms of knowing what reactants and products were involved.

Events 2 and 5 appear to be least well-conceived in terms of reactants and products, during the L6 interviews. However, even then, at least one out of the two key elements (at least 50%) was included on average by students in each school, and by the U6, most schools made progression.

On aspect A, event 2, it was schools C and E which did not show progression, and for different reasons. In school C, the students still did not know what reactants were involved in the burning candle; where the students in school E (the majority of whom
were boys) had already almost full scores at L6, hence there was not much room for improvement.

On aspect A, event 5, it was the two all-girls schools C and P which seemed to make the most progression.

The lower L6 scores (of around 1KE) for 4 out of the 5 schools in events 2 and 5 seemed to be arisen from different causes. In the case of event 2 it was largely due to the dominance of perceptual thinking: wax was not conceptualised as being involved in chemical change by some students (mostly female) because it was seen as not burning but merely melting. In the case of event 5, a number of students predicted correctly the identities of the 2 products but showed lack of understanding when they thought both products would be formed in the aqueous state. This lack of understanding was further revealed when they predicted that if aqueous copper sulphate, instead of aqueous lead nitrate, were added to aqueous sodium chloride (event 5b - the event parallel to event 5, see chapter 3), there would be a chemical reaction.

4.3 ANALYSIS OF STUDENTS' RESPONSES ON ASPECT A BY EVENT BY SEX

To examine the difference between the sexes in terms of the U6 and L6 KE scores on aspect A by event, mean scores are set out in the following table 4.4.

<table>
<thead>
<tr>
<th></th>
<th>A1U</th>
<th>A1L</th>
<th>A2U</th>
<th>A2L</th>
<th>A3U</th>
<th>A3L</th>
<th>A4U</th>
<th>A4L</th>
<th>A5U</th>
<th>A5L</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>1.9</td>
<td>2.0</td>
<td>1.2</td>
<td>0.7</td>
<td>1.8</td>
<td>1.5</td>
<td>1.8</td>
<td>1.8</td>
<td>1.6</td>
<td>1.3</td>
</tr>
<tr>
<td>M</td>
<td>1.5</td>
<td>1.5</td>
<td>1.8</td>
<td>1.9</td>
<td>1.8</td>
<td>2.0</td>
<td>1.8</td>
<td>1.9</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td>p</td>
<td>.083</td>
<td>.007</td>
<td>.010</td>
<td>.000</td>
<td>.878</td>
<td>.028</td>
<td>.888</td>
<td>.486</td>
<td>.296</td>
<td>.895</td>
</tr>
</tbody>
</table>
From table 4.4 it can be seen between the U6 and L6 the p values increased in all events, except 5, indicating that significance of the gender effect generally decreased with increased formal chemistry instruction.

However, within this generalisation, it can be seen that, in event 1, the girls did better than the boys at the both levels, the boys not improving at all on their scores.

This is contrasted to event 2, where the boys did significantly better than the girls at both U6 and L6 levels.

One tentative hypothesis that this researcher has about the gender differences in events 1 and 2 is:

The girls were less able to generalise across events 2 and 3. They conceptualised them as unrelated, isolated events whereas the boys clearly saw them as similar. However, in event 1, it seemed that the boys (some) were associating it with activities like metal working and metal shaping when they predicted that copper will not oxidise but will only melt.

4.4 STUDENTS' ALTERNATIVE CONCEPTIONS ASSOCIATED WITH ASPECT A, PREDICTION ABOUT TYPE OF CHANGE (IN TERMS OF REACTANTS AND PRODUCTS)

This section discusses some of the ACs elicited with respect to aspect A, most of which pertain to combustion reactions, i.e., events 1, 2 and 3.

ACs under Aspect A can be grouped as follows (a formal categorisation of ACs is established in chapter 8, the full list of categorised ACs is provided in Appendix H.):

Group A1: ACs arising mainly from perceptual (as opposed to conceptual) thinking.
Group A2: ACs which show ideas of conservation and have some scientific basis, and arising mainly from the lack of understanding about the driving force of chemical reactions: e.g., ACs involving products and reactants which appear to be chemically possible but do not take place because of energy considerations.

Group A3: ACs which show ideas of conservation but otherwise have little or no scientific basis, where, 'anything goes as long as the elements are in a soup'; e.g., ACs involving impossible reactants or products.

Group A4: ACs which show no ideas of conservation, but instead ideas of transmutation where particles, hence substances, are transmuted from one kind into another

Examples of ACs are given below for each of the above 4 groupings.

Since the more prevalent ACs revealed in students' responses under aspect A, prediction of the type of change, pertained to conceptions about burning, i.e., in the context of events 1, 2 and 3, in this chapter, only these more significant ACs are discussed. Other ACs will be discussed, where appropriate, in other chapters. Also in this chapter, as in chapters 5, 6 and 7, two methods are used in describing the students who subscribed to each AC. Where the numbers of students subscribing to a particular AC are high, these are presented in the form of a table, showing whether the AC was held at the L6 (L) only or U6 (U) level only or at both levels (U+L) delineated by schools. Where the numbers of students involved were small, then these are presented as a list.

The interview extracts used to illustrate each type of AC usually contain statements which also illustrate other ACs, as will be indicated.
GROUP A1: ACs those arising from the dominance of perceptual thinking

AC A1a: substantialisation of heat; heat or flame is seen as a substance, more specifically, it is seen as a reactant or the active agent of chemical change.

<table>
<thead>
<tr>
<th></th>
<th>U only</th>
<th>L only</th>
<th>U&amp;L</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC A1a:</td>
<td>C12, C18</td>
<td>C14, C16</td>
<td>C6</td>
</tr>
<tr>
<td>substantialisation</td>
<td>P10</td>
<td>E1</td>
<td></td>
</tr>
<tr>
<td>of heat/flame</td>
<td>R2, R4</td>
<td>E2, E5, E17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S4</td>
<td>S12</td>
<td>S6, S20</td>
</tr>
<tr>
<td>Totals:</td>
<td>3</td>
<td>9</td>
<td>4</td>
</tr>
</tbody>
</table>

This AC was subscribed to by 16 students, 7 in the U6, of whom 4 revealed this same AC at both U6 and L6 interviews. This AC is very closely related to AC D1a (heat as causal agent of chemical change, section 7.3, chapter 7) where flame or heat is not merely seen as the result of reaction; instead it is conceived of as an active agent, a reactant and a cause of chemical change. These ACs probably arise as a result of perceptually dominated or everyday thinking.

Copper when put in the flame, turned black, i.e., formed a new substance. Without the flame, it appeared that nothing changed, but change came about as a result of it being placed in the flame. Thus perceptually, the flame was an active agent, a reactant in the chemical change. With some students, who did not understand the role of oxygen in burning, the misconception of heat as substance went a step further: since they learnt at an early stage in the school science curriculum that oxygen/air is necessary for burning, without oxygen/air, there is no flame; so it appears they drew the inference that flame is synonymous to oxygen/air, i.e., oxygen/air is flame and flame is oxygen/air.
This AC is illustrated in cases II and IV, chapter 12, and in the following extracts of interviews with students S20, C6, C16 and C18 (students' verbatim responses in italics):

EXTRACT 1: From U6 interview with S20 (It also illustrates AC D1a.)

S20.2 in reply to what she understood by the term 'chemical reaction' said: ".. one reactant affects another reactant to form something else or to bond together."

I: "There must be two reactants.. one single reactant cannot undergo chemical reaction..?"

S20.2: "But if it's heated, then it's oxygen that is affecting it.. there's still something affecting it"

I: "Let's take calcium carbonate, if we heat it, it will form calcium oxide and carbon dioxide gas.. is this a chemical reaction?"

S20.2: "Yeah because bonds are still broken".

I:"But there is only one reactant here.."

S20.2: "Yeah but that can't.. there must be something else.. it can't break up on its own just like that.. so there must be something else affecting it".

I: "What is this something else.."

S20.2: "Must be heat.. 'cos it is breaking the bond.. it's endothermic.. which means it's taking heat in so there must be heat there.. I don't know whether you'd class heat as a reactant 'cos usually it's the driving force.. it makes the reaction start". [Her last statement illustrates AC D1a: heat as causal agent.]
EXTRACT 2: From U6 interview with C6 (It also illustrates AC D1a.)

I: "Do you think there are chemical reactions going on in this bunsen flame?"

C6.2: "Yes, there are. I don't know whether to call it light or heat or oxygen. Knowing you
strike a match, I don't know what you call the match itself. The light that comes from the
match... if it was oxygen or heat... heat is usually taken as oxygen"

I: "What do you think is the driving force of this bunsen flame reaction?"

C6.2: "Oxygen"

I: "For candle flame, you said driving force is heat"

C6.2: "I also mean oxygen as well... are they different, oxygen and heat? What is the
difference between oxygen and heat?"

I: "What do you think...?"

C6.2: "I think the chemicals in the match is the heat... I don't actually know what chemicals
are but I usually take heat as oxygen."

EXTRACT 3: From L6 interview with C16

C16.1, in predicting what would happen to copper if put in the very hot bunsen flame,
said: "I expect it to lose its colour... the surface reacted with the heat and you got an oxide
there".

I: "What do you mean by 'reacted with'... or a 'reaction'?"

C16.1: "A reaction happens when 2 substances come together and you get a result from
it... something comes out of it"
C16.1: "Copper surface reacted with the heat."

I: "What do you mean by term 'heat'?"

C16.1: "Heat is when you got like a high temperature really...it's hot air. when the air is really hot, we experience it as heat."

There were no evidence of this substantialisation of heat as hot air at the U6 interview with C16.

Like many other students, S20, C6 and C16 had conceived of a chemical reaction as typically involving 2 substances coming together. The idea that it could involve just a single substance seemed remote or beyond the conception of these students. With the firm notion that chemical reactions typically involve 2 substances, where one reactant is imperceptible (e.g., oxygen in event 1), and where besides the perceptibility of the other reactant (copper in event 1), the flame or heat was also perceptible, it seemed understandable that flame or heat was thus conceptualised as a reactant, a substance, an active partner in the change. Then since school science had planted in the students' minds the idea that oxygen is needed for burning or the idea that where there is a flame, there is oxygen and vice versa, many of the students, especially those in school C (4 out of the 9 interviewees, i.e., 44%, held this AC) had inferred for themselves that heat is a substance and that in fact heat is oxygen and oxygen is heat.

It also seemed to this interviewer, that to some students (4) that flame or fire was something of a mystique or mystery; in some other cases (2), it appeared to be just a flame, like any other paraphenelia in the lab, such as a burette or pipette or an electric hot plate (no chemical reactions are involved). For example, L6 interviewee R2 when asked whether there were any chemical reactions going on in the bunsen flame, responded by saying that "There's no chemical reaction but there is heat and light given off...the methane...just go back into the atmosphere again". When asked to how she imagined the light and heat were produced, she said, "Hm...we just learn about ionisation energy...when you give it heat, then when it jumps, it gives off heat and light...the electrons are moving, so I suppose it could go back again and you could get the gas again."
Her statements illustrate how new knowledge associated with electron transitions could be over-emphasised and allowed to distort her existing conceptual frameworks. From examination of GCSE syllabuses, it was evident that concepts of burning had been covered. Yet, she seemed to have totally ignored or forgotten about her old knowledge. Perhaps, this syndrome of allowing new knowledge to distort existing conceptual frameworks is a necessary step to acquiring scientific views. That this was true of R2 could be seen at the U6 when she seemed to have acquired views closer to the chemist's.

**AC A1b:**

the conception of burning as catching fire or simply, as heating, the application of heat; oxygen may or may not in involved as a reactant; if oxygen is involved, its role of oxygen was either unclear or misconceived; and the result of burning is not necessarily a chemical change.

<table>
<thead>
<tr>
<th></th>
<th>U only</th>
<th>L only</th>
<th>U&amp;L</th>
</tr>
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<tbody>
<tr>
<td>AC A1b:</td>
<td></td>
<td></td>
<td>C4,C6,C18</td>
</tr>
<tr>
<td>burning is</td>
<td></td>
<td>R4, R7</td>
<td>R2,R6</td>
</tr>
<tr>
<td>catching fire</td>
<td>P20</td>
<td>P16</td>
<td>P10,</td>
</tr>
<tr>
<td>or simply,</td>
<td>E3</td>
<td></td>
<td>E1,E2,E5,E7,E19</td>
</tr>
<tr>
<td>heating</td>
<td>S4,S6,S18</td>
<td>S8,S10</td>
<td>S2,S12,S20</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>5</td>
<td>14</td>
</tr>
</tbody>
</table>

It can seen be that this AC was revealed by 24 out of the 48 interviewees, 14 of whom revealed it at both U6 and L6. Five of them who held it at the L6 level, appeared to have made some progression and abandoned it. (As will be discussed later in chapters 8 and 12, the abandonment of an AC cannot be regarded as a clear indication of overall progression, because it was could be accompanied by the acquisition of new ACs.)

This AC arises mainly as a result of the dominance of perceptual thinking, and the confusion between the everyday and the scientific meaning of the term 'burning', and is
clearly at variance with scientists' view of burning as the chemical interaction between particles in air (i.e., oxygen molecules) and the particles of the substance being burned, which results in the formation of new kinds of particles, constituting the oxides, and hence a chemical change.

It also seemed to be associated with a naive view of chemical change as involving one active agent acting on a passive substance (which is at variance with the chemist's view of chemical change as involving the interaction of equal partners). Two opposite versions of this view were discovered: one group of students (10 of them) viewed oxygen as the active agent causing the change and the rest of the students generally viewed oxygen as a facilitator or helper of change (the permissive agentive role, in the terms of Brosnan, 1992).

A subset of AC A1b is the misconception held by a number of the students that oxygen is the active causal agent of burning.

The group which viewed oxygen as the active causal agent, conceptualised it in various ways, such as:

S4.: "Oxygen is like a force, it causes the C-H bonds (referring to methane in event 3) to break... bonds has to be knocked off... knocked apart." [Like many other students, she also revealed a conception of bonds as a physical entity (Chi et al, 1994, refer to the mental process as "coding the concept of 'chemical bond' into the ontological category of 'matter' instead of seeing it as a constraint-based event and coding it into the ontological category of 'processes'").

Other students such as E7 held the view at both U6 and L6 that oxygen causes partial charges to be formed in the C-H bonds in methane which then break.

A further subset viewed oxygen as the facilitator of burning.

E3.2 on event 2: "Oxygen helps in the burning... if there is no oxygen, it will not burn. You need three things in order to burn: oxygen, fuel and temperature." [E3 is interesting in that he did not conceptualised copper as capable of burning in event 1. He had a very
interesting theory about how metals like copper and magnesium, will expand, trap oxygen, increase in weight and form oxide but the process is a physical change and not a chemical one - see AC A1c, section 8.5.2, chapter 8].

(See also Case II, student E1, in Appendix M which illustrates how this AC could co-exist with scientific views.)

The following extract illustrates the view of burning as merely catching fire and not necessarily involving chemical change:

Student S20 (quoted in the preceding section as holding AC A1a) is not a untypical of the interviewees by holding both ACs A1a and A1b at the same time. The following dialogue in the L6 interview illustrates AC A1b:

I: "Do you think there are chemical reactions going on in the bunsen flame?"

S20.1: "Bunsen flame is just the gas burning. I don't know if there's a chemical reaction when the gas burns. I don't think there is."

In the same interview, asked what she understood by the term 'burning', she was unable to explain...but merely said (after a fairly long pause, "...er...I don't know. just burning. I don't know."

[The fact that she did not think that there is a chemical reaction involved in the gas (methane) indicated that she had the layman's view of burning as merely catching fire.]

At the U6 interview, in replying to the same question on the meaning of 'burning' she said, "Burning is when you get something in a flame, it reduces it to ashes. Metals burn to ash or oxide but plastics just melt when burned".

Between the U6 and L6 interviews, she appeared not to have shifted from AC A1b, i.e., burning is essentially catching fire so that materials like plastic only melt when they are burned.
AC A1c: metals do not burn

Under this AC, there are 2 different variations in the thinking:

In the first case, metals are seen as capable of forming oxides when put in the very hot bunsen flame but not capable of burning (E1.1, E10.2, E6.2, R2.2, S20.2); in the second case, metals are seen as incapable of burning and hence, incapable of forming the oxide. Both variations in thinking had their roots in perceptual thinking: metals are not seen to 'catch fire' in the way that materials like wood and paper do, hence metals are misconceived as incapable of burning (E3.1,2, E11.1,2, E17.1,2, S18.2).

It was interesting to note that the 4 out of the 5 students who thought copper would oxidise but not burn were female students; and that 3 out of the 4 students who thought that copper would not oxidise but would only melt were male students. In fact, there were another 2 male students R5 and R7 who initially maintained that copper would not oxidise but only melt. However, upon further probing, they both abandoned this AC. (See also the discussion in the preceding section 4.2)

The cases of the 4 students who conceptualised the copper in event 1 as undergoing oxidation but not burning illustrates how school science views are superimposed upon naive or everyday views of burning (Gilbert, Osborne and Fensham, 1982).

(NB. In the counting of KEs under aspect A in these cases, the full score of '2KEs' was scored (see Appendix C 'Key elements in the expected responses.) At the same time, '1AC' (viz. AC A1c) was counted. These cases illustrate how one would not necessarily expect a straightforward inverse relationship between KEs and ACs (See section 9.2, chapter 9 for more discussion on this issue.))

Students E3, E5 and E17, provide some interesting insights on this AC when they both insisted in the L6 and U6 interviews that copper would not oxidise or burn, and therefore would not undergo chemical reaction, but would merely melt, and vaporise, if heated to high enough temperatures.
For example, E3.1 maintained that his prediction was based on the kinetic theory of matter. (It was a pity that at both interviews, there was not enough time for the interviewer to perform the experiment to challenge him to review his conceptions.) At the U6 interview, however, when talking in the context of wax and methane burning (events 2 and 3), he submitted that metals like magnesium did get burned (and "get heavier", he had "seen it from past experience") but by a process different to that of wax and methane burning, and the product was magnesium oxide. The reason he gave for the difference in the burning process of methane and magnesium was "the bonding of the structure was different...methylene's covalent where electrons are shared between the atoms but with metals...positive atoms...like a sea of electrons in between holding them together...very closely packed together...when you heat them, this heat energy caused these ions to vibrate...so the heat gets passed through the metal...the metal ions get further apart as they are vibrating so oxygen might get trapped in there...magnesium oxide weighs more than magnesium because it traps oxygen somehow...takes in oxygen."

At the U6 interview, E3 also explained why he thought metals do not burn in the same sense as wax and methane, which were burned to form carbon dioxide and water. He said it was the metal bonds in metals which allowed heat to pass through, without breaking of bonds (as evident from his statement on his understanding of the term 'chemical reaction': "the breaking and formation of bonds within the structure...there are structural changes...it's not just physical like when you heat something, it just expands or increases in volume...therefore if oxygen's trapped in here...in the metal...it's not chemical reaction...it's not reacted I think") whereas the covalent bonds in wax and methane "absorb heat and break". This was how he imagined the process of change in event 2 "C-H bonds absorb heat...so at a certain point where the electrons jumped, excited...that's the point where they break away and come out...free floating electrons...atoms of hydrogen...maybe some C-C bonds break as well...cos under heat energy, that's possible...these wandering about and they react with oxygen...if there's enough oxygen present they form water and carbon dioxide 'cos it's stable...if there isn't enough they form carbon monoxide".

This AC is thus linked with the thinking that there is something different or 'special' about the nature of bonds in a metal which prevent it from burning. This kind of thinking was also evident in the interview with S18; and like many other interviewees, S18 also seemed
to hold confused and inconsistent ideas about burning and what it involved.

An extract from the U6 interview with S18: illustrating AC A1b: burning as catching fire; and AC A1c: metals do not burn because of the nature of bonds within them:

I: "What do you predict if this copper is placed in the very hot bunsen flame?"

S18.2: "Melt..burn to make copper(II) oxide"

I: "Burn..what do you understand by the term 'burn'...or 'burning'?"

S18.2: "Set light to it..when heat energy..one form of energy being converted to another one using oxygen for combustion to keep it..cos when you burn a candle in the absence of oxygen it won't burn at all..so when you use a candle which is like chemical energy and light from chemical energy from match..you're converting that form to heat and light energy so burning is a form of energy to liberate heat"

I:" What happens to the oxygen during the burning?"

S18.2: "It combines with whatever that's being burned..they will convert to another form of something to help the burning"

I: "Can metals burn..like can copper burn?"

S18.2: "Copper..no, it can get..no copper just get heated and warmed..copper will be a heat conductor but it won't melt or burn like other elements like plastics because of the covalent bond or whatever..it would burn and melt but metals don't..metals in general anyway don't burn because metals got metallic bonding..doesn't melt, they're just good conductor and electrical conductor "

Thus, superficially it seemed that S18.2 had contradicted her very first statement (in which she predicted that copper would form copper oxide) when she later stated her belief that metals do not burn nor melt. However, further analysis of all her statements revealed that her difficulties was related to her lack of understanding of the concept of burning, as well
as her inability to see that metal or copper could undergo simultaneously several changes when heated, i.e., it could conduct heat and electricity, burn (i.e. react with oxygen to form oxide(s) at the surface mainly) and also melt.

This inability to see that many different kinds of changes could happen at the same time to the same substance was common among the interviewees, and gave rise to several ACs about the phenomena presented to them for discussion. It seemed to this researcher-cum-interviewer, that nonformal thinking (or 'one factor only' type thinking) or dichotomous thinking, i.e., things are either this way or that way, black or white, and there is no room for grey areas or for multiple possibilities was prevalent among the interviewees.

**AC A1d:** wax does not burn, only melts

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<tr>
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<th>L only</th>
<th>U&amp;L</th>
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<tbody>
<tr>
<td>AC A1d: wax</td>
<td>C6</td>
<td>C4,C10,C12,C14,C16,C18,C20</td>
</tr>
<tr>
<td>does not burn</td>
<td>R2</td>
<td>R4,R6</td>
</tr>
<tr>
<td>only melts</td>
<td>P2,P4,P18,P20</td>
<td>P6,P10,P14</td>
</tr>
<tr>
<td></td>
<td>S4,S6,S8,S12,S18</td>
<td>S2,S14,S16,S20</td>
</tr>
<tr>
<td>no. students</td>
<td>11</td>
<td>16</td>
</tr>
</tbody>
</table>

This AC is very closely linked to AC A1b (burning is catching fire) and A1c (metals do not burn). The rather large numbers of students who subscribed to this AC, 27 out of 48 or 56%, was very surprising. Out of these 27 students, 16 or 33% of all interviewees, held the same misconception through both interviews. It seemed almost incredible that sixth formers, who had studied chemistry formally for 3 to 4 years could think of the candle wax as not being involved in the burning process of the burning candle, and that it was merely melting (and solidifying, as mentioned by some interviewees), and that its function is merely to hold up the wick, which was being burned.
Herein, the power of perception in the mental world of the students is demonstrated: the wax in the burning candle was not seen to be catching fire, therefore it was misconceived as not being involved in burning.

It was noteworthy that none of the 13 male interviewees held this AC, not even at the L6 interview, while 16 out of the total of 35 female interviewees (46%), held the same AC at both U6 and L6 interviews (See section 4.2 on this researcher's hypothesis on the sex differences associated with AC A1c and AC A1d.)

For illustration of AC A1d, see cases III and IV, Appendix M.

**AC A1e:** burning always results in carbon dioxide being produced

This AC was subscribed to by students: C10.1,2, C18.1,2, E1.1, E17.1, R4.1, S10.1.

This AC is related to AC A1c (metals do not burn) and seemed to be related to the everyday view of burning - that materials like wood and paper (which contains carbon) can burn but not materials such as metals. For illustration of this AC, see cases II and IV, Appendix M.

**AC A1f:** role of solvent is unknown - chemicals dissolve in each other.

This AC was subscribed to by students S8.1, S18.1, S20.1

This AC was covered mainly with respect to event 5b, adding of aqueous copper sulphate to aqueous sodium chloride. These 3 students maintained that no solids were seen because the products formed sodium sulphate and copper chloride which dissolve each other.

This reflects either a lack of understanding of the role of water, the solvent, or the use of perceptually dominated thinking where the role of water is ignored because it is not reflected explicitly in the chemical equation.
GROUP A2: ACs which show ideas of conservation and have some scientific basis, and arising mainly from the lack of understanding about the driving force of chemical reactions: e.g., ACs involving products and reactants which appear to be chemically possible but do not take place because of energy considerations

AC A2a: when alkanes burn, if the oxygen supply is insufficient, carbon monoxide instead of carbon dioxide will be formed, and/or hydrogen gas instead of water vapour

This AC was subscribed to by students E2.1, E10.1, E11.1, P12.1, P14.1, P16.1, R5.1, S14.2.

For illustration of this AC, see case II, Appendix M.

Most of the students who subscribed to this AC seemed to be using a logical deduction process, based on their knowledge of the formulae of carbon dioxide vis-a-vis that of carbon monoxide; water vis-a-vis hydrogen: the amount of oxygen in the formula of CO₂ suggested that carbon monoxide CO would be formed if there is insufficient O present; likewise H₂ would be formed, instead of H₂O if there is insufficient oxygen.

[In some other cases, e.g. S12.2, this AC arose as a result of the dominance of perceptual thinking: "water can't be one of the products released into the air. because you don't see droplets of water. can't be produced. you get H₂ not H₂O".]

Another manifestation of a Group A2 AC is the case of student S10.1 who said that when sodium chloride is added to water, it forms sodium hydroxide and hydrochloric acid, and there is no more sodium chloride.
GROUP A3: ACs which show some ideas of conservation but otherwise have little or no scientific basis, 'where anything goes as long as the elements are in a soup': e.g., ACs involving impossible reactants or products

AC A3a: when oxygen in air is used up in burning, then carbon dioxide is used instead of oxygen

This AC was subscribed to by students C10.1,2, C18.2.

This AC is illustrated in case IV, student C10, (Appendix M) as well as in the following extract from C18.2 discussed under AC A3b below.

AC A3b: carbon dioxide, as well as oxygen or instead of oxygen, from the air is involved as a reactant in burning

This AC was subscribed to by C6.1,2, C12.1,2, C16.1,2, C18.1.

AC 3a and 3b are extremely surprising, coming from students who had done well at GCSE and who had voluntarily opted to study chemistry at A-level. The involvement of oxygen as a reactant in burning is introduced early in the secondary science curriculum, yet these students seemed not to have grasped that fact. One could only speculate that perhaps, these students had confused burning with photosynthesis, which involves the intake of carbon dioxide.

AC A3a and A3b are illustrated in the following extracts from the L6 and U6 interviews with C18:

Extract from U6 interview with C18:

C18.1: "The wax melts..then the wick burns."

I: "Is anything produced?"
C18.1: "Yeah, soot..black smoke coming up.. I think that's soot."

I: "Anything else produced besides soot..?"

C18.1: "Carbon dioxide maybe..yeah."

I: "Where is the soot from?"

C18.1: "Maybe.. from the carbon dioxide..'cos when it burns in the oxygen and carbon is left over..it doesn't burn completely, so that's what's left over."

I: "Can you write down a chemical equation to show what you think is happening in the candle flame..to show how soot is produced.."

C18.1: "Okay.. You have heat over here (writing the words 'HEAT' above the arrow sign in the chemical equation) ..you get heat like flame..you get the oxygen burns so you're left with carbon..don't know..maybe it's carbon plus oxygen because there's oxygen in the air anyway..(writing 'O + CO₂ → C + O₂') so there's oxygen left over but doesn't burn.'cos the flame uses oxygen to burn..doesn't use carbon..so the carbon is leftover product..carbonated..so it makes the soot."

I: "CO₂..where does CO₂ on the left hand side of this equation come from?"

C18.1: "Comes from the air..CO₂ in the air."

[C18 appeared to think that wax was not burned; instead it was carbon dioxide from the air as well as oxygen which was involved in the burning candle, that the carbon dioxide "burns in the oxygen". - AC A3b]

Extract from U6 interview with C18:

C18.2: "Yes, there are chemical reactions in the candle flame..oxygen is burning..product is carbon dioxide"
I: "Where does the carbon in carbon dioxide come from?"

C18.2: "soot of flame is carbon. lots of carbon."

I: "Where does the soot come from?"

C18.2: "When there's not enough oxygen for flame to burn completely, then carbon comes from that."

I: "Any other reactant besides oxygen?"

C18.2: "The wick is burning but I don't know what it is made of."

I: "Use 'WICK' to represent the formula of the wick"

C18.2: (writing equation 'WICK + O₂ → CO₂ + C)

I: "Where do these 'Cs' come from (referring to the 2 'Cs' on the right hand side of the equation written)?"

C18.2: "Come from where there is incomplete burning of oxygen. not enough oxygen for complete burning so carbon is formed"

I: "All burning involves carbon dioxide as a product?"

C18.2: "No, yes. I think so."

I: "All cases of burning involve carbon dioxide being formed?"

C18.2: "Yeah. and other things as well but carbon dioxide mostly."

I: "Where does the carbon come from?"
C18.2: "There is carbon dioxide in the atmosphere around and when there's not enough oxygen to burn, some of the carbon is burned as well, it's like black sooty flame and then and it can make carbon dioxide and free carbon, which will be formed as soot."

Between the 2 interviews, it appeared that C18 did not noticeably shift from her conception of candle burning as involving carbon dioxide in the air.

AC A3c: burning alkanes such as methane results in carbon monoxide (instead of carbon dioxide), hydrogen instead of water vapour

This AC was subscribed to by students C6.1, C10.1,2, C12.1, C14.2, C18.1,2, E2.1,2, E17.1, R6.1,2, R7.1, S10.1,2, S12.2, S16.1,2, S20.2.

It was also surprising that these A-level students were not aware of the extremely toxic nature of carbon monoxide, and could conceive of it being formed as the main product of alkane burning.

This AC is illustrated in case IV, student C10, (Appendix M).

AC A3d: Other examples of 'anything goes as long as the elements are in the soup'.

Included in this group were students (E3.1, P18.1, R7.1, S10.1) who predicted correctly that magnesium would react with dilute HCl to form hydrogen gas; but who then went on to suggest that the hydrogen gas would react with oxygen in air to form water or hydroxyl group (see case I, chapter 12, student R7, who at the L6 interview suggested that the hydrogen evolved in event 4 would react with oxygen in the air to form hydroxy group).
GROUP A4: ACs which appear to show no ideas of conservation, but instead ideas of transmutation where particles, hence substances, are transmuted from one kind into another.

Prima facie there seemed to be some interviewees, e.g., C10.1,2 (see case IV in Appendix M) who showed this category of ACs; however, there is a possibility that this AC is different to that held by younger students mentioned in studies such as Andersson (1986a, 1990). There is a possibility that this AC could be associated with the inability to distinguish between what constitutes the reaction system and what its surroundings; as well as with the lack of understanding of the driving force of chemical reactions (i.e., understanding why it is that some substances will not react with each other at all, no matter how much heat is supplied whereas some will react readily even without any heat being supplied). In which case, these ACs should fall more appropriately into Group A3, which seemed more likely, since one would expect that by the sixth form, the interviewees concerned must have had some ideas of conservation and no ideas of transmutation. In any case, because students were generally used to writing equations to represent the chemical reactions involved, even if they were holding ideas of transmutation (Andersson's category 4), the very act of equation writing seemed to jolt them out of most of not all, transmutation thinking.

AC A4a: copper when heated in air forms copper oxide and soot, etc

This AC was subscribed to by students C10.1,2, C16.1,2, C18.1,2

This AC is illustrated and discussed in case IV, student C10, (Appendix M).

4.5. SUMMARY OF CHAPTER

The analysis of students' responses on Aspect A, prediction on type of change, shows that generally students knew what reactants and products were involved in the change.

For this group of students who have chosen to specialise in chemistry, such a result would
have been expected, since knowledge of reactants and products constitutes only a superficial knowledge of the chemical process.

The results also show that while students knew what reactants and products were involved (i.e., included all or most of the KEs defined in the expected response), at the same time, they also held a number of ACs. In other words, there are no simple inverse relationship between the number of KEs and ACs counted (See chapter 9, section 9.2).

Most of the ACs were found in the area of combustion reactions, where explanations or views reflected everyday meanings and perceptually dominated thinking rather than conceptual thinking (Driver, 1985).
CHAPTER 5

STUDENTS' UNDERSTANDINGS AND ALTERNATIVE CONCEPTIONS WITH RESPECT TO ASPECT B, TYPE OF CHANGE PREDICTED

5.0 OVERVIEW

This chapter examines the students' responses under aspect B, prediction about the overall energy change.

Section 5.1 examines students' total scores on aspect B across events by school and by sex.

Section 5.2 examines students' scores on aspect B by event by school and by sex.

Section 5.3 examines students' alternative conceptions (ACs) associated with aspect B.

The details on the scoring of KEs on students' responses on this aspect are given at Appendix D. The maximum KE defined per event is 3, so that over the 5 events, the total number of KEs defined was 5x3 or 15KEs.

5.1 ANALYSIS OF STUDENTS' RESPONSES ON ASPECT B OVER ALL 5 EVENTS

To examine the difference between schools in terms of the U6 and L6 KE scores; and in terms of progression (U-L) scores, on aspect B across events, mean KE scores are set out in the following table 5.1.

From Table 5.1 it can be seen that the differences in the progression recorded between schools are significant (p≤0.05); students from school E showed the smallest progression, while students from R made the greatest progression.
TABLE 5.1
MEAN U6, L6 AND PROGRESSION SCORES ON ASPECT B BY SCHOOL

<table>
<thead>
<tr>
<th>School</th>
<th>B-U</th>
<th>B-L</th>
<th>B (U-L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (n=9)</td>
<td>2.2</td>
<td>0.2</td>
<td>2.0</td>
</tr>
<tr>
<td>R (n=6)</td>
<td>8.2</td>
<td>0.8</td>
<td>7.3</td>
</tr>
<tr>
<td>P (n=10)</td>
<td>6.0</td>
<td>1.6</td>
<td>4.4</td>
</tr>
<tr>
<td>E (n=10)</td>
<td>3.8</td>
<td>2.1</td>
<td>1.7</td>
</tr>
<tr>
<td>S (n=13)</td>
<td>5.4</td>
<td>1.8</td>
<td>3.6</td>
</tr>
<tr>
<td>Average</td>
<td>5.12</td>
<td>1.3</td>
<td>3.8</td>
</tr>
<tr>
<td>p</td>
<td>0.001</td>
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<td>0.000</td>
</tr>
</tbody>
</table>

It can also be seen the p values between the U6 and L6 scores decreased, suggesting that with increased formal instruction, the difference between schools became greater.

To examine the difference between the sexes in terms of the U6 and L6 KE scores; and in terms of progression (U-L) scores, on aspect B across events, mean scores are set out in the following table 5.2.

TABLE 5.2
MEAN U6, L6 AND PROGRESSION SCORES ON ASPECT B BY SEX

<table>
<thead>
<tr>
<th>Sex</th>
<th>B-U</th>
<th>B-L</th>
<th>B (U-L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEMALES (n=35)</td>
<td>4.5</td>
<td>1.2</td>
<td>3.3</td>
</tr>
<tr>
<td>MALES (n=13)</td>
<td>6.2</td>
<td>1.9</td>
<td>4.2</td>
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<tr>
<td>p</td>
<td>0.091</td>
<td>0.183</td>
<td>.295</td>
</tr>
</tbody>
</table>

From table 5.2 it can be seen that at the L6 although the boys did better than the girls on aspect B, there were no significant difference between their scores. However, with increased formal instruction, the p value decreased, suggesting that the boys progressed more than the girls with formal chemistry instruction (though not significantly so (p<0.05)).
5.2 ANALYSIS OF STUDENTS’ RESPONSES ON ASPECT B BY EVENT BY SCHOOL

To examine the difference between the schools in terms of the U6 and L6 KE scores on aspect B by event, mean scores are set out in the following table 5.3.

<table>
<thead>
<tr>
<th>Sc</th>
<th>B1U</th>
<th>B1L</th>
<th>B2U</th>
<th>B2L</th>
<th>B3U</th>
<th>B3L</th>
<th>B4U</th>
<th>B4L</th>
<th>B5U</th>
<th>B5L</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.5</td>
<td>0.1</td>
<td>0.4</td>
<td>0.0</td>
<td>0.4</td>
<td>0.1</td>
<td>0.4</td>
<td>0.1</td>
<td>0.4</td>
<td>0.0</td>
</tr>
<tr>
<td>R</td>
<td>2.0</td>
<td>0.2</td>
<td>1.8</td>
<td>0.1</td>
<td>2.1</td>
<td>0.3</td>
<td>1.4</td>
<td>0.1</td>
<td>0.6</td>
<td>0.1</td>
</tr>
<tr>
<td>P</td>
<td>1.5</td>
<td>0.3</td>
<td>0.9</td>
<td>0.4</td>
<td>1.7</td>
<td>0.8</td>
<td>1.0</td>
<td>0.3</td>
<td>0.8</td>
<td>0.1</td>
</tr>
<tr>
<td>E</td>
<td>0.8</td>
<td>0.3</td>
<td>0.9</td>
<td>0.5</td>
<td>1.3</td>
<td>0.7</td>
<td>0.5</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>S</td>
<td>1.6</td>
<td>0.8</td>
<td>1.0</td>
<td>0.1</td>
<td>1.6</td>
<td>0.3</td>
<td>0.6</td>
<td>0.2</td>
<td>0.3</td>
<td>0.0</td>
</tr>
<tr>
<td>p</td>
<td>.005</td>
<td>.032</td>
<td>.063</td>
<td>.044</td>
<td>.006</td>
<td>.042</td>
<td>.014</td>
<td>.742</td>
<td>.153</td>
<td>.362</td>
</tr>
</tbody>
</table>

From table 5.3 it can be seen from the generally decreasing p values (except event 2) that with increased formal instruction, the differences between schools became more significant (i.e., at the U6 scores, the gap between the schools generally became greater). Also at both U6 and L6 levels, there were significant differences (p ≤ 0.05) between schools on aspect B scores in events 1, 2 and 3; and in event 4, only at the U6 level.

It can be seen that across each of the events, it was either school R or P or both that made the greatest progression on this aspect, whereas it was either school C or E or both which made the least progression. School S seemed to be intermediate between these 2 groups of schools.
TABLE 5.4
MEAN U6 AND L6 SCORES ON ASPECT B BY EVENT BY SEX

<table>
<thead>
<tr>
<th>Sex</th>
<th>B1U</th>
<th>B1L</th>
<th>B2U</th>
<th>B2L</th>
<th>B3U</th>
<th>B3L</th>
<th>B4U</th>
<th>B4L</th>
<th>B5U</th>
<th>B5L</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>1.2</td>
<td>0.4</td>
<td>0.8</td>
<td>0.2</td>
<td>1.2</td>
<td>0.4</td>
<td>0.6</td>
<td>0.1</td>
<td>0.5</td>
<td>0.0</td>
</tr>
<tr>
<td>M</td>
<td>1.5</td>
<td>0.3</td>
<td>1.3</td>
<td>0.4</td>
<td>1.8</td>
<td>0.5</td>
<td>1.0</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>p</td>
<td>.227</td>
<td>.701</td>
<td>.076</td>
<td>.135</td>
<td>.041</td>
<td>.475</td>
<td>.149</td>
<td>.147</td>
<td>.352</td>
<td>.019</td>
</tr>
</tbody>
</table>

From L6 to U6, the p values in Table 5.4 decrease in the combustion reactions (events 1, 2 and 3), suggesting that boys progressed more with formal instruction. The data in Table 5.8 also seem to suggest that boys generally did better than girls on aspect B, and in particular in event 3, the bunsen flame where the difference was significant (p≤0.05).

5.3 STUDENTS' ALTERNATIVE CONCEPTIONS ASSOCIATED MAINLY WITH ASPECT B, PREDICTION ON OVERALL ENERGY CHANGE

A list of the alternative conceptions (ACs) elicited in association with aspect B, prediction on overall energy change is given at Appendix H. This section discusses some of the more prevalent ACs. These ACs are placed in the following 3 groups:

Group B1: ACs arising mainly from the dominance of perceptual thinking. Some ACs in this category could also be put in Group B2.

Group B2: ACs arising from over-generalisation or 'one factor only' type reasoning (i.e., ACs arising from lack of comprehensiveness in reasoning)

Group B3: ACs associated with misconceived ideas about the nature of bonds; and wrong direction of energy change involved in bond breaking and bond making

The same notations as those described in chapter 4 are used to indicate the students and interview sessions, whether L6 or U6.
GROUP B1: ACs arising mainly from the dominance of perceptual thinking. Some ACs in this category could also be put in Group B2.

AC B1a: a reaction must be overall endothermic if heat/heating is needed; conversely, if heat is not needed then the reaction must be exothermic and spontaneous.

<table>
<thead>
<tr>
<th></th>
<th>U only</th>
<th>L only</th>
<th>U&amp;L</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC B1a: a reaction is</td>
<td>C12</td>
<td>C8</td>
<td>C20</td>
</tr>
<tr>
<td>overall endo if heat is needed;</td>
<td>P20</td>
<td>P4,P18</td>
<td>P12</td>
</tr>
<tr>
<td>spontaneous</td>
<td>2</td>
<td>11</td>
<td>6</td>
</tr>
</tbody>
</table>

Here students who held this AC seemed to be governed by perceptually dominated thinking (e.g., If a piece of copper needs to be placed in a very hot bunsen flame to bring about chemical change, then there must be net absorption of heat in the reaction; the concept of energy barrier which needs to be overcome, and the related concepts of bond breaking and bond making seemed to be excluded in the reasoning) or 'one factor only' type reasoning where only spontaneous reactions are seen to be exothermic. (Note: there was a common mis-understanding amongst these students of the term 'spontaneous' when applied to chemical reaction).

Nineteen or 40% of all interviewees showed this AC, 8 of whom were in U6, and 6 held it at both U6 and L6.

This AC is illustrated in cases I at chapter 12 and II at Appendix M and also in the following extract from the L6 interview with student S1, who responded thus when asked to predict the overall energy change in event 1: "It doesn't give out heat; it's endothermic reaction and the reason is..it has to be because you need the bunsen burner heat for that
reaction to absorb the heat for the reaction to take place...it isn't exothermic, it is endothermic."

At the U6 interview, S1 did not shift from his prediction of an overall endothermic reaction although his reasons became more elaborate and different. His reason was essentially that "it's energy that forms the bonding [Note the imprecise language, the lack of distinction between the terms 'bonds' and 'bonding']. the binding energy that's called' [Note the confusion with nuclear binding energy and the misconception of energy as bonds.] This U6 response is categorised as an example under AC B3a, under which a fuller quote is given.

**GROUP B2:** ACs arising from over-generalisation or one factor only type reasoning (i.e., ACs arising from lack of comprehensiveness or depth in reasoning)

**AC B2a:** a reaction is overall exothermic because heat is given out from the excitement of electrons/molecules; a reaction is overall exothermic because chemicals give out energy.

[This view is at variance with the chemist's view that it is the interaction of chemicals in bond formation that results in energy release and not that chemicals by themselves release energy.]

**TABLE 5.6**

<table>
<thead>
<tr>
<th>STUDENTS SUBSCRIBING TO AC B2a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>AC B2a: C6,C10,C12,C18,C20</td>
</tr>
<tr>
<td>excitement of R5</td>
</tr>
<tr>
<td>electrons P10,P20</td>
</tr>
<tr>
<td>molecules E10 E5,E17</td>
</tr>
<tr>
<td>chemicals S7,S10,S18 S1,S16</td>
</tr>
<tr>
<td>release energy 1 7 9</td>
</tr>
</tbody>
</table>
17 (35%) of students subscribed to this AC, of which 10 (21%) are at U6.

This AC is illustrated in case IV, Appendix M; and in the following extract of the L6 interview with student S1:

S1 on aspect B, event 2: "It's giving out heat so it's exothermic reaction."

I: "Where is heat given out from?"

S1: "The heat is coming from the paraffin (i.e. the candle wax) which is being burned in oxygen and that is producing more and more heat. Paraffin itself is an exothermic reaction, meaning that it will give out heat from the chemicals that it has in the paraffin itself."

I: "Chemicals in the paraffin give out heat...."

S1: "The heat is stored in the paraffin, the chemicals in the paraffin and they are stored and they are released by... if you put paraffin as you put it there in the actual candle, nothing occurs but because the paraffin has got chemicals inside it, you need to have a heat to kind of actually break away these chemicals to form into other forms of energy, one is light energy, others heat energy, etc. so yes if you ask me where the heat comes from, heat comes from the actual paraffin itself, the actual chemicals that are stored in the paraffin itself but it will not be able to react unless you have heat to be able to push the reaction like how you push dominos, so the heat actually comes from heating up the chemicals in the paraffin itself."

This AC reflects a lack of comprehensiveness or depth in reasoning. While heat released during an exothermic process is associated with the electrons, it is the result of electrons falling from higher to lower energy levels, a consequence of bond making in the system in question. Therefore to view the heat released in the reaction as being given out by electrons (or by excitement of molecules or, more globally by chemicals) is misconceived or inadequate.
Another example is the following response by U6 interviewee, C6 when asked to predict the overall energy change for the bunsen flame reaction: "The reaction is overall exothermic because of the heat given out by oxygen." Later, she modified her answer by saying that heat was also released by the fuel, methane. Later on the same question on the overall energy change of the Mg-HCl reaction, she said, "It is overall exothermic like the previous 3 reactions (referring to events 1 to 3). the activation energy comes from the HCl acid, which has energy like the oxygen."

AC B2b: overall there is no energy change if number of bonds broken equals number of bonds made; a reaction must be overall endothermic if one of the bonds to be broken is very strong, eg the bond within O₂ molecule; a reaction must be overall exothermic if one of the products is very stable (or more stable) than one of the reactants

This AC was revealed in interviews: C8.2, E1.2, P12.2, P18.1, R4.2, S2.2, S14.1, S7.2 (Total = 8/48 = 17% of all students).

Here again, this AC arises mainly from 'one factor only' type of reasoning, incomprehensive and shallow reasoning which does not take into consideration all relevent factors involved, for example, the overall energy change depends on several factors not just the relative number of bonds made and broken; the relative strengths of all the bonds made and broken are also involved.

(See cases I at chapter 12 and II at Appendix M for illustrations.)

AC B2c: confusions between kinetic and thermodynamic stability eg a reaction is overall endothermic if a solid (wax) is being changed into a liquid and a gas (water and carbon dioxide) because gas is less stable than liquid which is less stable than a solid; bunsen flame releases more energy than a candle flame because a reactant in gas form has a lot of energy; a gas (like methane) is unstable so it is more easily broken down by oxygen than solid wax.
This AC was revealed in interviews: E1.2, P2.1, P18.1, P20.1.

This AC could also be related to the use of 'one factor only' reasoning as well as confusion between thermodynamic and kinetic stability. A gas could be thermodynamically less stable than a solid but it could be kinetically more stable if the energy barrier or activation energy required for it to react is higher than that of a solid.

**GROUP B3:** ACs associated with misconceived ideas about the nature of bonds; and wrong direction of energy change involved in bond breaking and bond making:

**AC B3a:**

- Bonds release energy when broken, absorb energy when made; energy is needed to form bonds; bonds store energy; energy holds or binds atoms together; the bond is basically energy which holds atoms together.

<table>
<thead>
<tr>
<th>TABLE 5.7</th>
<th>STUDENTS SUBSCRIBING TO AC B3a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U only</td>
</tr>
<tr>
<td>AC B3a: bonds</td>
<td>C12, C14, C16, C18</td>
</tr>
<tr>
<td>release energy</td>
<td>E10</td>
</tr>
<tr>
<td>when broken</td>
<td>P14</td>
</tr>
<tr>
<td>absorb energy</td>
<td>R1, R4</td>
</tr>
<tr>
<td>when made</td>
<td>S8, S10</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

29 (60%) of students subscribed to this AC.

This AC is illustrated by case IV, Appendix M; also in the following response made by S1 during the U6 interview, when asked to predict the overall energy change of the reaction between copper and oxygen:
S1.2: "It has to accept energy before reaction can take place; I'd say endothermic because you have to give it energy for the reaction to take place but the reverse, break this down probably gives out energy...it takes in energy to produce the oxide...so endothermic reaction...but when they separate it release energy because it consists of energy; you know it's the energy that forms the bonding...the binding energy that's called."

Among the students who held this AC, some wavered constantly between the correct and incorrect view of the direction of energy change.

It seemed that while they learned from their lessons on thermochemistry or energetics or organic chemistry that bonds require energy to break them, they could not shake off their preconceived notion that bonds comprise energy. This naive notion seemed to be derived from their view that something must be holding atoms together, and that something is energy; since they were told that bonds hold atoms together, they drew the inference that bonds must comprise energy. In their mental schemas, it means that when bonds are formed, energy must be absorbed; and converse to that, when bonds are broken, energy must be released.

The following extract of the L6 interview with S18 illustrates the point, although here there was a slight variation; here energy was thought of as holding the bonds not constituting the bonds:

S18.2 on event 3: "When bonds are broken it releases energy...I mean it's energy that's holding the bonds together...you need energy to hold the bonds together, so when you break the bonds, you release energy."

Such naive views are contrary to scientists' views. From the scientific perspective, when bonds are make, energy is released, and to break bonds, energy needs to be absorbed.

There were also a number of students, e.g. S6.1, S7.1, who tried to incorporate the scientific view into their preconceived view, as illustrated in the following statement by S6.1 on event 3: "You need a little bit of energy to break the bonds between the carbon and the hydrogen, but once they are broken, then it releases energy."
The naive view that bonds which comprise energy hold atoms together seemed to have arisen and/or been reinforced in a some way. For example, some students seemed to reason along these lines: "Energy is the capacity to do work. Therefore, if there is something between 2 atoms doing the work of holding them together, that something must be energy. Hence, chemical bonds are nothing other than energy."

In some other cases, the ACs could arise as a result of unclear statements, models or analogies used by textbooks or teachers. For example, analogies drawn between elastic springs and bonds for instance could be a source of this AC. In the students' analogous reasoning, if springs store potential or elastic energy, then bonds must also store energy. This means that bond making must be an endothermic process; and its converse, bond breaking must be an exothermic process.

**AC B3b:** energy given off during bond making is energy which was put in to break bonds which it no longer needs

This AC was often revealed by the same students who held AC B3a, the previous AC. The interviewees who subscribed to this AC are: R2.2, S8.2, S10.2, S16.1 (Total = 4/48 = 8.5% of all students).

This AC is very closely related to the AC B3a in that although there is the recognition that energy is released during bond making, and that energy is absorbed during bond breaking, there is no (real) understanding. Hence, the energy that is released during bond making is conceived of as just the leftover of the energy which had been taken in to break bonds, which was subsequently released when bonds are made.

The following interview extract illustrates this AC:

S8.2 on why heat is released in event 1: "...because like I said, energy's taken to break that bond. it's a lot of energy...and so the energy which is a lot to break the bonds is used to make these two to bond together and because it doesn't take the same amount of energy to make these two bonds as it does to break those two bonds, there's energy in excess, so that's given out."
AC B3c: energy is required to break and to make bonds

Again this AC is very closely related to AC B3a, and was often revealed by the same students who also revealed AC B3a. This AC was revealed in interviews: E5.1,2, C16.1,2, E17.1,2, S2.1,2, S18.1 (total = 5/48 = 10% of all students).

This AC seemed to arise again from the view of chemical bond as a physical link, the constructing and breaking of it requires energy input. Included within this AC is the view that heat energy is needed or absorbed to initiate or to begin the bond breaking process. But once bond breaking begins, energy is then released by the bonds which are breaking up (AC B3a).

AC B3d: a covalent bond is weaker than ionic or metallic bond

This AC was revealed in interviews: C12.1,2, P10.1, R2.2, R5.1, S1.1 (total = 5/48 = 10% of all students).

This AC seemed to arise from two different ways of thinking. Firstly, the thinking that covalent compounds tended to have lower melting and boiling points than ionic compounds, therefore, covalent bonds must be weaker than ionic bonds. Secondly, the thinking that bonds formed between atoms (or elements) which are very different (or opposite) in nature (such as one is electropositive and electronegative) are stronger than bonds formed between atoms (or elements) which are similar in nature.

5.4 SUMMARY OF CHAPTER

The results of students' responses on aspect B show that students were generally weak in this area of energetics.

Three categories of ACs associated with aspect B are identified. These were concerned with the use of perceptual thinking; the use of incomprehensive or shallow thinking and
having misconceptions about the nature of bonds.

A large number of students were unable to predict the overall energy change because of their misconceptions about the nature of a chemical bond. For a large number of the students, the chemical bond was seen as a physical entity. This notion of a chemical bond as matter is then linked to the everyday notion that the construction of any structure requires energy input; and its converse, the destruction of any structure releases energy, to form the bases for the prevalent AC that bond making requires input of energy and bond breaking releases energy. In other words, the notion that bond making requires energy input may be the result of extrapolating views about events in the macroscopic world into the microscopic world - in the macroscopic world, energy is needed to make things, therefore in the microscopic world, energy is also needed to make bonds!

A fuller discussion on issues related to the perception of chemical bonds is presented in chapter 8.
CHAPTER 6

STUDENTS' UNDERSTANDINGS AND ALTERNATIVE CONCEPTIONS WITH RESPECT TO ASPECT C, HOW THE REACTION TAKES PLACE

6.0 OVERVIEW

This chapter examines the students' responses under aspect C, how the reaction takes place.

Section 6.1 examines students' total scores on aspect C across events by school and by sex.

Section 6.2 examines students' scores on aspect C by event by school and by sex.

Section 6.3 examines students' alternative conceptions (ACs) associated with aspect C.

The details on the scoring of KEs on students' responses on this aspect are given at Appendix G. The maximum KE defined per event is 4, so that over the 5 events, the total number of KEs defined was thus 5x4 or 20KEs.

6.1 ANALYSIS OF STUDENTS' RESPONSES ON ASPECT C OVER 5 MAIN EVENTS

To examine the difference between schools in terms of the U6 and L6 KE scores; and in terms of progression (U-L) scores, on aspect C across events, mean scores are set out in the following table 6.1.

From Table 6.1, it can be seen that between U6 and L6, the p value decreased showing that the significance of school effect increased with formal instruction, i.e., schools P and R seemed to have more effect on students' acquisition of this aspect than schools C, E and S.
TABLE 6.1

MEAN U6, L6 AND PROGRESSION SCORES ON ASPECT C BY SCHOOL

<table>
<thead>
<tr>
<th>School</th>
<th>C-U</th>
<th>C-L</th>
<th>C (U-L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (n=9)</td>
<td>4.7</td>
<td>1.8</td>
<td>2.9</td>
</tr>
<tr>
<td>R (n=6)</td>
<td>8.0</td>
<td>2.3</td>
<td>5.7</td>
</tr>
<tr>
<td>P (n=10)</td>
<td>11.3</td>
<td>3.8</td>
<td>7.5</td>
</tr>
<tr>
<td>E (n=10)</td>
<td>6.4</td>
<td>3.3</td>
<td>3.1</td>
</tr>
<tr>
<td>S (n=13)</td>
<td>6.6</td>
<td>3.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Average</td>
<td>7.4</td>
<td>2.9</td>
<td>4.5</td>
</tr>
<tr>
<td>p</td>
<td>0.001</td>
<td>0.250</td>
<td>0.005</td>
</tr>
</tbody>
</table>

To examine the difference between the sexes in terms of the U6 and L6 KE scores; and in terms of progression (U-L) scores, on aspect C across events, mean scores by sex are set out in the following Table 6.2.

TABLE 6.2

MEAN U6, L6 AND PROGRESSION SCORES ON ASPECT C BY SEX

<table>
<thead>
<tr>
<th>Sex</th>
<th>C-U</th>
<th>C-L</th>
<th>C (U-L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEMALES (n=35)</td>
<td>7.0</td>
<td>2.6</td>
<td>4.4</td>
</tr>
<tr>
<td>MALES (n=13)</td>
<td>8.3</td>
<td>4.1</td>
<td>4.2</td>
</tr>
<tr>
<td>p</td>
<td>0.294</td>
<td>0.032*</td>
<td>.881</td>
</tr>
</tbody>
</table>

From table 6.2, between U6 and L6, the p value increased, showing that the gap between the sexes became less significant with formal instruction. In other words, at L6 the boys did significantly better than the girls but the girls seemed to have benefitted more from instruction.
6.2 ANALYSIS OF STUDENTS' RESPONSES ON ASPECT C BY EVENT BY SCHOOL

To examine the difference between the schools in terms of the U6 and L6 KE scores on aspect A by event, mean scores are set out in the following table 6.3.

<table>
<thead>
<tr>
<th>Sc</th>
<th>C1U</th>
<th>C1L</th>
<th>C2U</th>
<th>C2L</th>
<th>C3U</th>
<th>C3L</th>
<th>C4U</th>
<th>C4L</th>
<th>C5U</th>
<th>C5L</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>1.3</td>
<td>0.7</td>
<td>0.4</td>
<td>0.0</td>
<td>1.3</td>
<td>0.2</td>
<td>0.7</td>
<td>0.3</td>
<td>0.8</td>
<td>0.4</td>
</tr>
<tr>
<td>R</td>
<td>1.8</td>
<td>0.9</td>
<td>1.6</td>
<td>0.3</td>
<td>2.0</td>
<td>0.5</td>
<td>1.8</td>
<td>0.2</td>
<td>0.8</td>
<td>0.3</td>
</tr>
<tr>
<td>P</td>
<td>2.4</td>
<td>1.4</td>
<td>2.0</td>
<td>0.6</td>
<td>3.1</td>
<td>1.2</td>
<td>2.2</td>
<td>0.2</td>
<td>1.5</td>
<td>0.5</td>
</tr>
<tr>
<td>E</td>
<td>1.2</td>
<td>0.5</td>
<td>1.7</td>
<td>1.1</td>
<td>2.1</td>
<td>1.2</td>
<td>0.7</td>
<td>0.2</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>S</td>
<td>1.7</td>
<td>1.2</td>
<td>1.4</td>
<td>0.2</td>
<td>1.7</td>
<td>0.7</td>
<td>0.9</td>
<td>0.6</td>
<td>0.7</td>
<td>0.4</td>
</tr>
<tr>
<td>Av</td>
<td>1.67</td>
<td>0.94</td>
<td>1.42</td>
<td>0.42</td>
<td>2.04</td>
<td>0.76</td>
<td>1.26</td>
<td>0.30</td>
<td>0.84</td>
<td>0.36</td>
</tr>
<tr>
<td>p</td>
<td>.060</td>
<td>.071</td>
<td>.072</td>
<td>.005</td>
<td>.000</td>
<td>.029</td>
<td>.004</td>
<td>.123</td>
<td>.180</td>
<td>.582</td>
</tr>
</tbody>
</table>

The p values in table 6.3 generally decrease from L6 to U6 (except event 2), suggesting again that the difference between schools became greater with increased formal instruction. Again the data shows that at the U6 level, schools R and P (and to some extent S) generally did better than schools C and E (except for events 2 and 3, involving the flames when school E with proportionally more boys seemed to do better than school S, which had proportionately more girls).

To examine the difference between the sexes in terms of the U6 and L6 KE scores on aspect C by event, mean scores are set out in the following Table 6.4.
Table 6.4 shows from L6 to U6, the p values in events 1 to 3 increase, showing that while overall the boys did better on aspect C in these 3 events where flames are involved, the significance became smaller with formal instruction, i.e., the girls seemed to be catching up with the boys.

### 6.3 ALTERNATIVE CONCEPTIONS ASSOCIATED MAINLY WITH ASPECT C, HOW THE REACTION TAKES PLACE

The ACs associated with aspect C can be grouped as follows:

**Group C1:** ACs associated with confusion between elements, mixtures and compounds; between particles of a substance and the substance itself; between oxidation numbers and electrical charges; between electronegativity/electropositivity and electrical charges;

**Group C2:** ACs associated with confusion between different types of bonding, especially between ionic and covalent bonding.

**Group C3:** ACs associated with confusion about the role of water as a solvent in reactions involving solutions; the solvation effect of water, the nature of ionic equilibrium involving sparingly soluble salts and the chemical energetics involved.
In effect, since all these categories of ACs are related to the global concept of bonding and the effects intertwine and work together in producing a multitude of concepts differing from the scientific concept, it is difficult to make definite demarcations between the ACs in the above categories as they are revealed in the interviews.

These various ACs are illustrated in the 4 case studies presented in chapter 12 and appendix M and in the extracts at the end of this chapter. As one extract can illustrate ACs from more than one of the above 3 groups since many students displayed much confusion on this aspect, it is more appropriate to give them only at the end, after the statements or descriptions of the various main ACs and their occurrences have been discussed.

**GROUP CI:** ACs associated with confusion between elements, mixtures and compounds; between particles of a substance and the substance itself; between oxidation numbers and electrical charges; between electronegativity/electropositivity and electrical charges

**AC CIa:** confusion between elements, mixtures and compounds; particles and substances; oxidation numbers and electrical charges; electronegativity/electropositivity and charges

This AC is associated with various confusions such as:

* lack of understanding of the concept of chemical reaction itself (as found in other studies of students aged 15 and below, eg Briggs and Holding, 1986; de Vos, 1985). Here students seemed to think that the properties of substances are conserved even after a chemical reaction; eg the reactivity of sodium is conserved in aqueous sodium chloride.

* lack of differentiation between, say sodium as an unrelated element and its form in solid or aqueous sodium chloride (Or it could be confusion between mixtures and compounds. Here, students could be thinking that the properties of sodium in the form of aqueous NaCl are the same as the unreacted sodium); e.g., when students view event 5 as involving a more reactive element (ie sodium) displacing
a less reactive one (ie lead). For illustration of this AC, see cases I in chapter 12 and IV in Appendix M.

when oxidation numbers are taken as meaning the same thing as electrical charges; this is manifested through the large numbers of students who postulated that in event 3, the result of breaking the C-H bonds is to produce carbon with 4 positive charges and hydrogen with a negative charge (others postulated that it was the other way round, yet others suggested that it results in both carbon and hydrogen having positive charges while oxygen has negative which then combine to give carbon dioxide and water. (The postulation of full or partial charges is inappropriate for the combustion of methane which is more likely to involve free radicals.)

some students confuse electropositivity with having positive charge itself, so that they conceptualise magnesium ribbon existing as Mg$^{2+}$.

lack of differentiation between particles themselves (atoms, ions and molecules); and also between particle and substance - e.g., students refer to chlorine atoms in dilute HCl reacting with magnesium instead of referring to chloride ions and magnesium atoms.

TABLE 6.5
STUDENTS SUBSCRIBING TO AC C1a

<table>
<thead>
<tr>
<th></th>
<th>U</th>
<th>L</th>
<th>U+L</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC C1a:</td>
<td></td>
<td>C8,C16</td>
<td>C10,C12,C14,C18</td>
</tr>
<tr>
<td>confusion bet.</td>
<td>E2,E19</td>
<td>E3,E17</td>
<td>E1,E11</td>
</tr>
<tr>
<td>element and</td>
<td></td>
<td>P8,P12,P16,P18</td>
<td>P2,P14</td>
</tr>
<tr>
<td>compound/</td>
<td>R2</td>
<td>R5,R7,R4</td>
<td></td>
</tr>
<tr>
<td>oxidation no.</td>
<td>S16</td>
<td>S12,S18</td>
<td>S7,S11,S6,S8,S10,S14</td>
</tr>
<tr>
<td>charges, etc.</td>
<td>4</td>
<td>14</td>
<td>14</td>
</tr>
</tbody>
</table>

**GROUP C2:** ACs associated with confusion between different types of bonding, especially between ionic and covalent bonding.

**AC C2a:** confusions between covalent and ionic bonding, which are manifested in various forms such as:

* confusion about the term 'electronegativity'; ionic compounds are formed by an atom or ion, e.g. O, O²⁻, Cl, Cl⁻ donating electrons to another atom or ion e.g., Cu, Cu²⁺, Mg, Mg²⁺ because the donor has many/more electrons compared to the receiver; CO₂ is ionic, a carbon atom gives each oxygen atom 2 electrons.

* an ionic bond, e.g., Cu-O, is formed by one atom, e.g. copper, donating electrons to another atom, e.g. oxygen, which they then share; ionic bonding illustrated by dot and cross diagrams which really showing covalent bonding, e.g. in solid sodium chloride, sodium and chloride share electrons.

* an ionic bond is formed when a positive and a negative charge come together to cancel out/neutralise each other, resulting in the formation of neutral molecules; ionic bond means positive and negative attract, no swapping of electrons. Here the ionic bond is conceived of as the cancelling out or neutralisation of charges between oppositely charged ions instead of electrostatic Coulombic attraction between opposite charges; misconception here could arise as a result of confusion between dipole moments and ionic charges or between oxidation numbers and ionic charges.

* in ionic compounds, bonds within molecules are stronger than bonds between molecules; molecules are held by VdW forces/bonds.
a metal and a nonmetal share one or more electrons each to form a covalent compound; if there is a big difference in the number of outer shell electrons then covalent bond is likely; a covalent bond is formed by one electron shared between two atoms, i.e., one atom donates the one electron to share, the other atom does not contribute any electrons.

Students seemed to find the concept of ionic bond difficult and to think of covalent bonds as the only valid bonds; thus even bonding between a metal and a nonmetal is conceived of as covalent.

**TABLE 6.6**

<table>
<thead>
<tr>
<th>STUDENTS SUBSCRIBING TO AC C2a</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
</tr>
<tr>
<td>AC C2a:</td>
</tr>
<tr>
<td>confusion</td>
</tr>
<tr>
<td>between ionic</td>
</tr>
<tr>
<td>and covalent</td>
</tr>
<tr>
<td>bonding</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

AC C2a was held by 38 students (79%) of the sample of whom 28 held it at both U6 and L6.

See all 4 cases at chapter 12 and Appendix M for illustrations of this AC.

**AC C2b:** confusion about various types of bonds, inter and intra-molecular bonds, Van der Waals bonds, e.g., in a metal Van der Waals bonds hold the atoms together; between different layers of atoms in a metal are Van der Waals forces.

This AC seemed to arise as a result of the confusion between giant molecular structures such as that of graphite, with giant metallic structures.
This AC was held students C10.2, E3.1, E19.1, S6.1, S8.1, S11.1 (total = 6/48 = 12.5%) 

This AC is illustrated in case IV, Appendix M.

**GROUP C3**: ACs associated with reactions in solution such as the solvation effect of water, the nature of ionic equilibrium involving sparingly soluble salts and the chemical energetics involved.

**AC C3a**: dissolved substances e.g., HCl, NaCl form separate ions (or molecules) with ionic (or covalent) bonds still there, i.e., ions are not free (or water breaks inter- but not intra- molecular bonds in dissolved salts).

<table>
<thead>
<tr>
<th>TABLE 6.7</th>
<th>STUDENTS SUBSCRIBING TO AC C3a</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>U+L</td>
</tr>
<tr>
<td>AC C3a: dissolved</td>
<td>C20 C8,C10,C12,C14,C16,C18,</td>
</tr>
<tr>
<td>substances form</td>
<td>E7,E19 E1,E3,E5,E11,E17,E2,E6,E10</td>
</tr>
<tr>
<td>ions but ions are not</td>
<td>P4,P12,P18,P20 P2,P6,P8,P14,P16</td>
</tr>
<tr>
<td>free, etc.</td>
<td>R1,R7 R2,R4,R6</td>
</tr>
<tr>
<td></td>
<td>S6 S1,S7,S11,S2,S4,S8,S10,</td>
</tr>
<tr>
<td></td>
<td>S12,S14,S16,S18,S20</td>
</tr>
<tr>
<td>10</td>
<td>34</td>
</tr>
</tbody>
</table>

This AC was held by 44 (92%) of the sample, of whom, 34 (71%) held the AC at both interviews.

This AC is illustrated in all 4 cases discussed in chapter 12 and Appendix M.
AC C3b: events 4 and 5 are seen as involving the displacement of something less reactive by something more reactive or seen as preferential attraction - chlorine preferentially bonds with magnesium, leaving hydrogen on its own; attraction between sodium and nitrate breaks lead-nitrate bond.

<table>
<thead>
<tr>
<th>TABLE 6.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>STUDENTS SUBSCRIBING TO AC C3b</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>U</th>
<th>L</th>
<th>U+L</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC C3b: ev. 4 &amp; 5 due to preferential attraction</td>
<td>C6</td>
<td>P6</td>
<td>R1,R5,R7,R2</td>
</tr>
<tr>
<td></td>
<td>E6</td>
<td>P2,P10,P12,P14,P18</td>
<td>R4,R6</td>
</tr>
<tr>
<td></td>
<td>P8,P16,P20</td>
<td>S12,S7,S11,S2,S4,S6,S8,S10,S14,S20</td>
<td></td>
</tr>
<tr>
<td>Mg &amp; Cl, Na &amp; nitrate</td>
<td>4</td>
<td>9</td>
<td>28</td>
</tr>
</tbody>
</table>

AC C3a and C3b are very similar; they have their roots primarily in the lack of understanding or confusion about the solvation effect of water and/or the ionic equilibrium involving sparingly soluble salts and chemical energetics (as well as, possibly, confusion between mixtures and compounds). Thus, it is not surprising that most of the students who held AC C3b also held AC C3a.

See cases I in chapter 12 and II and IV in Appendix M, for illustrations of AC C3b.

AC C3c: in the aqueous medium, H-Cl bond undergoes homolytic fission, i.e., when the H-Cl bond breaks, H comes off with 1 electron and Cl with 7 electrons in their outermost shells respectively; Mg loses electrons to Cl forming Mg-Cl bond in solution.
This AC was held by 24 (50%) of the sample. Of these, 18 (38%) were U6 interviewees; and 13 (27%) held this AC at both interviews.

This AC is illustrated in cases II, III and IV, Appendix M.

**AC C3d:** water, the solvent, in event 4 and/or event 5 plays no significant part; reaction is faster or the same if water is absent.

<table>
<thead>
<tr>
<th>TABLE 6.10</th>
<th>STUDENTS SUBSCRIBING TO AC C3d</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>U</strong></td>
<td><strong>L</strong></td>
</tr>
<tr>
<td>AC C3d: water</td>
<td>C18</td>
</tr>
<tr>
<td>plays no part;</td>
<td>E2</td>
</tr>
<tr>
<td>rate higher</td>
<td>P20</td>
</tr>
<tr>
<td>or same if water</td>
<td>R2,R7</td>
</tr>
<tr>
<td>is absent</td>
<td>S4</td>
</tr>
<tr>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>

It must be noted that not all interviewees were posed the question on what they predicted would happen if no water was present in event 4, because of the limitations of time. However, in spite of this, there was still a significant proportion 54% who revealed this AC. Of these, 19 (40%) were in U6, and 13 held this AC at both U6 and L6.
This AC is illustrated in cases I in chapter 12 and III and IV in Appendix M.

EXAMPLES OF VARIOUS ACs ASSOCIATED WITH ASPECT C

ACs C1a, C3a and C3b are illustrated in the following 3 extracts of the L6 interviews with S6, S10 and S14 which are typical.

S6.1 saw both reactions in events 4 and 5 as similar in the sense that they involved the displacement of a less reactive element by a more reactive (AC C3b).

S6.1 after predicting correctly the identity and physical states of the products in event 5, went on to say: "Magnesium is more reactive, so it would take chlorine away from the HCl and break the bond between them [AC C3b: preferential attraction] thus releasing energy... same here, if you got lead nitrate in ions and you got a bond between them, then you got sodium chloride... then sodium would take the nitrate away from the Pb and Pb would combine with the chloride to form PbCl and NaNO3 [AC C3b: preferential attraction] and bonds are broken between them and new bonds are formed between them... the fact that this reaction happens proves that sodium [AC C1a: confusion of sodium element with sodium chloride or confusing atom with ion] here is more reactive than lead, and it can displace lead from lead nitrate."

S10.1: "Something happens because magnesium gets rid of the hydrogen which is joined to the chloride... because of that it has to be displacement and stuff, one is more reactive than the other... hydrogen and chlorine are bonded covalently... magnesium steal chlorine away."

I: "How does magnesium steal chlorine away?"

S10.1: "Polarising power."

I: "What do you understand by the term 'polarising power'?"
S10.1: "Magnesium is neutral atom but it wants to get rid of its 2 electrons. Hydrogen wants to gain one so does chlorine. If it's like that, then hydrogen make bonds easier with magnesium as well, won't it? But chlorine bonds with Mg. Oh, I don't know." [Note her lack of understanding of the term 'polarising power'.]

S10.1 on event 5: "I think it's again displacement. Sodium is more reactive than lead, so then sodium is displacing lead and because sodium steals the nitrate from the lead, so lead has no choice but to combine with the chloride."

The confusion between atom and ions, and the view that sodium is bonded to nitrate when sodium nitrate is dissolved or formed in the aqueous state is evident. It appears that because these students held very firmly the preferential attraction/displacement theory, they tended to fit everything else within this framework, sometimes even against their own understanding of other scientific concepts, as illustrated in the next example with U6 interviewee S14.

S14.2: "Sodium displace lead and take nitrate...lead is larger, less polarising...sodium is smaller...nitrate is large and very polarisable, therefore sodium just got rid of lead." This explanation of how the reaction takes place was in fact inconsistent with her remark that the two products lead chloride and sodium nitrate cannot both be aqueous, because it would mean that "nothing will happen." This remark had sprung from her understanding that when a salt like sodium chloride dissolves in water, "the ionic bond breaks, and free ions are formed."

The next extract of the L6 interview with S14 revealed ACs about the fact that ionic bonds are still present when a salt is dissolved (AC C3a), as well as the confusion of electronegativity or electropositivity with electrical charges (AC C1a):

Preceding this extract, S14 had seen the experiment performed; and observed that magnesium chloride was formed as solution while the other product was observed as effervescence. She had also postulated that the process involved complete transfer of electrons from magnesium to chlorine, forming ionic bond between them.
I: "What do you predict would happen if no water is present, i.e., this piece of magnesium ribbon is added to a gas jar of pure HCl which exists as a gas?"

S14.1: "There would be no reaction 'cos water has to be present."

I: "What do you think is the part played by water in this reaction?"

S14.1: "It helps to split the HCl."

I: "In what way does water help to split the HCl?"

S14.1: "Cos it's an acid, yes, and it donates protons so I don't know."

I: "Does water help split the HCl only when magnesium's added or before?"

S14.1: "I think before."

I: "Then do you need to modify this drawing where you show the H-Cl unsplit?"

S14.1: "Yeah. (writing 'Cl + H₂O' in place of her earlier drawing showing 'H-Cl', i.e. essentially as a molecule with the covalent bond between hydrogen and chlorine intact)."

I: "You said just now that chlorine accepts electrons from magnesium.. can chlorine as Cl- still accept electrons from magnesium?"

S14.1: "By writing 'Cl' I don't mean to say that it has one extra electron, I mean it has capacity for one more electron."

A number of other interviewees also had the same AC; where the representation of dissolved HCl in water as 'H' and 'Cl-' did not stand for electrically charged particles; instead, they were viewed as merely reflecting a tendency to gain or lose electrons; where positive signs were attached, such as 'H' it meant that the hydrogen atom tends to lose one electron, and where a negative sign was attached, such as 'Cl-' it meant that there was a tendency or capacity to accept one more electron.
The following extract from the U6 interview with R2 revealed a related confusion, which was the confusion between oxidation numbers and electrical charges (AC C1a). It also illustrated confusion between electrovalency and covalency (AC C2a).

R2.2 began by responding to the trigger question on how the reaction between copper and oxygen was conceptualised:

R2.2: "..got little copper and it's got 2+ charge on it, then it gets introduced to oxygen, oxygen joins with it so they both get right number of electrons and get copper oxide."

I: "Copper metal exist as copper 2+..."

R2.2: "No..don't know how it can be positive and neutral..

I: "How do you picture the joining process."

R2.2: "They bond because neither got enough electrons..one of them is going to give the other one electrons so they're going to share them so they both have the same amount..if copper is plus and oxygen is a minus then they'll attract"

I: "Oxygen in air is a minus.?

R2.2: "Depends on what it's joined to..if joined to another oxygen, then no charge on it..if joined with hydrogen, get H₂O, then it still got a charge of 2 minus, but the whole thing got no charge."

I: "How does oxygen in H₂O get a 2 minus charge?

R2.2: "We're told it has..don't know..when trying to work out oxidation numbers, we're always told oxygen has 2 minus charge so we accept it."

I: "This copper metal here..does it exist as copper plus?"
R2.2: "No, but when we heat it, heat removes electrons from copper."

I: "Heat affects the electrons in oxygen as well?"

R2.2: "No."

I: "Heat has no effect on electrons in oxygen."

R2.2: "I suppose oxygen changes as well... by joining with copper and changing colour."

I: "What happens to the electrons removed from copper by heat?"

R2.2: "Joined onto oxygen... copper and oxygen probably share electrons... then they'll have 8 electrons."

I: "Copper and oxygen share electrons?"

R2.2: "Yeah... I don't see how copper can lose both electrons and then join."

I: "Copper first loses its electrons to oxygen."

R2.2: "No, copper keeps its electrons and the oxygen will keep its electron and they both join and share so they both got full shells."

I: "This bond formed by copper and oxygen... what do you call it?"

R2.2: "Dative covalent bond."

Note how R2 had reverted from an acceptable conception of copper losing electrons to oxygen, to copper and oxygen both keeping their own electrons and sharing, which is probably a reflection of her inability to visualise how an ionic bond is formed; which in turn is related to her lack of understanding of the nature of electrical charges, having confused them with oxidation numbers. Note also how the concept of dative covalent bond was misconceived.
AC C1a, (confusion between oxidation numbers and electrical charges, etc) was also found in the L6 interview with student R4, where R4 actually conceived of oxygen in the atmosphere, as having 4 minus charges, because it comprised 2 atoms in a molecule, and each atom had a 2 minus charge.

AC C2a, (confusion between ionic and covalent bonding) was quite prevalent, even among students who could talk sensibly about copper losing its 2 electrons to oxygen in the process of heating, and who then made drawings which illustrated covalent rather than ionic bonds.

Similar problems were found in event 4 where drawings showing covalency, instead of electrovalency, were used to illustrate the formation of ionic magnesium chloride. Thus, it appeared that while the bond was thought to be formed ionically, by magnesium atom losing its 2 valence electrons to 2 chlorine atoms; the students seemed to have difficulty in representing ionic bonding or ionic bonds by means of diagrams.

Another sort of confusion between ionic and covalent bonds arises right at the beginning, at the very definition of the two kinds of bonds, as illustrated by the U6 response of S16:

S16.2: "Oxygen has got 6 electrons, it wants to get 8 so it takes 2 electrons from copper... so it becomes stable octet so then you get your product so they are covalently bonded."

I: "What is your understanding of the term 'covalent bond'?"

S16.2: "When one takes their electron... an electronegative element takes an electron from an electropositive one completely... when you have an ionic bond, they share them."

A number of ACs or confusions are in fact revealed by the above short extract, such as:

AC C1a, 'confusion of substance with particles' - S16.2 should be referring to an atom of a electronegative element taking electron... instead of making reference to just the element itself.
AC C2a, (confusion of ionic and covalent bonding) - swapping the definition of covalent and ionic bond around, i.e. the scientists' definition of the 2 terms is the other way around.

For a number of students, there was yet another kind of difficulty. This was related to their belief that ionic bonds, and/or metallic bonds are not really bonds, but are electrostatic attraction. To these students a bond between any 2 atoms was conceived of as comprising 2 electrons, one from each atom. In this conception then covalent bonds are the only kind of real bonds; since it was possible to refer to the 2 electrons between 2 atoms. Thus, for these students, since it was not possible to refer in the same way to 2 electrons between atoms in the case of metals and ionic compounds, they inferred in their own minds that metallic and ionic bonds are not real bonds. Somehow, these students seemed to be 'hung up' on the idea that a bond is real, is there only when it is possible to draw a line representing 2 electrons between 2 atoms; where it is not possible to do this, then no real or significant bond exists.

The following are extracts showing the sense that some students made of bonds:

P10.1 on covalent bond: "When atoms are sharing the 2 electrons in the middle so they can have full outer shell."

In the U6 interview, P10 did not seem to shift from her conception of a covalent bond as comprising the 2 electrons, and in addition, had the following conception about bonds in metals:

P10.2: "There's no bonds in metals..but I'm not sure..it's definitely not covalent bonds, right? and it's not ionic bond 'cos it's not actually ions..they're sort of held together by each other..I don't know..they're just held together."

The following extract of the U6 interview with P14 on how the reaction between copper and oxygen was conceptualised revealed how ionic bond is not thought of as a real bond:

P14.2: "As it gets hotter..electrons jump from copper to oxygen, so form ions..don't know how but somehow they transfer..then 'cos one's more positive, one's more negative, they join together but are not attached in any way..like electromagnetic sort of thing, they're
like stuck together, but there's nothing actually bridging between them sort of join them together."

Later when she was to predict the overall energy change, she said: "...no bonds are made 'cos there's no actual bond like in a covalent bond, it's like attraction...not bond."

These students seemed to lack the understanding that all types of bonds involve electrostatic attraction of some sort; and that in the case of covalency, it is not the 2 electrons between 2 atoms which constitute the bond, but rather, the electrostatic attraction between the shared electrons and the 2 positively charged nuclei which constitute the bond.

For some other students, the inference that metals have no 'bonds' or that the bonds in metals are insignificant compared to covalent bonds seemed to be made based on the fact that in chemical equations, metals are represented as a single, solitary atom (or a mole of atoms), e.g. 'Mg+2HCl→MgCl₂+H₂'.

An example is given in the L6 interview with E10 who made the following statement when asked whether there was any bond breaking process in magnesium ribbon:

E10.1 on event 4: "No, there's no bond breaking in magnesium, it's not joined to anything...it's an atom by itself."

The following extracts from the L6 and U6 interviews with S2 on event 5 illustrate the lack of understanding of the solvation effect of water, i.e., the effect that water has on the structure and bonds of ionic solutes and the AC that energy input is the driving force:

S2.1, when asked to predict what would happen if the aqueous sodium chloride was added to aqueous lead nitrate: "Nothing will happen 'cos they're both really stable..I mean that's ionic compound in solution and the bonds are very hard to break...and lead nitrate I think is a covalent bond...when they come into contact with each other I don't think enough energy is produced in order for anything to happen..I think they are too stable for anything to happen to them."
Later when the experiment was performed, and she observed the white precipitate formed, she said: "white precipitate is lead chloride."

I: "What do you think is the driving force of the reaction?"

S2.1: "I don't know..I mean I didn't think anything's going to happen because sodium is more reactive than lead. [AC C1a: confusion of element with its compounds] because it has strong bonds, it's very stable..but since something happened, there must be something in this substance which is reactive and.. will split..and lead will split from the nitrate which means it will join with the chloride ions."

I: "Any bond breaking.?"

S2.1: "Yeah, there's bond breaking between the sodium and the chloride, lead and nitrate; and bond made between the lead and the chloride, and sodium and nitrate [AC C3a: ionic bond in solute unaffected by water]."

I: "What do you predict will happen if no water is present..suppose we mixed finely powdered sodium chloride and lead nitrate.?"

S2.1: "If you can't dissolve these things in water, I don't think they will react. I think it's something about being dissolved which allows the two to react."

S2 did not change her view that aqueous sodium chloride and aqueous lead nitrate would not react at the U6 interview when she again predicted: "Nothing will happen...because when they interact, there's no energy given..there's no energy made so they don't break their bonds because they are both very stable..sodium chloride is very stable, it's hard to break the bonds, you need a lot a lot..loads of energy to break that bond and unless that bond is broken you can't interact with that, so there's no reaction."

Thus, the above extracts revealed S2's lack of awareness of the solvation effect of water in breaking the ionic bonds of sodium chloride, which was prevalent among the vast majority of the interviewees who postulated the formation of ionic bonds between magnesium and chlorine in event 4, and between sodium and nitrate in event 5.
6.4 SUMMARY OF CHAPTER

The results of the analysis of the students' responses on aspect C show a generally low level of understanding at both U6 and L6 interviews.

Results show that at the L6 interviews, no student scored 10 or more KEs out of the 20 possible KEs, while 81% scored 4 or less KEs. Better results were achieved at the U6 interviews, where about a quarter of the students (23%) scored at least 10 KEs out of the total of 20 possible KEs (an improvement of 23%), and another quarter (27%) scored 4 or less KEs out of the 20 possible KEs (an improvement of 54%).

This study has revealed, as not been before in the literature, the multiplicity of ways in which ionic and covalent bonding can be confused with each other, and with other kinds of bonds. It clearly shows the mismatch between the expectations and perspectives of the teacher and the students. Writing as a teacher, the distinction between ionic and covalent bonds and bonding as typified by sodium chloride and hydrogen chloride are straightforward and clearcut, whereas from the students' viewpoints, there seemed to be a multitude of ways of visualising the bonds and bonding process.

Again, on the effect of solvation in water, in spite of having taught concepts of lattice energies and hydration energies of salts, the polar nature of the water molecule and so forth, the vast majority of the A-level chemistry students were still holding alternative conceptions about the nature of solutions, and also reactions involving solutions. They were also not able to reason in terms of the energy changes that accompany solvation. In a number of cases, the students refer to the salts as dissolving in each other (e.g., as a supplement to event 5, when a solution of copper sulphate is added to a solution of sodium chloride before their eyes, a number of them referred to one of the products formed, i.e., copper chloride or sodium sulphate, as soluble in the other) and completely disregard the presence of water, in spite of having the solutions in front of them.

The lack of understanding about energy changes involved and the role of solvent was similar to some of the findings by Cachapuz and Martins (1987) who found, among other things, that many of the students studied by them conceptualised the process of chemical
change as simply involving a transfer of energy existing between the water molecules, the "non-bonding" energy, to the bonds being formed in the solution. This, among other things, led the researchers to infer that the students had applied the principle of conservation of energy which they learnt in a physics class to another inappropriate context; they had not appreciated the energy changes which occur at the microscopic level.

Another problem (similar again in some ways to the one reported by Cachapuz and Martins, 1987) which plagued some of the interviewees was the inability to discern what constitutes the reaction system in question and what its surroundings. For example, some students thought that an exothermic reaction would result in the reaction vessel becoming cold because heat is given out to the surroundings. Another example is student P4 who seemed to think that the product of event 1 has more energy than the two reactants, which is manifested as heat evolved. In some other cases, this had led to difficulties in predicting the type of chemical change expected, and in other cases, it had led to problems in predicting the energy changes involved.
CHAPTER 7

STUDENTS' UNDERSTANDINGS AND ALTERNATIVE CONCEPTIONS WITH RESPECT TO ASPECT D, HOW THE REACTION TAKES PLACE

7.0 OVERVIEW

This chapter examines the students' responses under aspect D, why the reaction takes place.

Section 7.1 examines students' total scores on aspect D across events by school and by sex.

Section 7.2 examines students' scores on aspect D by event by school and by sex.

Section 7.3 examines students' alternative conceptions (ACs) associated with aspect D.

For aspect D, responses revolved around knowing why a chemical change takes place at all. Students are expected to show that awareness that chemical reactions occur through a combination of thermodynamic and kinetic factors; i.e., they involve both thermodynamically and kinetically favourable conditions. Thus, 2 key elements (KEs) are defined, one pertaining to kinetic and the other to thermodynamic factors (see Appendix C). Hence the maximum number of KEs defined across the 5 events are 2x5 or 10KEs.

7.1 ANALYSIS OF STUDENTS' RESPONSES ON ASPECT D OVER ALL 5 EVENTS

Table 7.1 shows that mean scores for both interviews in for all 5 schools together with p values of significance. The scores were generally low, ranging from 0 to 1.1 at the L6, and 0.9 to 2.8 at the U6; and there were no significant differences (p≤0.05) between schools in any of the scores.

143
TABLE 7.1
MEAN U6, L6 AND PROGRESSION SCORES ON ASPECT D BY SCHOOL

<table>
<thead>
<tr>
<th>School</th>
<th>D-U</th>
<th>D-L</th>
<th>D (U-L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (n=9)</td>
<td>0.9</td>
<td>0.0</td>
<td>0.9</td>
</tr>
<tr>
<td>R (n=6)</td>
<td>2.8</td>
<td>0.0</td>
<td>2.8</td>
</tr>
<tr>
<td>P (n=10)</td>
<td>1.2</td>
<td>1.1</td>
<td>0.1</td>
</tr>
<tr>
<td>E (n=10)</td>
<td>1.1</td>
<td>0.4</td>
<td>0.7</td>
</tr>
<tr>
<td>S (n=13)</td>
<td>1.3</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>p</td>
<td>0.365</td>
<td>0.172</td>
<td>0.077</td>
</tr>
</tbody>
</table>

To examine the difference between the sexes in terms of the U6 and L6 KE scores; and in terms of progression (U-L) scores, on aspect D across events, mean scores together with p values of significance are set out in the following table 7.2.

TABLE 7.2
MEAN U6, L6 AND PROGRESSION SCORES ON ASPECT D BY SEX

<table>
<thead>
<tr>
<th>Sex</th>
<th>D-U</th>
<th>D-L</th>
<th>D (U-L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEMALES (n=35)</td>
<td>1.1</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td>MALES (n=13)</td>
<td>2.1</td>
<td>0.7</td>
<td>1.4</td>
</tr>
<tr>
<td>p</td>
<td>0.110</td>
<td>0.320</td>
<td>.300</td>
</tr>
</tbody>
</table>

From the results on aspect D in table 7.2, it can be seen that there is no significant difference in the scores between the sexes.

The absence of significant differences between either schools or sexes is not surprising given the overall low scores.
7.2 ANALYSIS OF STUDENTS' RESPONSES ON ASPECT D BY EVENT BY SCHOOL

To examine the difference between the schools in terms of the U6 and L6 KE scores on aspect D by event, mean scores, together with p values of significance, are set out in the following table 7.3.

TABLE 7.3
MEAN U6 AND L6 SCORES ON ASPECT D BY EVENT BY SCHOOL

<table>
<thead>
<tr>
<th>Sc</th>
<th>D1U</th>
<th>D1L</th>
<th>D2U</th>
<th>D2L</th>
<th>D3U</th>
<th>D3L</th>
<th>D4U</th>
<th>D4L</th>
<th>D5U</th>
<th>D5L</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.2</td>
<td>0.0</td>
<td>0.2</td>
<td>0.0</td>
<td>0.2</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>R</td>
<td>0.5</td>
<td>0.0</td>
<td>0.8</td>
<td>0.0</td>
<td>0.8</td>
<td>0.0</td>
<td>0.3</td>
<td>0.0</td>
<td>0.3</td>
<td>0.0</td>
</tr>
<tr>
<td>P</td>
<td>0.3</td>
<td>0.3</td>
<td>0.4</td>
<td>0.3</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>E</td>
<td>0.4</td>
<td>0.2</td>
<td>0.4</td>
<td>0.2</td>
<td>0.2</td>
<td>0.0</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>S</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
<td>0.2</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.0</td>
<td>0.2</td>
<td>0.0</td>
</tr>
<tr>
<td>p</td>
<td>.699</td>
<td>.413</td>
<td>.136</td>
<td>.296</td>
<td>.182</td>
<td>.163</td>
<td>.846</td>
<td>.258</td>
<td>.379</td>
<td>.447</td>
</tr>
</tbody>
</table>

From table 7.3, it can be that at both U6 and L6 the mean scores of each school by event were low with no significant differences between the schools.

TABLE 7.4
MEAN SCORES ON ASPECT D BY EVENT BY SEX

<table>
<thead>
<tr>
<th>Sex</th>
<th>D1U</th>
<th>D1L</th>
<th>D2U</th>
<th>D2L</th>
<th>D3U</th>
<th>D3L</th>
<th>D4U</th>
<th>D4L</th>
<th>D5U</th>
<th>D5L</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>0.2</td>
<td>0.1</td>
<td>0.3</td>
<td>0.1</td>
<td>0.3</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>M</td>
<td>0.5</td>
<td>0.3</td>
<td>0.5</td>
<td>0.2</td>
<td>0.5</td>
<td>0.2</td>
<td>0.3</td>
<td>0.1</td>
<td>0.3</td>
<td>0.0</td>
</tr>
<tr>
<td>p</td>
<td>.119</td>
<td>.054</td>
<td>.312</td>
<td>.434</td>
<td>.360</td>
<td>.525</td>
<td>.067</td>
<td>.787</td>
<td>.128</td>
<td>.548</td>
</tr>
</tbody>
</table>

From table 7.4, it can be that at both U6 and L6 the mean scores of each sex by event were low with no significant differences between the sexes.
7.3 ALTERNATIVE CONCEPTIONS ASSOCIATED MAINLY WITH ASPECT D, DRIVING FORCE OR WHY THE REACTION TAKES PLACE

It should be mentioned here that a number of interviewees (eg cases III and IV, Appendix M; and responses of students S1 and C4 below) seemed to interpret the question on driving force ("Why do you think this reaction happens at all?") differently to its intended meaning. They seemed to have interpreted it as "What do you think activates or triggers off this reaction?" This is in spite of the emphasis made by the interviewer that the question was why the reaction should happen at all. In this researcher's view, the main reason for this seemed to be that students have not grasped the concept of driving force, which could probably be linked to either the lack of emphasis given by the teacher or that it is too abstract or difficult and is rejected by students.

Some indication of this could be seen in the fact that about 10 students managed to shift from interpreting the question as "What activates or triggers off this reaction?" at the L6 to the way intended at the U6. This was reflected in responses such as "becoming more stable" or "to have lower entropy" which were closer to scientific views (than their L6 responses which typically suggested that heat input was the driving force) but still incorporating ACs. The fact there were one or two U6 interviewees from each school who mentioned the concept of entropy in relation to their explanations on driving force (see section 10.2, chapter 10; case I, chapter 12) indicates that the concept had been taught in class. But the fact that the other U6 interviewees did not mention it at all seemed to suggest that they had rejected it or "pushed it to the back of their minds" (in the words of a student when she referred to things which the teacher taught and which she could not comprehend).

On aspect D, the vast majority of the students offered at least two different kinds of explanations across the 5 events because they seemed not recognise the underlying generic concepts involved (See chapter 10).

The ACs associated mainly with this aspect D, are limited in number (as discussed in chapter 10) and can be grouped as follows:
Group D1: ACs associated with the idea of energy input, in particular heat energy input as the driving force. The idea of energy input as driving force could be the result of everyday experience and perceptually dominated thinking.

Group D2: ACs associated with the idea of balance of reactivity, or preferential attraction which results in the displacement of one thing by another. Under this category, are some views which are anthropomorphic.

Group D3: ACs associated with the idea of water, the solvent, as the driving force.

Group D4: ACs associated with misunderstanding the concept of entropy.

GROUP D1: ACs associated with the idea of heat/energy input as the driving force.

AC D1a: driving force is heat input; heat is the causal agent of chemical change

<table>
<thead>
<tr>
<th></th>
<th>U only</th>
<th>L only</th>
<th>U&amp;L</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC D1a:</td>
<td>C6, C20</td>
<td>C8</td>
<td>C8, C10, C12, C14, C16, C18</td>
</tr>
<tr>
<td>energy</td>
<td>E2</td>
<td>E1</td>
<td>E3, E5, E7, E11, E19, E6</td>
</tr>
<tr>
<td>/heat</td>
<td>P8, P20</td>
<td>P10</td>
<td>P2, P4, P6, P12, P14, P16</td>
</tr>
<tr>
<td>input is</td>
<td>R4</td>
<td>R7</td>
<td>R1, R5, R2, R6</td>
</tr>
<tr>
<td>causal</td>
<td>S18</td>
<td>S14</td>
<td>S1, S7, S11, S2, S4, S6, S10, S12, S16, S20</td>
</tr>
<tr>
<td>agent</td>
<td>7</td>
<td>5</td>
<td>32</td>
</tr>
</tbody>
</table>

This AC is closely related to AC A1a substantialisation of heat, and was subscribed to by 44 (92%) students; of these 39 were at U6, and among them, 32 held the same AC at both U6 and L6.
It should be noted here that generally the 5 L6 interviewees who abandoned this AC at the U6 level had showed some progression by including ideas that are closer to scientific views in their explanations of driving force (See case I, chapter 12; and case II, Appendix M respectively, which are in contrast to students P4 and C10, cases III and IV, Appendix M, who did not abandon this AC).

This is to be contrasted, in a way, with the 7 U6 interviewees who subscribed to this AC. In most of these cases, it was a shift from saying, "I don't know" or "I have no idea" at the L6 level, to suggesting that it was heat supplied which causes the reaction(s) to take place.

An example is the response of S1.1 on aspect D, event 1: "Basically heat..if you leave copper there..copper is not reacting with oxygen now because..the actual molecules [Note AC C1a: confusion between atoms and molecules, section 6.3, chapter 6] are bound together, no reaction occurring; but using heat, the heat is breaking the bonding and is forcing [This seems to reflect AC D1a - the view that chemical change will not take place unless there is an active causal agent, i.e., heat] it to react with the oxygen so it is the driving force..that's where I assume the force comes from, the heat itself, the heat from the bunsen burner."

In discussing the candle flame, S1.1 in fact volunteered, without being asked, that "the match to start the reaction..that's the driving force." This view that heat is driving force was further elaborated when he was trying to explain where the heat of the candle flame came from: "If you ask me where the heat comes from, heat comes from the actual paraffin itself, the actual chemicals that are stored in the paraffin itself [AC B2a - heat comes from chemicals, section 5.3, chapter 5] but it will not be able to react unless you have heat to be able to push the reaction like how you push dominoes, so the heat actually comes from heating up the chemicals in the paraffin itself."

At the U6 interview, S1 like most of the students in this category did not shift from this AC:
S1.2 on what is the driving force of the reaction between copper and oxygen: "Driving force is the use of the bunsen flame because it triggers off the chemical reaction."

With reference to the candle flame reaction, S1.2 said, "Driving force is the heat supplied by the flame, without the flame this reaction would never occur."

And again with reference to the bunsen flame he said, "Driving force is the bunsen flame because it is the flame that triggers off the chemical reaction, it's the flame that reacts with this, without the flame you won't be able to get this forming, you need heat."

Another example is C4.1 who when asked what was the driving force of the reaction in event 1, said, "Heat, because without heat copper doesn't combine with oxygen."

One year later at the U6 interview, she again said that heat from the bunsen flame was the driving force; however, on further probing she revealed that in fact when she mentioned 'heat as the driving force', she also meant 'oxygen is the driving force' because to her, oxygen and heat meant the same thing. [The idea that oxygen and heat meant the same thing was held by at least 4 other interviewees from school C as well as some students in all the other 4 schools as presented in chapter 4 section 4.3, AC A1a. See also students C6 and S20 responses in section 4.3, for further examples of AC D1a.]

Here heat is deemed as the necessary and sufficient condition for the occurrence of a chemical change; this appear to have arisen as a result of the substantialisation of heat, and/or the associated thinking that "something" must cause a chemical reaction to take place, and that something is energy or energy related. It is common knowledge that in the human and biological world, and even in the world of physics, nothing happens without a cause and that cause is often energy itself or energy related (Andersson, 1986b, Ogborn, 1990). A extrapolation of this, into the microscopic world of atoms and molecules, appears to lead to the inference that energy, more specifically, energy input, is the force or the cause behind chemical reactions, which make them 'go'. After all, it is only when energy is supplied or added on, that motors, engines, machines, and other things 'work' or 'go'.
Another way in which this AC could arise is through incomprehensive teaching or where there is over-emphasis on the concept of activation energy in relation to the kinetics of a reaction, without placing it in a proper context, i.e., that of thermodynamics.

This AC in fact reappeared in slightly different guises as AC D1b, D1c and D1d; which all have the roots in the idea that energy input is needed to drive any chemical reaction.

**AC D1b:** driving force is internal energy of chemicals or the energy and power between the bonds

<table>
<thead>
<tr>
<th></th>
<th>U only</th>
<th>L only</th>
<th>U&amp;L</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AC D1b:</strong></td>
<td>C4,C6,C8,C20</td>
<td>C10,C16</td>
<td>C12,C14,C18</td>
</tr>
<tr>
<td>driving</td>
<td>E6</td>
<td>E2</td>
<td>E3,E5,E17,E19</td>
</tr>
<tr>
<td>force is</td>
<td>P8,P14</td>
<td>P16</td>
<td>P2,P4,P10,P12,P20</td>
</tr>
<tr>
<td>internal</td>
<td>R1,R4</td>
<td>R5</td>
<td></td>
</tr>
<tr>
<td>energy of</td>
<td>S4,S8,S20</td>
<td>S11</td>
<td>S1,S2,S10,S12</td>
</tr>
<tr>
<td>chemicals</td>
<td>n=10</td>
<td>n=7</td>
<td>n=17</td>
</tr>
</tbody>
</table>

This AC was held by 34 interviewees, 17 of whom held it at both U6 and L6. This is illustrated by L6 interviewee C10's response on driving force in event 4 (see case IV; also case III, Appendix M) as well as in the responses of S2 and C6 below.

This AC is very similar to, and perhaps could be considered as a subset or a more specific instance of, AC D1a, in that there is the belief that energy input or heat supplied is the reason why a reaction takes place. It was generally elicited in connection with event 4 and 5 where it was obvious that unlike events 1 to 3, there was no heat supplied. The view here was that it was energy in chemicals which was the driving force. Thus, it seemed that in the case where heat input was clearly seen to trigger off the reaction, the driving force was the heat input. In cases where no heat was applied, then the needed energy
input actually comes from within the reacting chemicals themselves, or more specifically, from the bonds.

Included within this AC are at least two variations: i and ii discussed in the following paragraphs. From the list of student identification codes, it could be seen that some students used both variations i and ii at the same level (e.g., S8.2); this is with respect to different events, e.g., events 4 and 5.

i. that it is the internal energy of one of the reactants which is the driving force (subscribed to by C4.2, C6.2, C8.2, C10.1, C12.1, C16.1, C20.2, E3.1, E5.1, E7.1, E19.1, E2.1; P2.1; P10.1, P12.2, P14.2, P16.1, P20.1, R1.1, R4.1, R5.1, S1.2, S11.1, S8.2, S10.2, S20.2). This variation is linked to naive explanations identified by researchers such as Brosnan (1992), in which chemical change is viewed as the result of one active causative agent acting on a passive one.

An example is C6.2 who was very consistent across the 5 events in viewing one of the reactants as the driving force: 'oxygen or heat' as driving force for events 1 to 3, [heat and oxygen being seen as synonymous] and 'acid' in the case of event 4 and 'sodium chloride' in event 5. And the reason was: "Oxygen or heat provides the activation energy," for the reactions in events 1 to 3; while for the Mg-HCl reaction: "it was the acid which provides the activation energy for the reaction". In the case of sodium chloride as driving force for event 5, the reasons were slightly different. It was: "Because it is most common, because that separates quicker and the chlorine attracts the lead and sodium is attracted to the nitrate."

It seems rather unusual to consider that sodium chloride was the driving force rather than lead nitrate because it was "most common". However, another reason was given; it was that it "separates quicker". Further light was thrown on this reason when she predicted that the reaction would probably be "overall endothermic because one of them, i.e., the lead nitrate needs heat for it to react". On further probing, the reason for this was because "sodium chloride is very soluble" whereas lead nitrate was not so.

151
These responses, coming from a student at the U6 level and who had predicted an 'A' grade for herself in the A-level examinations (see Appendix L.6) appear surprising, because of the numerous ACs (across aspects) and zero KEs counted.

ii. that it is the internal energy of both reactants which is the driving force (subscribed to by C14.1,2, C16.1, C18.1,2, E3.1, E17.2, E2.1, E6.2, P2.2, P4.1,2 P8.2, P10.2, P12.1, S1.1, S2.1,2, S4.2, S8.2, S10.1,2, S12.1,2).

Within this variation, there were 2 subgroups: a group who appeared superficial in thinking - who simply attributed the driving force to "the reactants are reactive..driving force is them being in contact with each other". The other is illustrated by the following extract with U6 interviewee S2, which reflects the view that somehow when certain substances are put together, they produce energy which drives the reaction. In this view then, the AC is very closely related to AC D1a.

S2.2 on why the reaction in event 5 takes place: "Nitrate is electronegative..the sodium is slightly positive..so again when they interact there must be energy made, bonds are broken here."

I: "When the bond is broken, energy is made..?"

S2.2: "No, energy must be made before the bond is broken, that's what I said."

I: "Energy must be made before the bond is broken.."

S2.2: "Yeah, because in order to break the bond, there must be energy to break it so there must be..when they come into contact there must be some energy made and so these bonds are broken and those are broken (referring to Na-Cl and lead-nitrate bonds) then those two join together and these two join together (referring to sodium joining with nitrate, and lead joining with chloride)"

152
GROUP D2: ACs associated with the idea of balance of reactivity, or preferential attraction, which results in displacement. Under this category, are some views which are anthropomorphic. Most of the ACs in this category are the result of superficial or incomprehensive thinking. E.g., if thinking is broadened or deepened, perhaps the idea about the formation of attractive forces or bonds might be linked to that of the decrease in enthalpy, and hence the driving force. Under AC D2, ACs related to the idea of "chemicals wanting to react to form full (electron) shells", more in-depth thinking could have led to the awareness that there are some types of chemical reaction which do not lead to the formation of full shells simply because the reactant particles already have an octet structure similar to the noble gases.

AC D2a: driving force is the difference in reactivity, or charge or electronegativity or competition between two things for something else.

<table>
<thead>
<tr>
<th>U only</th>
<th>L only</th>
<th>U&amp;L</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC D2a</td>
<td>C12, C18, C20</td>
<td>C4, C10,</td>
</tr>
<tr>
<td>driving force is</td>
<td>E3</td>
<td>E7, E11</td>
</tr>
<tr>
<td>difference in</td>
<td>E2</td>
<td>E6</td>
</tr>
<tr>
<td>reactivity, etc.</td>
<td>P20</td>
<td>P2, P8, P16</td>
</tr>
<tr>
<td></td>
<td>R5, R7, R2</td>
<td>R1, R4, R6</td>
</tr>
<tr>
<td></td>
<td>S16, S18, S20</td>
<td>S11, S2, S6, S10</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>13</td>
</tr>
</tbody>
</table>

This AC is illustrated in case IV, Appendix M, where driving force in event 5 is thought to be "the attraction between Na and nitrate and the Cl and Pb".
AC D2b: anthropomorphic explanations, such as chemicals wanting to react to form full shells (exemplified by students E5.1, E6.1, E10.1, P10.1, R2.1), or just wanting to combine with one substance more than another because it is happier that way (students C8.1, R4.1, R7.1, S7.1, S14.1, S18.1).

See student R7, case I, chapter 12 for an illustration of this AC.

The explanation by students that chemicals react to attain full shells of electrons is lacking comprehensiveness and does not explain reactions involving ions or precipitation, e.g., $2\text{NaCl}_{(aq)} + \text{Pb(NO}_3)_2{(_{2(\text{aq})})} \rightarrow \text{PbCl}_2{(_{2(\text{s})})} + 2\text{NaNO}_3{(_{2(aq)})}$, where the reaction does not involve any change in the number of electrons in the outermost shells.

**GROUP D3:** ACs associated with water as the driving force.

**AC D3a:** water, the solvent, is the driving force (subscribed to by C8.1, C14.2, C16.2, E3.1, P6.1, P10.2, P16.2, S6.2, S16.1)

This AC which is held by 9 (19%) of the interviewees, arises mainly from the thinking that without water, the reaction does not take place, hence water is the driving force.

**GROUP D4:** ACs associated with misconceptions about the concept of entropy.

**AC D4a:** the entropy of a system depends on the number of products vis-a-vis the number of reactants (i.e., there was no concept of the entropy dependence on the physical states) (E3.2).

**AC D4b:** driving force is to decrease the entropy of a chemical system (E10.2, P10.2, P18.2).

**AC D4c:** driving force is to increase the entropy of a chemical system (R7.2).
7.4 SUMMARY OF CHAPTER

The analysis of results of students' responses on aspect D, driving force of the reaction, shows a generally low level of understanding of the driving force behind chemical reactions.

Four main groups of ACs associated with aspect D are identified. These were: group 1, those arising mainly from the dominance of everyday experience or perceptual thinking and related to the idea of energy input as the driving force; group 2, those associated with the idea of balance of reactivity, or preferential attraction which results in the displacement of one thing by another, under this category, are some views which are anthropomorphic; group 3, those which view water, the solvent, as the driving force; and group 4, those associated with misunderstanding of the concept of entropy.

The reasons for this general lack of understanding of the driving force are related to confusions about energy changes; this is discussed in detail in chapter 8.
CHAPTER 8

DISCUSSION AND CATEGORISATION OF STUDENTS' UNDERSTANDINGS AND ALTERNATIVE CONCEPTIONS OF THE NATURE OF CHEMICAL REACTIONS

8.0 INTRODUCTION

The purpose of this chapter is to consider the students' overall understandings of chemical reaction as elicited through the interviews and to compare and contrast with the output of earlier studies.

The approach taken is to summarise students' understandings along the dimensions of the interview itself, ie by events and by aspects in order to discern whether or not the students are working within a scientist's framework (of using a generalised dynamic model effectively made up of a set of fixed processes) or working within a range of alternative models perceived to be appropriate to the events or aspects discussed. Students' consistency of use within and between such alternative models is discussed separately in chapter 10.

A classification of the range of alternative conceptions (ACs) revealed is presented and discussed.

The relationship between the ACs held and students' progression is discussed in chapter 9.

For completeness, this chapter includes a brief discussion of students' understandings of the differences between chemical and physical changes.
8.1 SUMMARY OF STUDENTS' SCORES OVER THE FOUR ASPECTS

That the chemical reactions involved in the 5 events chosen in this study were familiar to the students was evident by the fact that the majority (28) when asked for the bases on which they made their predictions either mentioned that they had done the experiments or that they had seen the experiments done before.

Table 8.1 compares the students' responses associated with each of the 4 aspects measured over all 5 main events for the U6 and L6 interviews in terms of percentage of total possible KEs included in the average student's responses. (Progression is discussed in chapter 9.)

Table 8.1

Aspects A to D: Percentage of key elements included in the average student's responses (over all students irrespective of school) in the U6 and L6 interviews

<table>
<thead>
<tr>
<th>Aspect</th>
<th>U (n=48)</th>
<th>L (n=48)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>84%</td>
<td>78%</td>
</tr>
<tr>
<td>B</td>
<td>33%</td>
<td>9%</td>
</tr>
<tr>
<td>C</td>
<td>36%</td>
<td>14%</td>
</tr>
<tr>
<td>D</td>
<td>14%</td>
<td>9%</td>
</tr>
</tbody>
</table>

From Table 8.1, it can be seen that the students performed best on aspect A and worst on aspect D at both U6 and L6 interviews. This indicates that on the whole, students did know what reactants and products were involved in the presented chemical changes, but were largely ignorant about the energetics and driving force behind the chemical change as represented by the related aspects B, C, and D.

To test if students' individual performance was related across these three aspects (B, C and D) the correlation coefficients between the KE scores on various aspects at U6 were examined; these are presented at Table 8.2 below.
<table>
<thead>
<tr>
<th></th>
<th>A-U-KE</th>
<th>B-U-KE</th>
<th>C-U-KE</th>
<th>D-U-KE</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-U-KE</td>
<td>0.30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-U-KE</td>
<td>0.46</td>
<td>0.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D-U-KE</td>
<td>0.27</td>
<td>0.38</td>
<td>0.37</td>
<td></td>
</tr>
<tr>
<td>TOT-U-KE</td>
<td>0.57</td>
<td>0.84</td>
<td>0.93</td>
<td>0.61</td>
</tr>
</tbody>
</table>

This table shows high correlation between the aspect B and C scores (0.67, significant at 0.2 level) indicating that in general students who poorly understood the process of chemical reaction were also likely to score poorly on overall energy change. It also shows that total KE scores at the U6 are more highly correlated with aspects B and C than the other 2 aspects. This suggests that most of the progression at the U6 level (ie the TOT-U-KE scores) comes from improvement on scores in aspects B and C, rather than those in aspects A and D. This conjecture is supported by this researcher's post-interview assessment that aspect A had been relatively easy for most students, whilst aspect D had proven to be very difficult for the majority of students, even at U6.

The relative difficulty with which the students handled aspects B, C and D as compared to aspect A indicates that, in general, students had a good understanding of the "what" of chemical reaction but a poor understanding of the process issues ie. the "how" and the "why".

From another perspective, aspects B, C and D are much more closely related to each other than to aspect A since they all pertain to changes at the microscopic level, whereas aspect A essentially refers to change at the macroscopic level indicating that students appeared to be well-versed on the macroscopic aspects but lacking understanding on the microscopic aspects.
8.2 SUMMARY OF STUDENT'S ATTAINMENT BY SCHOOL BY EVENT

Table 8.3 presents the attainment of the U6 and L6 interviewees over the 4 aspects by event and by school in terms of the total number of KEs included in the average student's responses (p values of significance are also included).

<table>
<thead>
<tr>
<th>Sc</th>
<th>1U</th>
<th>1L</th>
<th>2U</th>
<th>2L</th>
<th>3U</th>
<th>3L</th>
<th>4U</th>
<th>4L</th>
<th>5U</th>
<th>5L</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>3.9</td>
<td>2.6</td>
<td>1.6</td>
<td>0.4</td>
<td>3.7</td>
<td>1.7</td>
<td>2.9</td>
<td>2.3</td>
<td>3.1</td>
<td>1.8</td>
</tr>
<tr>
<td>R</td>
<td>5.9</td>
<td>3.1</td>
<td>5.7</td>
<td>1.4</td>
<td>6.8</td>
<td>2.3</td>
<td>5.2</td>
<td>2.3</td>
<td>3.3</td>
<td>1.6</td>
</tr>
<tr>
<td>P</td>
<td>6.2</td>
<td>3.9</td>
<td>4.8</td>
<td>2.1</td>
<td>7.1</td>
<td>4.2</td>
<td>5.3</td>
<td>2.4</td>
<td>4.2</td>
<td>1.6</td>
</tr>
<tr>
<td>E</td>
<td>3.6</td>
<td>2.3</td>
<td>4.6</td>
<td>3.4</td>
<td>5.5</td>
<td>3.9</td>
<td>3.1</td>
<td>2.3</td>
<td>1.8</td>
<td>1.7</td>
</tr>
<tr>
<td>S</td>
<td>5.5</td>
<td>4.2</td>
<td>4.0</td>
<td>1.2</td>
<td>5.3</td>
<td>2.7</td>
<td>3.6</td>
<td>2.7</td>
<td>2.8</td>
<td>2.0</td>
</tr>
<tr>
<td>p</td>
<td>.041</td>
<td>.013</td>
<td>.018</td>
<td>.002</td>
<td>.002</td>
<td>.005</td>
<td>.010</td>
<td>.631</td>
<td>.053</td>
<td>.859</td>
</tr>
<tr>
<td>Av</td>
<td>5.02</td>
<td>3.22</td>
<td>4.14</td>
<td>1.70</td>
<td>5.68</td>
<td>2.96</td>
<td>4.02</td>
<td>2.40</td>
<td>3.04</td>
<td>1.74</td>
</tr>
</tbody>
</table>

From Table 8.3 it can be seen that U6 scores were highest for event 3, followed by event 1, then 2, 4 and 5 in descending order; while the L6 scores were highest for event 1, followed by event 3, then events 4, 5 and 2 in descending order. Also there were significant differences (p<0.05) between schools on all events at the U6 level; at the L6 level, there were significant differences on events 1 to 3 but not 4 and 5, which seemed to be the most difficult for students, as predicted by this researcher. The fact that there were significant differences on events 4 and 5 at the U6 level suggests that some schools made more contribution on students' learning than others. (This is discussed further in chapters 9 and 11.)
8.3 STUDENTS UNDERSTANDINGS ACROSS EVENTS

In this section, the major ACs, as they were revealed by event types, are presented in subsection 8.3.1 whilst section 8.3.2 presents a discussion of students' understanding of the events and relates these to the findings of previous studies.

8.3.1 SUMMARY OF STUDENTS' ACs BY EVENT TYPE

(Numbers of students subscribing to specific ACs are provided in Table H.1 in Appendix H.)

a. ACs related to burning

a.1. In a number of cases, the everyday notions about burning co-exist with scientific views. For example, metals like copper can only melt (or form the oxide) but not be burned; only carbon containing compounds burn to release energy.

a.2. Some students thought that burning can take place without oxygen - because the everyday understanding of the term burning as catching fire or application of heat was used.

a.3. The role of oxygen in burning was not understood; oxygen was seen as playing a permissive or an active role.

a.4. The similarity between the candle flame and bunsen flame was not recognised.

a.5. Metals are thought to melt but not burn.

a.6. Metals are thought to oxidise but not burn.
a. 7. Only carbon containing compounds were thought to be capable of burning.

a. 8. The candle wax in a burning candle was perceived as not to be burning but only melting.

b. Acids related to metal-acid redox reaction (Mg-dilute HCl interaction)

b. 1. Water, the solvent, was not seen as playing any significant role, so that the non-aqueous reaction was thought to have a faster speed than the one occurring in aqueous medium (which is contrary to the chemist's view, where no reaction is expected between pure HCl and magnesium ribbon).

b. 2. In the aqueous medium, HCl was generally conceived to exist as a polar covalent molecule or as $\text{H}^+$ and $\text{Cl}^-$ ions with ionic bonds between the ions, rather than as free ions.

b. 3. The concept of ion-solvent bonds is largely unknown or unclear.

b. 4. The chemical mechanism involving electron transfer between magnesium atoms and hydrogen ions was largely unknown or misconstrued.

b. 5. There was confusion between oxidation numbers and electrical charges, which led to magnesium being conceived as existing as 'Mg$^{2+}$' ions rather than as 'Mg' atoms.

b. 6. The reaction was generally known to be exothermic but the heat evolved was thought to come from the breaking of the bonds between H and Cl in the acid as well as in the metal.

b. 7. The driving force was thought to be either the magnesium (when it was perceived as being more reactive than hydrogen) or the HCl (when the view that 'acids
attack metals' is held). In both cases, one chemical was perceived to be the 'active' agent which 'causes' the reaction.

c. **ACs related to precipitation reaction**

While the role of water as solvent was better known than in the metal-acid reaction, the effect of solvation and concept of ion-solvent bonds were largely not understood. The result was various ACs about how the process took place.

c.1. During the reaction, the bond between sodium and chloride as well as that between lead and nitrate break; new bonds between sodium and nitrate (as well as between lead and chloride) were formed.

c.2. The energy change involved was generally unknown; even at the U6 only about one-third could predict correctly the energy change involved.

c.3. Sodium metal was perceived to be more reactive and therefore displaced lead out of lead nitrate, i.e., relative reactivity between elements is the perceived driving force.

c.4. Water is perceived to be the driving force (this was the response where the student did not confuse an element with its compounds and go for the previous AC, i.e., sodium as the driving force).

**8.3.2 DISCUSSION OF STUDENTS' UNDERSTANDING OF THE EVENTS**

It seemed that only a handful of the sixth formers interviewed were able to generalise across the 5 events and see them as representing chemical change in the way that a chemist would, i.e., involving collisions between reactant particles, bond breaking, bond
making, and being the consequence of the same driving force behind them.

At another level, a significant proportion of the students were not able to generalise across the first three events, i.e., they did not conceive of them as involving essentially the same chemical interaction between oxygen molecules in air and the particles of the substances involved (copper atoms in event 1, wax molecules in event 2 and methane molecules in event 3) resulting in net heat evolved to the surroundings.

Some of the students, in particular some of the male students in the sample, conceptualised metals such as copper as incapable of burning. Instead, they thought it would melt if heated to high enough temperatures. This seemed rather surprising to this interviewer, since it was quite obvious from the responses of the female students that they had done the experiment involving the heating of copper before. For some of the female students, however, their AC involved believing that copper will oxidise (form copper oxide) but it will not burn. Here, it seemed that the prototypic view of burning, i.e. catching fire, producing smoke and ash (Driver, 1985) was applied. This also illustrates how these students could identify the key elements set out in Appendix C and at the same time subscribed to ACs about the concept of burning. This is a pointer to why there is no strong inverse correlation between the students' KE scores and the number of ACs counted in their L6 responses (see section 9.2, chapter 9). It also supported what had been found in other studies that new concepts or scientists' ideas could be incorporated into the learner's thinking while the old ACs or preconceptions are left intact (Gilbert, Osborne and Fensham, 1982; Head and Sutton, 1985; Pines and West, 1986; Marton and Ramsden, 1988).

One possible reason why students conceptualised metals as incapable of burning could be found in textbooks. An example is the statement found by this researcher on p. 290, Hill and Holman (1978) which states that metals such as copper, lead and mercury "will not burn but only form a surface layer of oxide". This is contrary to the scientific view that burning is a chemical reaction involving interaction between oxygen and the substance being burned, resulting in the formation of oxides, and which is usually
accompanied by loss of energy. However, as textbooks are often taken as authoritative sources of knowledge, such a statement could easily reinforce some naive ideas that learners have, i.e., that only carbon-containing compounds like wood and paper burn, but not metals.

As for the male students in this sample who thought metals could not burn, in this researcher's view, among the possible reasons, is their tendency to think of welding and metal working, which involves heating or melting and then shaping metals. It seemed that these students had forgotten or ignored the fact that metals could both burn and melt at the same time, which was probably a reflection of the "one factor only" type thinking identified in numerous instances in this study.

Students not only failed to grasp the scientists' view, which is a generalised concept of burning or combustion, but a number of them also appeared to think of flame as a substance, an active causal agent or reactant, rather than the evidence and outcome of chemical reaction. This view of flames held by students has also been reported elsewhere (e.g. Prieto, Watson and Dillion, 1993; Ross, 1991).

As reported in studies on younger students (aged 11-12), the sixth formers studied had no difficulty appreciating that air or oxygen is needed for burning. However, a number of them, like their younger counterparts from earlier studies (Driver, 1985; Mehuet et al., 1985; Donnelly and Welford, 1988) were not clear about the exact role of oxygen, other than it is one of the three "elements" (in some of the students' own words), viz., oxygen, fuel and a source of ignition, needed for burning. Ross (1991) also found the same of some of his subjects, who perceived oxygen, as a helper/facilitator of burning, rather than as a reactant.

There was yet another view of oxygen, which was found among a small number of the interviewees, an almost opposite view - that oxygen plays an active role in burning, that it is a force which knocks off the electrons in the substance being burned (i.e., the substance being burned is seen as passive).
As suggested by Brosnan (1992), both views of oxygen - as a permissive agent (i.e., the role of oxygen as helper) or as an active agent of chemical change - which were held by a number of students, are at variance with the chemist's view of chemical change as the interaction of equal partners.

On the whole, to the students, burning or combustion is conceived of as a mixed bag of things, depending on what was being burned. In some cases, the everyday understanding of the term 'burning' (as merely the application of heat) was held together with the view that fuels burn to release energy. In this scheme, burning can sometimes be endothermic and sometimes exothermic. For example, a metal like copper was thought to burn, but the effect was a change of state (melting, not oxidation) and the process was thought to be overall endothermic. Fuels like methane was also thought to burn but the reaction is exothermic, i.e., releases energy.

A significant number of these sixth form students also conceived of the flame/heat as a substance which reacted with the copper in much the same way that younger students (aged 13-15) did (e.g., Bell and Brook, 1984; Schollum and Osborne, 1985; Sanmarti, 1990; Pinto, 1991; Sanmarti, Izquierdo and Watson, 1994).

For some of the interviewees, flame or fire seemed to remain a mystique or mystery - and they viewed the flame as mainly substance (e.g., as containing soot when the focus of discussion was a non-luminous flame; some viewed the flame as "the same thing as oxygen"). In some cases, the carbon in the flame was thought to be formed as a result of carbon dioxide in the air taking part in the burning (i.e., as a reactant)!

With a small number of other interviewees, it seemed to this interviewer that they were quite happy to accept that somehow things like soot are the stuff that flame or fire is made of, and it seemed that to them, a bunsen flame was just a flame, like any other paraphernalia in the laboratory, such as an electric hot plate or a burette or pipette. The consequence was they told the interviewer that they did not think that there was a chemical reaction involved in the candle flame or even the bunsen flame!
On the whole, many of the interviewees did not conceive of the flame as the evidence of chemical reaction, but rather the active agent of change. This might be a reflection of their everyday experience - the experiential gestalt of causation (Andersson, 1986b; Ogborn, 1990). This inference was further supported by the fact that the vast majority of the interviewees conceived of heat as the driving force behind chemical change.

In the case of the events 4 and 5, the vast majority did not appreciate the role of the solvent (a finding also reported of their study subjects by Prieto et al., 1989; Ribeiro et al., 1990); and among those who saw the solvent as playing some part in the reaction, the link between the two events was not perceived.

In the case of event 4, the magnesium-dilute HCl reaction, it seemed probable that, among other factors, that students had not appreciated that there are different levels of understanding. There is the macroscopic level of understanding (ie the level of bulk matter, which allows one to say that magnesium chloride, and hydrogen gas, are formed which is represented by the chemical equation, \( \text{Mg} + \text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2 \)). But there is yet the next level of explanation in terms of microscopic processes, which views the chloride ions as 'spectator' ions ie not involved in the chemical reaction.

Not having learned to differentiate between the 2 levels of understanding, students (about two-thirds) seemed to cling to the notion that because magnesium chloride is formed, there must be a bond formed between magnesium and chloride or chlorine (the vast majority of the students did not seem to differentiate between the terms 'chlorine' and chloride') even at the microscopic level (See case studies I to IV, chapter 12 and Appendix M). Having insisted that a bond is formed between Mg and chloride/chlorine even in the aqueous product, led them to postulate further that the Mg-chloride/chlorine bond is unaffected by the solvent. Since most students learned that the bond formed between a metal (Mg) and nonmetal (Cl) is ionic, this led to the inference that the ionic bond is unaffected by the presence of water, the solvent. For some students, this notion that the ionic bond is unaffected by the presence of water seemed to fit in very well with their preconception of an "ionic molecule", where bonds within an ionic molecule are
different to and much stronger than bonds between "ionic molecules". In such an alternative framework, the effect of dissolving is to break the weak inter-molecular bonds but not the intra-molecular bonds.

On the precipitation reaction in event 5, as in event 4, most students had difficulties understanding the role of the solvent as well as the fact that the reaction does not involve the displacement of a less reactive substance by a more reactive one (See case studies I to IV, in chapter 12 and Appendix M).

Many students' ideas did not reflect understanding of the role of the solvent in either of the reactions in events 4 and 5; and among those who thought water had a part in breaking the bonds in the ionic salts which were dissolved, there were different kinds of ACs. One common AC was that water only breaks the weaker inter-molecular bonds (which in most cases were said to be Van der Waals bonds) which exist between the "ionic molecules" in the ionic solid but not the intra-molecular bonds (which are the ionic bonds) within an "ionic molecule". The vast majority of the students had the notion of molecules within the framework of ionic bonding, a finding also reported by Butts and Smith (1987) and Taber (1994).

This notion of an "ionic molecule" could arise from various sources, among which are the following:

* the thinking that when a positively charged ion like Cu$^{2+}$ attracts a negatively charged ion like O$_2^-$ and come together (as a result of this attraction), their opposite charges "cancel each other out" resulting in the formation of a neutral molecule.

* the 'pseudo-molecular' presentation of the concept of ionic bonding in teaching, highlighted in Taber (1994) - where ionic bonding is taught immediately after covalent bonding; and represented by one metallic atom (usually 'Na') transferring electron(s) to a nonmetallic atom (usually 'Cl'). The results of this form of
presentation are possible ACs involving the conception of the ionic bond as involving only one particle to another particle (instead of conceptualising it as non-directional, extending in all directions and involving each particle being bonded to numerous particles at the same time).

* the practice and procedure of chemical equation writing which has been inculcated in the early stages of chemistry learning, where for example, an ionic compound like sodium chloride is represented as 'NaCl', without adequate emphasis that it is one mole of Na\(^+\) and Cl\(^-\) particles which are being represented, and not just one unit of each. This has led to the misconception that the ionic bond is a bond which pertains only to one particle of sodium and one particle of chlorine.

On the mechanism of the precipitation reaction, no students interviewed had the naive notion reported by Schollum (1982) that precipitation consists of the conglomeration of the two reactants to form a new substance. However, at the same time, the vast majority did not have the scientists' view of the process involved.

For example, most of them conceptualised the sodium and nitrate ions as taking part in the reaction. In fact, many (two-thirds of the U6 interviewees) viewed the reaction as one involving the displacement of a less reactive element/substance by a more reactive one. More specifically, many of the students viewed the process as involving sodium, the more reactive element, displacing the less reactive lead to form sodium nitrate, "leaving lead with no choice but to combine with chloride" (in the words of some of the interviewees).

This AC could be a reflection of the lack of understanding of the concept of chemical reaction (which involves conservation of atoms but not of substance, as discussed in De Vos and Verdonk, 1987a, b; Vogelezang, 1987). Or it could be the result of confusion between elements, mixtures and compounds (Briggs and Holding, 1985) or the confusion between a substances and its particles (Selley, 1978) or both.

168
8.4 STUDENTS' UNDERSTANDINGS ACROSS THE FOUR ASPECTS

In this section, the major ACs revealed about the process of chemical reaction, are presented in sub-section 8.4.1 whilst section 8.4.2 presents a discussion of students' understanding of the process issues and relates these to the findings of previous studies.

8.4.1 SUMMARY OF STUDENTS' ACs REGARDING THE PROCESS OF CHEMICAL REACTION

(Numbers of students subscribing to specific ACs are provided in Table H.1 in appendix H.)

* Many of the intuitive or naive ideas found in much younger pupils were still prevalent, e.g., transmutation, substantialisation of heat.

* Many students have the "anything goes" view of chemical change, and did not seem to have scientists' notions of chemical energetics, and driving force of chemical change.

* Many student seemed to be confused about the microscopic particles as well as the processes involved in chemical reactions; they were generally confused about the various types of bonds, for example:

  - there was confusion between the various particles: atoms, molecules and ions.

  - there was confusion between the particles of a substance and the substance itself.

  - there was confusion between ionic and covalent bonds.
there was little understanding of inter-molecular bonds such as hydrogen bonds and Van der Waals bonds.

there was little understanding about ion-solvent bonds

* Many students held ACs about the nature of bonds, for example

- bonds are material entities held together by energy.

- bonds comprised energy, which is released during bond breaking.

* Many students had difficulty in differentiating between physical and chemical changes. This particular AC is discussed in detail in section 8.6.

8.4.2 DISCUSSION OF STUDENTS' UNDERSTANDING OF THE PROCESS OF CHEMICAL REACTION

This section summarises the various understandings held by the students with respect to the 4 aspects of the study and relates these understandings to the findings of earlier studies.

The study has revealed that, beyond a reasonable understanding of the reactants and products of each reaction (the exception being the significant number of students who thought that there was no chemical reaction involved in either the candle or bunsen flames), the students had no clear understanding of the processes or energetics involved. What to the researcher, approaching the subject with a scientists' framework, was a clear delineation between the related aspects B, C and D, to the students was a confusion of partial unrelated understandings.
With respect to aspect C, how they view the process of chemical change, this study has revealed, as not been done before in the literature, the multiplicity of ways in which ionic and covalent bonds and bonding could be confused with each other, and with other kinds of bonds.

On the effect of solvation in water, in spite of having been taught the concepts of lattice energies and hydration energies of salts, the polar nature of the water molecule and so forth, the vast majority of the students were still holding alternative conceptions about the nature of solutions, and also reactions involving solutions. They were also not able to reason in terms of the energy changes that accompany solvation (in line with findings reported by Cachapuz and Martins, 1987). In fact, to nearly half of the U6 interviewees, water had a passive role in the metal-acid reaction. This seemed again to be another indication of the use of perceptual thinking or single factor reasoning (associated with the view that water, 'H₂O' is not reflected in the chemical equation, hence it has no significant or active role in the reaction) instead of conceptual thinking. Similar findings about how the role of solvent was ignored or not understood were reported in other studies (eg Prieto et al., 1989; Ribeiro et al., 1990).

In a small number of cases (3 L6 interviewees), salts were conceptualised as dissolving in each other (eg., in event 5b, which is supplementary to event 5, when a solution of copper sulphate is added to a solution of sodium chloride before their eyes, these students referred to one of the products formed, ie., copper chloride or sodium sulphate, as soluble in the other) and completely disregard the presence of water, in spite of having the solutions in front of them.

Another problem (similar again to findings reported by Cachapuz and Martins, 1987) which plagued some of the interviewees is the inability to discern what constitutes the reaction system in question and what its surroundings. For example, some students thought that an exothermic reaction would result in the reaction vessel becoming cold because heat is given out to the surroundings. Another example is student P4 (case III,
Appendix M) who seemed to think that the product of event 1 has more energy than the two reactants, which is manifested as heat evolved. In some other cases, this had led to difficulties in predicting the type of chemical change expected, and in other cases, it had led to problems in predicting the energy changes involved, in relation to aspect B.

With respect to aspect B, there was preponderance of single factor reasoning and/or perceptual thinking. For example, with respect to event 1, 18 students (40%) thought that it was an overall endothermic reaction based on the reason that "without heating, no copper oxide would be formed". Similar misconceptions were also reported by De Vos and Verdonk (1986); and Johnstone, MacDonald and Webb (1977) of their study subjects.

In addition, the majority of the students were unable to predict the overall energy change because of their misconceptions about the nature of a chemical bond. For a large number of the students, the chemical bond was seen as a physical entity, which led to it being coded, in the terms of Chi et al. (1994), into the ontological category of "matter". This was in contrast to the chemist's view of the bond as a "constraint-based event"; which means that it should be coded into the ontological category of "processes".

This notion of a chemical bond as matter is then linked to the everyday notion that the construction of any structure requires energy input; and its converse, the destruction of any structure releases energy, to form the bases for the prevalent AC that bond making requires input of energy and bond breaking releases energy. In other words, the notion that bond making requires energy input may be the result of extrapolating views about events in the macroscopic world into the microscopic world - in the macroscopic world, energy is needed to make things, therefore in the microscopic world, energy is also needed to make bonds.

In another variation, both bond breaking and bond making are viewed as requiring energy. In this framework, bonds are viewed as requiring energy input to begin the process of breaking up; during the bond breaking process, energy is released. This framework is probably the result of students superimposing school science (that bond breaking requires
energy) upon their own preconceived views (that bonds release energy when they break up); a finding in line with those reported by Gilbert, Osborne and Fensham (1982).

For some other students, who seemed to be operating at the non-formal Piagetian cognitive developmental stage, and who seemed unable to reason by taking into consideration various factors at the same time, the fact that most chemical reactions require input of heat energy seemed to reinforce their naive view - that the heat input has been used to make new compounds, which to them is synonymous to making bonds. Somehow, they seemed unable to view the existing bonds and structure as needing to be broken, before or during the formation of new bonds/compounds.

This study has also shown up from a new perspective what other studies (especially those in physics) have shown - that the concept of energy is very abstract and difficult for most students (Duit, 1984; Bliss and Ogborn, 1985; Gilbert and Pope, 1986; Ogborn, 1990). It has shown clearly the lack of understanding about chemical energetics among the A-level chemistry students. This is in spite of having been taught relevant concepts such as lattice energy, enthalpy of reaction and bond enthalpies, and so forth; concepts which the vast majority did not voluntarily mention. Related to this might be the lack of understanding of the nature of heat, which was revealed by a number of the interviewees. If they do not understand the nature of heat itself, and conceptualised it as a substance such as hot air or oxygen, then it is not surprising that they did not feel comfortable reasoning in terms of chemical energetics.

It seemed very surprising to this researcher that there were still a number (albeit a small number) of A-level students who seemed to have transmutationist ideas reported by Schollum (1982) and Andersson (1986a, 1990) of younger students. An example was student C10, (case IV, Appendix M), who thought that when copper reacts with oxygen, carbon dioxide or hydrogen gas might be emitted!

Such findings raise questions about the kinds of curricula in-situ (i.e., that which transpire in classroom situations) and feedback mechanisms and procedures that had been
experienced by learners such as student C10, who seemed not to be fully cognizant of her weaknesses and ACs; and had aspirations for further study within a science discipline (to become a doctor).

Related to ideas of transmutation discussed in the preceding paragraph, there were a significant number of students who exhibited what this researcher terms the 'anything goes' syndrome. For these students, there was clearly the idea that atoms must be conserved in a chemical change, but beyond that, it seemed to be: 'anything goes as long as the elements are in the soup'. Thus, 4 students thought that carbon dioxide in air is involved as a reactant in burning. Three students conceptualised the oxygen in the air as reacting with the hydrogen gas evolved in event 4 (Mg-dilute HCl reaction) to form water (2 cases); and hydroxyl group (case I, chapter 12) which then accept electrons from Mg to form hydroxide ion. Yet another example is the postulate by a student that when sodium chloride is dissolved in water, sodium hydroxide and hydrochloric acid would be formed, and that there would be no more sodium chloride!

In relation to energy change, some of the interviewees seemed to exhibit transmutation ideas similar to those held by younger students (Andersson, 1983, 1986a). For example, a handful of the interviewees had the view that matter such as oxygen in the combustion reactions such as event 1 was transmuted into energy. In some of these cases, it seemed that the misconception could be linked to the new knowledge that the students acquired with respect to Einstein's mass - energy equivalence relationship (E = mc²) which seemed to be not properly integrated into students' conceptual frameworks, and was given overemphasis and applied in the wrong context.

It seemed to this researcher that the main problem was students had not learned the 'WHY' behind chemical reactions (i.e., the driving force). If students have not understood why it is that some substances put together, and/or heated together react and some do not, then it is not surprising that a significant number were labouring under the misconception that heat is the necessary and sufficient causal agent of chemical change; and having no proper concept of energy nor the amount involved, a number of the interviewees have
postulated that heat input from the surroundings is the causal agent for change.

8.5 CATEGORISATION OF ALTERNATIVE CONCEPTIONS

The data collected revealed the numerous alternative conceptions (ACs) held by the students about the nature of chemical reaction.

Categorisation, in this context, can best be considered by analogy to a three dimensional model. The interview process with its five events can be considered the x-axis which provides the platform for providing the Key Elements of aspects A to D, the y-axis. The y-axis data, ACs grouped by aspects, are presented in appendix H and discussed in chapters 4 to 7. The final stage is to categorise into the z-axis based on global commonalities across aspects.

Three distinct categories of AC can be delineated and are presented below. Each category contains a number of sub-categories each containing one or more of the AC groups identified under aspects A to D in chapters 4 to 7.

Category 1: ACs associated with naive chemistry

Sub-category 1.i. Groups A1 and B1 (ACs associated with perceptual thinking)

Sub-category 1.ii Group B2 (ACs associated with 'one factor only' reasoning)

Sub-category 1.iii Groups A3 and A4 (ACs associated with 'anything goes')
Category 2: ACs associated with the process of bonding and the nature of bonds

Sub-category 2.i Group B3 (ACs associated with misconceived ideas about the nature of bonds and wrong direction of the energy change involved in bond breaking and bond making)

Sub-category 2.ii Groups C1 and C2 (ACs associated with various confusions, between particles and substances, and different types of bonds and bonding);

Sub-category 2.iii Group C3 (ACs associated with reactions in solutions).

Category 3: ACs associated with the driving force of chemical reaction

Sub-category 3.i Group A2 (ACs which show ideas of conservation and have some scientific basis, and arising mainly from the lack of understanding about the driving force);

Sub-category 3.ii Group D1 (ACs associated with the idea of energy input as the driving force);

Sub-category 3.iii Groups D2, D3 and D4 (ACs associated with relative reactivity or preferential attraction;
with water as the driving force, or with entropy).

The complete categorisation and frequencies of these various ACs are presented in Appendix H.

The three categories are next discussed in detail.

8.5.1 CATEGORY 1: ACs ASSOCIATED WITH NAIVE CHEMISTRY

Although three sub-categories of ACs associated with naive chemistry have been identified, many students revealed ACs in two or more of these sub-categories, showing interaction between these naive chemistry ACs. Therefore they are discussed here as a single entity.

Within this category are students whose view of burning was perceptually dominated, and was also governed by everyday notions of the meaning of the term 'burning'. Such students considered the candle wax as not involved in burning, and hence, not involved in chemical change.

There was another group of students who seemed to conceive of burning as involving fire (hence some sort of heat or energy change) but had no conception of the true nature of burning. For these students, burning need not involve oxygen at all or if it did involve oxygen, the role of oxygen was largely unknown. An example is L6 interviewee R2 who when asked whether she thought there were chemical reactions going on in the candle flame replied: "I think the air burning is a chemical reaction, but I don't think the candle wax itself is".
There were yet others (such as L6 interviewees E1, E17, R4 and S10) who conceived of burning as a process which always resulted in the production of carbon dioxide because of their preconceived notion that only things which contain carbon can burn. Such views probably again arise from the dominance of perceptual thinking and everyday notions of the term 'burning' where carbon-containing things like wood and paper are conceived of as capable of burning but not things like metals.

Within the group of students who conceived of metals as incapable of burning, two subgroups were distinguishable. The first group comprised those described in the preceding paragraph as naive thinkers, who were misled by prototypic notions of the term burning described by Driver (1985) where burning is associated with being set alight, and disintegration into ash and smoke; in this view, metals were seen as incapable of burning. Instead, they merely could get hot and melt (and vaporised if heated enough).

Then there is a more sophisticated group who are placed and described in the next category 2, who viewed metals as capable of forming oxides but incapable of burning because of something special in their bonds e.g., E3.1,2; S18.2.

Then there was view of burning as merely heating or the application of heat, which could be related to an everyday notion that 'things burned when there is excess heat applied' such as the reference of food/dinner burning or skin being burned because of over-exposure to the sun or accidental contact with hot objects. An example is student R5, who during the L6 interview proposed that there are two kinds of burning, one which involved "carbon compounds, for instance, when you burn them in oxygen, they give off energy...and another kind of burning which is an endothermic reaction. it doesn't give out energy but it actually take in energy so it (referring to the substance being burned) can change from solid to a liquid to gas." This latter view seemed to indicate confusion between heating and burning.
The dominance of 'one factor only' type reasoning (and perceptual thinking) was also evident in the way some students reasoned about the overall direction of energy change involved (eg in event 1, 40% reasoned that the reaction must be overall endothermic because heat is needed to bring about the change.

This study had found a small number of students who seemed to have the 'transmutation' view of chemistry reported in the literature of younger students (eg Andersson, 1986a, 1990) (see case IV, Appendix M). It seemed to this researcher that there would have been more such views revealed at the interviews, if not for the fact that students were generally requested to write chemical equations representing the chemical reactions; in the process of which, a number of students seemed to be jolted out of any transmutationist view that they might otherwise still entertain. This might suggest that chemical equations are important for developing ideas of conservation.

Another group of students revealed ideas which initially appeared to be transmutation ideas. However, on further probing, it became clear that because these students had poor understanding of the concept of driving force behind chemical change; to them it was 'anything goes' as long as the elements were present in the surroundings. Eg., C6 mentioned that copper when heated in the bunsen flame would form copper oxide and carbon. On further probing, it became clear that she conceived of the reaction as involving the reaction of carbon dioxide with copper to form copper oxide and carbon, showing a lack of understanding of the concept of driving force of chemical reactions. It also appeared that she had another difficulty. She was confused between reaction systems. She appeared to associate soot wrongly with the nonluminous bunsen flame which was shown to her (like a number of other students such as C18 mentioned in section 4.3), and then was trying to account for its presence in the flame.

Another example of the 'anything goes' view which revealed the lack of any understanding of driving force was given by students E17 and S10 who both predicted that copper in event 1 would first react to form copper oxide, which then reacts with
8.5.2 CATEGORY 2: ACs ASSOCIATED WITH THE PROCESS OF BONDING AND THE NATURE OF BONDS

8.5.2.1 Sub-category (2.i): ACs associated with misconceived ideas about the nature of bonds and wrong direction of the energy change involved in bond making and bond breaking

As mentioned in the preceding sections, within this second category are students such as E3 and S18 who viewed metals as incapable of burning because of alternative conceptions about the nature of metallic bonds. Here metallic bonds were seen as different to covalent bonds in say, alkanes, and were seen as incapable of breaking when exposed to heat; instead these bonds allowed heat to pass through. Thus, the observation that metals like magnesium increased in weight was explained away by the absorption or trapping of oxygen between the spaces created by metal ions vibrating faster and moving further away from each other as a result of the heat passing through them. Thus, in this conception, the formation of magnesium oxide was viewed as a physical and not a chemical change.

Within this category is yet another prevalent AC about the nature of bonds, which was the view of the chemical bond as comprising energy so that when bonds are broken, energy, usually in the form of heat, is released; and so that when bonds are formed energy is absorbed. In this view, the bonds were seen as doing work in holding atoms together and since energy is normally viewed as "the capacity to do work" (in the words of one student), bonds were then conceptualised as comprising energy. From this, it thus appeared to follow that when bonds are broken, energy must be released and vice versa when bonds are made.
Another AC is the conception of bonds as matter. In the words of one student, "bonds must be held together by energy". She, like a number of other students appeared to be conceptualising the bond as a physical link, a structure like a bridge. Hence in her view it required energy both to break and to make bonds.

In these alternative views, the heat that was released in the exothermic reactions (e.g., the combustion of alkanes) was seen as arising from the breaking of bonds (e.g., C-H and C-C bonds), instead of the scientific view that the heat released was as a result of the formation of bonds (e.g., C=O and C-H bonds). And the overall exothermicity was generally seen as the result of the greater number of bonds being broken compared with the number of bonds being made (see category ii, Table 10.1, chapter 10).

8.5.2.2 Sub-category (2.ii): ACs associated with various confusions, between particles and substances and different types of bonds

One group of prevalent ACs is associated with the confusion of element with compound, particles of the substance with the substance itself, and also those which involved the confusion of oxidation numbers/electronegativity/electropositivity with electrical charges. Among these was the view that ionic species such as C\(^{+}\) and H\(^{+}\) were involved in the mechanism of the combustion reactions discussed in events 2 and 3; which was contrary to the scientific view, that free radicals rather than ions were more likely to be involved.

Among those who confused element with compound were those who viewed the precipitation reaction in event 5 (i.e., \(\text{NaCl}_{(aq)} + \text{Pb(NO}_3\text{)}_{2(aq)} \rightarrow \text{PbCl}_2(s) + \text{NaNO}_3(\text{aq})\)) as arising from the displacement of a less reactive element (Pb) by a more reactive element (Na). Here, there was confusion between the properties of mixtures and compounds (students seemed to be thinking that sodium in sodium chloride still retained the properties it had before it was combined with chloride). This problem of confusion between mixtures and compounds had been found with respect to younger students aged
15 and below (e.g., Briggs and Holding, 1985).

With a few of these students, in the Mg + HCl reaction, the hydrogen gas which was released was represented by "H" in the chemical equation for the reaction, which read thus, "Mg + 2HCl → MgCl₂ + 2H". Thus, these students did not seem to know the difference between an ion and a molecule, which in turn could be traced to a lot of confusion about oxidation numbers and electrical charges, and so forth. An example was the case of U6 interviewee S14, who explicitly stated that when she wrote "H" as formed from the dissolving of hydrogen chloride in water, she did not mean a charged particle, instead, it meant that "hydrogen is electropositive, it had a tendency to lose one electron". In this scheme of things then two 'H' particles combine together to give H₂, hydrogen gas. The converse of such a view was expressed by L6 interviewee, R4 who represented oxygen gas in the air as 'O⁻' i.e., oxygen in air has "four minus charges since each oxygen has two minus charge". Another AC expressed by some students was that the statement, "magnesium is electropositive" means that "it exists as Mg with 2 positive charges".

Further examples of the confusion between elements and substances, atoms, molecules and ions are provided in the discussion under sub-category 2.iii on ACs relating to solutions and show quite graphically how ACs in one area support and foster ACs in another.

Then there were a number of students who were confused between ionic and covalent bonding, and within these, there were many different kinds of confusion.

a) There were those who got the terms swapped in their view; i.e., ionic bond was seen to involve sharing and covalent bonding to involve transfer of electrons.

b) There were those who conceived of a covalent bond as formed by the sharing of one electron between two atoms; i.e., one of the atoms donates an electron which is then shared between the two atoms which are said to be held by the covalent
bond.

c) There were those who had no proper concept of electronegativity, and hence no concept of electronegativity difference, and to whom, there seemed to be no rules governing the bonding process. To these students metals, such as magnesium and copper, could form covalent bonds with non-metals like chlorine or oxygen.

d) Then there were those who seemed to find it difficult to conceive of the ionic bond; who either seemed fixated on the idea that a bond must necessarily involved a pair of electrons (or more pairs of electrons in some cases) between two atoms, say, A and B, which could then be represented by a line drawn between the two atoms, such as 'A-B' or who found it difficult to conceptualise the ionic bond diagrammatically. Among these were students who explicitly stated that they did not know how to draw the ionic bond; there were also others who said that the ionic bond and metallic bonds were "not real bonds, in the sense of covalent bonds".

e) Among the students who seemed to know that a metal and a non-metal tend to form an ionic bond, and who could picture the process of electron transfer between copper and oxygen, were those who had the misconception that the result of the attraction between the two oppositely charged ions formed was the neutralisation or the cancelling of charges, leading to the formation of a neutral molecule. From this, they further theorised that not only do ionic compounds comprise discrete, neutral molecules but that the bonds within the molecules were stronger than the bonds between molecules.

f) Some students created their own rule about how electrons in a bond were shared; eg, in referring to copper oxide, oxygen was said to donate electrons for sharing because it had "more electrons in its outer shell than copper".
8.5.2.3 Sub-category (2.iii): ACs associated with reactions in solutions

For students who seemed to have some scientifically acceptable views of the ionic bond, there were numerous other ACs which were identified in connection with events 4 and 5, in the discussion involving the role of solvent in the breaking of ionic bonds in a soluble salt such as sodium chloride. For example, there was the conception of the breaking of the ionic bond as the reversal of the process of electrovalency, i.e., when the ionic bonds in sodium chloride are broken by the water molecules, the positively charged sodium ion (which was formed by the sodium atom transferring its valence electron in the first instance to the chlorine atom, which resulted in the formation of negatively charged chloride ions which then attract each other to form solid sodium chloride) took back its lost electron, i.e., the charge on the sodium ion became neutralised.

Another prevalent AC associated with reactions in solution was the opposite view that ionic bonds, which were seen as intra-molecular bonds, were not affected at all in the dissolving process, i.e., the solvent was seen as not playing a significant part other than bringing about dilution of the substances involved or other than the provision of a medium for the reaction to occur. Instead, only the weaker bonds between molecules were broken. Thus, in this view, magnesium was conceived of as forming a bond with chlorine even though the magnesium chloride was formed in solution; and the sodium was conceived of as forming a bond with the nitrate ion even though again sodium nitrate was soluble.

The misconception about the role of the solvent and its non-effect on ionic bonds discussed in the preceding paragraph seemed related to another preconceived notion that students have: the fact that the reaction between the metal and acid in event 4 and the precipitation reaction in event were both seen as displacement reactions, involving the displacement of a less reactive substance by a more reactive substance. Such a concept of displacement appeared to have been introduced in the early stage of chemistry learning. Then at the lower levels, these students appeared to have been told that only metals which are more reactive than hydrogen in the activity series would react with dilute acids to
form salt and hydrogen gas. (Another example of the displacement AC was revealed in the precipitation reaction in event 5, i.e., $\text{NaCl}_{(aq)} + \text{Pb(NO}_3)_2_{(aq)} \rightarrow \text{PbCl}_2_{(s)} + \text{NaNO}_3_{(aq)}$; where sodium, as the 'more reactive' substance, displaces the 'less reactive' lead. As discussed under category 2(ii), there appeared to be various confusions which led students to think that sodium in sodium chloride still retained the properties it had before it was combined with chloride.)

As a result of firm entrenchment of this notion about displacement at the lower levels, this notion, which had become a preconception, had been resistant to further instruction, and additional ideas introduced at upper levels had merely been interpreted in the light of the old preconceived ideas which had led to view that the ionic bond is retained when a substance is in the aqueous state; and that it was weaker bonds within "ionic" molecules, (which in many cases are seen as Van der Waals bonds) which were broken in the process of dissolving.

In the case of event 4, the preconceived notion about the reaction being a displacement type reaction had also rendered it difficult for the students to properly conceive of the reaction as involving the transfer of electrons from magnesium to hydrogen. Instead, new learning about bonds and types of bonds had been misinterpreted in the light of the students' preconceptions. For example, students who were bugged by the preconceived or misunderstood notion of displacement, who had learned at some earlier stage in their science/chemistry curriculum that the metal-acid reaction is the result of the displacement of hydrogen by magnesium (a more reactive substance or a substance higher than hydrogen in the activity series), had interpreted the microscopic process in event 4 as involving "magnesium taking the place of hydrogen in the compound HCl". Their subsequent exposure to the concept of chemical bonds, ionic, covalent and so forth, seemed to be interpreted in the light of displacement: thus they view the reaction process as involving the displacement or "pushing out" of hydrogen by magnesium, i.e., involving the breaking of the H-Cl bond and its replacement by the Mg-Cl bond.

185
Another source of students' difficulties could be traced to their preconception that if an ionic compound is formed, then electron transfer must be involved. In this view, because magnesium chloride was regarded as being formed (besides hydrogen gas) and because it was known to be an ionic compound, the process through which it was formed must therefore involve the transfer of electrons from the metal atom to the non-metal atom. (In a sense this type of AC could also be placed in category as a result of shallow or 'one factor only' type thinking.)

In many cases where the acid was seen as undissociated ie still retaining its molecular state, the reaction process was viewed as involving the transfer of electrons from magnesium atoms to the Cl in the H-Cl molecule, resulting in the breaking of the H-Cl bond and the formation of the Mg-Cl bond. Within this framework, there were a number of students who also confused ionic and covalent bonding - these students maintained that the Mg-Cl bond was ionic, but they could only draw covalent diagrams to represent the bond.

It was surprising that the various ACs and preconceptions prevailed even among students who could recall learning that in dilute HCl there were hydrogen ions and chloride ions formed. In such cases, there were a few common approaches to the resolution in favour of their preconceptions.

One approach was to view the ionic bond between H\textsuperscript{+} ions and Cl\textsuperscript{-} ions as still existing in the presence of large amounts of water; and that the addition of magnesium led to the replacement of one ionic bond by another. Here, the magnesium metal was viewed as comprising Mg\textsuperscript{2+} ions (a reflection of the confusion of oxidation numbers/electropositivity with electrical charges; i.e., to these students, the fact that magnesium is electropositive means it has a positive charge), thus the reaction was viewed as the replacement of the bond between hydrogen and chlorine with a bond, a similar bond, between magnesium and chlorine.
Another approach was to view the chloride ions as "giving back" the electron that it had taken from hydrogen to the H⁺ ions; and the chlorine atoms thus formed then accepted electrons from magnesium atoms resulting in the formation of an ionic bond between Mg and Cl.

There were yet other different variations within this view of electron transfer between magnesium and chlorine:

- There were some students who maintained that writing Cl⁻ from dilute HCl does not mean that chlorine has already got the extra electron that it needs; instead, to them, it meant that chlorine has one more vacancy for electrons.

- There were yet other students who regressed, i.e., changed their view of the dilute acid as comprising H⁺ ions and Cl⁻ ions to the view of HCl as comprising H-Cl molecules (some students had the additional view of HCl as a polar molecule, comprising a permanent dipole as a result of the difference in electronegativity between hydrogen and chlorine. A number seemed to know that chlorine is more electronegative, hence it has a partial negative charge while H has a partial positive charge). Thus, for those who viewed dilute HCl as comprising covalent H-Cl molecules, the reaction process was viewed as magnesium, the more reactive metal, pushing its electrons towards the chlorine, resulting in the formation of the magnesium-chloride bond, and the breaking of the H-Cl bond. Here, the bond breaking was seen as essentially involving homolytic fission, i.e., the H and the Cl each took back its own electron which was used to form the covalent bond.

Besides these, there were a small number of other students who had other views of how the displacement of hydrogen by magnesium took place:

- Magnesium has a larger nucleus than hydrogen, therefore it is more electronegative than hydrogen and was able to grab the electrons of chlorine from hydrogen in the H-Cl bond. (In this view, there was clearly shallow or 'one factor
only type reasoning, as manifested for example in making reference to particle size without making specific reference to the nuclear charge and the screening effect of inner shells of electrons, etc and the misunderstanding and misapplication of the term 'electronegative' to magnesium.)

Magnesium has a bigger overall charge of +2 compared to the +1 charge of hydrogen so Mg has a greater power to attract and bond with chlorine. (This view was an extension of the view discussed earlier; the only difference was that here a different reason was given to explain the displacement of hydrogen by magnesium. Whereas the earlier view was based essentially on the reason that "magnesium is more reactive than hydrogen, its position in the activity series being higher than that of hydrogen", in this present view, the relative magnitude of the electrical charges was seen to be the reason for the displacement. However, practically all the students who held this view could not explain why the magnesium came to have a 2+ charge in the first place.

8.5.3 CATEGORY 3: ACs ASSOCIATED WITH DRIVING FORCE

In this category, as in the Category 1, the three sub-categories are discussed in total. However, the reasons are different. Whereas in the case of Category 1 ACs, there were numerous different ACs associated with naive chemistry which interacted with each other, in this category, there were relatively fewer varieties of ACs. Here, in fact at both U6 and L6, the prevalent AC was that chemical reactions needed a causal agent; and in the vast majority of cases, that causal agent is either heat or the internal energy of one (sometimes both) of the chemicals involved.

In events 4 and 5, where clearly no energy was supplied, two main views were seen. In one view, heat absorbed from the surroundings was the driving force. In the other view, the reactive substances present (such as magnesium or the acid in event 4, and the sodium in event 5) was seen as capable of releasing energy which drives the reactions.
Within this category are ACs about the concept of entropy which were held by some students. These students appeared to have difficulty grasping the concept of entropy, and even more so, the idea of the increase in entropy of the universe as the driving force of chemical reactions. An example of the nature of ACs related to entropy was that expressed by L6 interviewee, P10 who when asked what was the driving force of the precipitation reaction in event 5, said, "Driving force? ...to make it more stable...make it a solid..less entropy...A solid..an insoluble solid is more stable than a solution..has less entropy..different if the solid is soluble in water..for example, sodium chloride dissolves because it is attracted by water". Here, her lack of understanding of the concept of entropy was evident. The fact that student P10 did not mention the term entropy at all at the U6 interview seemed to suggest that she had not resolved her difficulties in handling the concept.

This was in contrast to student P18 who mentioned the term entropy in both interviews and who appeared to show some improved understanding of the concept, albeit still vague. At the L6 interview, when P18 was asked why she thought magnesium was more reactive than copper in the context of a metal-acid reaction, she said, "It's something to do with the energy levels in it..like magnesium has a higher energy level than copper, and, or higher entropy. I'm not very sure what entropy is..I'm not very good at entropy..I assume that the reaction of dilute HCl is more likely to occur than reaction with copper because.. it's more easy to stabilise because it can give out more energy or it's more likely to stabilise."

At the U6 interview, P18 seemed to have more idea of the concept of entropy, but got it the opposite way round, by confusing it with enthalpy and associating it with less order as can be inferred from what she thought was the driving force of the precipitation reaction in event 5, "It's the change in entropy..it's losing energy when it becomes a solid so that's the reason for reaction to occur..becoming less..becoming more structured."
8.6 STUDENTS' UNDERSTANDING OF CHEMICAL CHANGE VERSUS PHYSICAL CHANGE

Some students seemed to have difficulties distinguishing between chemical and physical change. This was evident in the number of interviewees who thought melting of metals and wax and/or dissolving was a chemical reaction. Blanco et al. (1988) (mentioned in Prieto et al., 1989) working with students aged 15-17 and Prieto et al. (1989) working with students aged 11-14 also found that students conceived of dissolving as involving a chemical change. Schollum (1982) also reported that some pupils had a 'conglomerate view' of dissolving, in which the solute and solvent interact to produce a new substance with new properties. Schollum (1981) also reported a similar finding in which students aged 11-18 years included the processes of dissolving and vaporisation in the category of chemical change.

Like some of the students in other studies, most of the students in the present study have learned the definition that a chemical change results in a new substance formed, but they also seemed to struggle with what constitutes a new substance. Is the outcome of melting (say a metal like copper) or dissolving table salt in water, a new substance? The outcome seemed more perceptible than that of adding a dilute acid to an alkaline solution. So how does one tell whether a new substance has been formed? Can heat change be a criterion or sign of chemical change? It seemed not because heat change was perceptible in all three cases (melting, dissolving and neutralisation). And in the case of some chemical change (e.g., precipitation) no heat change is perceptible. It seems that one has no choice but to use the criterion of new chemical properties to decide if new substances have been formed. The test for new chemical properties however, again involve the concept of chemical change, so it seemed like a circular argument.

Moreover, in the case of hydrogen chloride added to water, it seemed that the aqueous HCl formed has different chemical properties to the separate 'reactants' i.e., water and gaseous HCl. For example, the 'product' aqueous HCl would react with magnesium ribbon...
whereas each of the 'reactants' (water or gaseous hydrogen chloride) on its own would not.

Thus, it seemed that the criterion of new properties (which leads to the inference that new substances are formed) could be problematic.

What about the criterion of bond breaking and bond making? Some students mentioned that chemical change involved breaking of intramolecular covalent bonds, whereas physical change does not. Is this a satisfactory definition? It would then mean that melting of substances with giant molecular structures should be considered as chemical change. What about the breaking of ionic bonds - should this be included in the category of chemical change? If it does, then it means dissolving of ionic salts would be considered a chemical change. If it does not include the breaking of ionic bonds, then it would seem incomprehensive because the numerous substances with ionic bonds would not be covered in the definition.

Students also struggled with the concept of reversibility/irreversibility of chemical reactions. It seemed that at the lower levels, they had been taught that one distinction between a chemical change and a physical change is that the latter is easily reversible whereas the former is not. Then at A-levels, they were taught the concept of equilibria and so forth and were told that all chemical reactions are theoretically reversible, and that a large number are easily reversible!

Some students have struggled with all these difficulties, and have tried to make sense of it all by concluding that a chemical reaction is a change, any change, including a physical change, occurring in any chemical. Based on this definition, they have concluded that the melting of wax, for example, is a chemical reaction because it involves wax changing its physical state and because wax is a chemical. It seemed that implicit in this thinking is the use of the everyday understanding of the term "reaction" - e.g., that of "a response to some foregoing action or stimulus".
The dominance of everyday meanings of terms over their scientific meanings in the thinking of these students is not entirely surprising in view of the fact that older students, with even more exposure to formal chemistry instruction, have suffered from the same problem as reported by Ribeiro et al. (1990) in relation to final year university chemistry students' understanding of the term 'chemical reaction'. In addition to the possible confusion with the everyday meaning of the term 'reaction', there is also the likelihood of confusion with its meaning in physics (e.g., as used in Newton's Third Law of Motion) which is different to the meaning in chemistry. Sometimes, confusion between chemical and physical change can also arise from the inadvertent/inappropriate use of words by teachers. The following example, taken from an article in the Science Teacher,\(^1\) in which a teacher was sharing words of wisdom with other teachers: "Explain to your students that melting is always an endothermic reaction because the attractive forces holding the ions or molecules together in the solid phase must be overcome." In such an instance, if chemistry teachers themselves refer to melting as a reaction, it is no wonder that students also refer to melting and other changes in physical states as a chemical reaction.

These difficulties of students with concept of chemical versus physical change/reaction suggest that perhaps we, chemistry teachers as well as curriculum developers should review the way the concept of chemical change/reaction is introduced and developed in teaching and in curricula materials.

\(^{1}\)Hapkiewicz (1991)
8.7 SUMMARY OF CHAPTER

The study has shown that A-level chemistry students hold a wide range of alternative conceptions about the nature of chemical reactions. Whilst the interaction of different ACs in students' minds seems at first sight to provide an almost infinite range of understandings, this study has identified three main categories of alternative conceptions:

- ACs associated with naive chemistry

- ACs associated with nature of chemical bonds and energetics

- ACs associated with the driving force of chemical reaction.

As well as the inevitable interaction of ACs in students' minds, matters are made worse by the low level of ability of students to generalise across all events and to see each of the five events presented in terms of the same model of colliding particles, bond breaking, bond making and energy changes. The findings suggest that, in general, students were misled by perceptual clues, to perceiving a number of different types of reactions, each governed by a different set of process rules.

Questions are raised concerning the level of cognitive development required by students to integrate microscopic concepts into existing macroscopic frameworks.
CHAPTER 9

PROGRESSION AND NON-PROGRESSION AMONG STUDENTS IN THE STUDY

9.0 OVERVIEW

Progression is generally defined as the extent to which students' conceptions change to match those of scientists' views. One of the chief aims of instruction is to bring about progression. This chapter is aimed at examining the kinds of progression or non-progression shown by students in the period between the 2 interviews. The purpose is to derive some possible explanations behind progression or non-progression, which in turn could be used to inform teaching and perhaps curriculum development and implementation.

Section 9.1 seeks to answer some general questions on progression:

* What are various forms of progression that were shown by students?

* How do students progress in terms of KE scores across events and aspects?

* How do students progress in terms of number of ACs held?

* How do the schools differ in terms of progression?

Section 9.2 further examines the relationship between KE and AC scores at both U6 and L6 levels.

Section 9.3 examines the ACs in terms of their persistence at the U6 level.

Section 9.4 delineates and describes generally two groups of students; the top group comprising students who showed the most progression, and the bottom group comprising students who showed the least progression.
Section 9.5 examines the patterns of progression between the two groups in terms of KE scores and ACs held by event and aspect.

Section 9.6 explores and suggests some reasons why the top group of students progress more than the bottom of group students.

Section 9.7 discusses some possible reasons for increase in ACs between interviews.

Section 9.8 discusses the relationship between chemistry understanding (in terms of KE and AC scores) and the science subjects studied at GCSE.

9.1 FORMS AND PATTERNS OF PROGRESSION

In a broad sense, the progression shown by the study students was seen in various forms, such as:

* a change from responding, "I don't know" to a question, to being willing to offer explanations and theories, even if they turn out to be at variance with scientists' views. This means that an increase in the number of ACs held by a particular student is not necessarily indicative of regression or non-progression. Instead it could be taken as an indication of progression. Conversely, a smaller number of ACs revealed at the U6 level is not necessarily indicative of progression if it were the result of students becoming less motivated and less willing to speculate and theorise (eg., student E1, case II, Appendix M)

* a change from using macroscopic or vague explanations (or an unwillingness to use explanations which involve particles) to using explanations which involve particles and microscopic processes. This again means that an increase in the number of ACs is not necessarily indicative of regression or non-progression. Instead it could be taken as an indication of progression (eg., student P4, case III, Appendix M - at L6 she was unwilling or unable to use explanations on aspect B which involve particles; but this was changed at the U6 to include particles and microscopic processes).
- a change from anthropomorphic explanations to more objective explanations. (Eg. student R7, case I, chapter 12 - at the L6 on aspect D in events 4 and 5, used anthropomorphic explanations. At the U6, he changed to more objective explanations invoking the concept of entropy.)

- a change from viewing chemical change as involving an active causal agent acting on one or more passive substances to viewing it as involving the interaction of equal partners (in the terms of Brosnan, 1992). One example is student P2 who at the L6 said that the driving force in event 4 was "magnesium" and that in event 5 was "sodium" because both metals were viewed as reactive and hence active causal agents. At the U6 she appeared to have shifted from her view of unequal partners to that of equal partners when she said that the driving force in events 4 and 5 was "all the reactants being in contact with each other".

- the increase in the number of key elements (KEs) in a scientifically acceptable explanation included in the U6 response compared with the L6 response;

- a general reduction in the number of ACs held;

While recognising that there are various forms of progression, only the last two forms (change/increase in KE scores, abbreviated as 'T-PRO-KE'; and change/decrease in number of ACs counted, abbreviated as 'T-PRO-AC') will be examined more closely in this chapter.

(A full list of alternative abbreviations is given in the glossary of terms preceding chapter 1.)

Table 9.1 compares the students' responses associated with each of the 4 aspects measured over all 5 main events for the U6 and L6 interviews in terms of percentage of total possible KEs included in the average student's responses. The final column gives the difference between the L6 and U6 scores which represents a measure of progression between the two interviews.
Table 9.1

Aspects A to D: Percentage of key elements included in the average student's responses (over all students irrespective of school) in the U6 and L6 interviews and the difference in scores between the 2 interviews

<table>
<thead>
<tr>
<th>Aspect</th>
<th>U (n=48)</th>
<th>L (n=48)</th>
<th>U-L</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>84%</td>
<td>78%</td>
<td>6%</td>
</tr>
<tr>
<td>B</td>
<td>33%</td>
<td>9%</td>
<td>24%</td>
</tr>
<tr>
<td>C</td>
<td>36%</td>
<td>14%</td>
<td>22%</td>
</tr>
<tr>
<td>D</td>
<td>14%</td>
<td>9%</td>
<td>5%</td>
</tr>
</tbody>
</table>

From Table 9.1, it can be seen that the students performed best on aspect A and worst on aspect D at both U6 and L6 interviews. This indicates that on the whole, students did know what reactants and products were involved in the presented chemical changes, but were ignorant about the driving force behind the chemical change.

It can also be seen that the progression (U-L) were smallest for aspects A and D (6 and 5% respectively). However, the reasons behind these were very different.

On aspect A, it seemed that students had already acquired most of the KEs at the L6 level (i.e., aspect A was easy for them even at the L6 level. This fact is perhaps more obvious in Table 4.3 (chapter 4), which shows the number of KEs included in the average student's responses by school and by event.) so that little progression could be made at the U6.

Aspect D, in contrast was difficult for the students even at the U6 level, so that the progression was small.

Table 9.2 shows the mean progression scores by aspect by school with p values of significance.
Table 9.2 shows that there were significant differences between the schools on the progression scores on aspects A, B and C ($p \leq 0.05$). On aspect A, students from school P made significantly better progress than students from the other schools; on aspects B and C, students from schools R and P made significantly greater improvements.

Table, 9.3, which shows the mean progression (U-L) scores by event with $p$ values of significance.

### TABLE 9.2
MEAN PROGRESSION SCORES (U-L) BY ASPECT BY SCHOOL

<table>
<thead>
<tr>
<th>School</th>
<th>A-PROG-KE</th>
<th>B-PROG-KE</th>
<th>C-PROG-KE</th>
<th>D-PROG-KE</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.8</td>
<td>2.0</td>
<td>2.9</td>
<td>0.9</td>
</tr>
<tr>
<td>R</td>
<td>0.2</td>
<td>7.3</td>
<td>5.7</td>
<td>2.8</td>
</tr>
<tr>
<td>P</td>
<td>1.7</td>
<td>4.3</td>
<td>7.5</td>
<td>0.1</td>
</tr>
<tr>
<td>E</td>
<td>-0.5</td>
<td>1.7</td>
<td>3.1</td>
<td>0.7</td>
</tr>
<tr>
<td>S</td>
<td>0.8</td>
<td>3.6</td>
<td>3.3</td>
<td>0.8</td>
</tr>
<tr>
<td>$p$</td>
<td>.013</td>
<td>.000</td>
<td>.005</td>
<td>.077</td>
</tr>
<tr>
<td>Av-PROG</td>
<td>0.60</td>
<td>3.78</td>
<td>4.50</td>
<td>1.06</td>
</tr>
</tbody>
</table>

### TABLE 9.3
MEAN PROGRESSION (U-L) SCORES BY EVENT

<table>
<thead>
<tr>
<th>School</th>
<th>E1-PROG</th>
<th>E2-PROG</th>
<th>E3-PROG</th>
<th>E4-PROG</th>
<th>E5-PROG</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>1.3</td>
<td>1.1</td>
<td>2.0</td>
<td>0.7</td>
<td>1.3</td>
</tr>
<tr>
<td>R</td>
<td>2.8</td>
<td>4.3</td>
<td>4.4</td>
<td>2.9</td>
<td>1.7</td>
</tr>
<tr>
<td>P</td>
<td>2.3</td>
<td>2.7</td>
<td>3.0</td>
<td>3.0</td>
<td>2.6</td>
</tr>
<tr>
<td>E</td>
<td>1.3</td>
<td>1.2</td>
<td>1.6</td>
<td>0.8</td>
<td>0.1</td>
</tr>
<tr>
<td>S</td>
<td>1.4</td>
<td>2.8</td>
<td>2.6</td>
<td>0.9</td>
<td>0.7</td>
</tr>
<tr>
<td>$p$</td>
<td>.379</td>
<td>.018</td>
<td>.023</td>
<td>.007</td>
<td>.010</td>
</tr>
<tr>
<td>Av-PROG</td>
<td>1.82</td>
<td>2.42</td>
<td>2.72</td>
<td>1.66</td>
<td>1.28</td>
</tr>
</tbody>
</table>

198
Across events it can be seen that students in schools R and P generally made the most progression (for convenience they are referred to as the good schools in this thesis) whereas students in schools C and E generally made the least progression (schools C and E are referred to as the weak schools in this thesis). School S generally produced results which were intermediate between the good and the weak schools.

It can be seen that the largest progression was made in event 3, followed by events 2, then 1, 4 and 5.

As could be seen from Table 8.3, chapter 8, the students' L6 scores were highest in event 3 followed by events 3, then 4, 5 and 2 in that order. That the greatest progression was made in event 3 and say, not event 1, is understandable because in event 1 the L6 scores were already rather high (leaving less room for improvement compared with event 1 say) and it had not been explicitly covered in the A-level syllabuses. This is different to the case of event 2, which had been explicitly covered in the A-level syllabuses in connection with topics on combustion of alkanes as part of the organic chemistry syllabuses and also as part of thermochemical calculations in the physical chemistry sections in the syllabuses (This point had been verified by informal discussion with some of the teachers and students involved.).

That there is high progression in event 2 could be explained perhaps by the fact that the L6 scores were lowest for this event, leaving much room for improvement and that as students progressed on event 3, they tended to make similar progression as they moved towards using a common explanation/model for the 2 flames reactions involved (see section 10.2, chapter 10).

The low progression on events 4 and 5 reflects the difficulties students had in understanding the role of the solvent (or even that the solvent had a role at all) with the accompanying solvation effects and ionic equilibrium involved.
9.2 RELATIONSHIPS BETWEEN THE KE AND AC SCORES

9.2.1 PROCEDURAL ISSUES

In the investigation of relationship between the number and nature of ACs held it is recognised that because of the nature of the interview process, the number and nature of ACs revealed at the interviews were not exhaustive or comprehensive. This was due to a number of reasons:

1. Where the student was not provoked or probed into revealing their ACs. For example, in both the L6 and U6 interviews of student E3 and E17, when they both mentioned in the context of event 1 that copper would not undergo a chemical reaction when placed in a very hot bunsen flame, questions on aspects B, C and D were not presented to them. As a consequence, the number of ACs recorded would be lower than it should be.

2. Where students were less confident (eg, Case IV, student C10, Appendix M) or less enthusiastic (eg, Case II, student E1, Appendix M) than others, this researcher did not probe extensively in view of the possibility of "upsetting" these students and losing whatever rapport that had been established with them.

3. In some there were insufficient time to cover all aspects of event 5.

4. Where students seemed to lack domain specific knowledge or who seemed rather narrow-minded and deeply entrenched in certain views. In such cases, fewer ACs would be recorded compared with more speculative and/or imaginative students. Eg, a narrow minded interviewee could respond to the question on driving force by saying that "heat supplied is the driving force" would have just 1AC recorded; whereas a more speculative student could postulate and proffer several views, one for each event and ended up with 5 different ACs recorded on this aspect.
Thus, because of the above reasons, it must be noted that having a smaller number of ACs is not necessarily reflective of having a more sound understanding.

In the AC-counting procedure, in order to make allowances for cases where the interviewee had not been sufficiently provoked to articulate his/her views, the 14 different groups delineated under each of the aspects A to D in chapters 4 to 7 (see Appendix H for a full classification of ACs) were counted against the 3 larger, 1 to 3, described in section 8.5, chapter 8.

In counting the number of ACs in each of the categories 1 to 3, in a student's response, a master list was drawn up showing each student's identification code vis-a-vis the various ACs delineated against the 3 categories.

Any student who displayed an AC in any one sub-category was given a count of '1'. The maximum count for any sub-category is '1', i.e., essentially, the counting procedure involves considering whether there is either at least one AC in each sub-category revealed by the student or not; if the answer is 'yes', a count of '1' is made; if the answer is 'no' then a zero count is made. Thus, the maximum number of ACs which could be counted in each category 1 to 3 is '3' and the minimum is '0'.

The total count for all categories 1 to 3 is then taken as the number of ACs revealed.

Such a counting procedure then goes some way to alleviate the effect of unequal provocation of interviewees into revealing their ACs. It is considered a fairly reasonable procedure given that at the interview, practically all interviewees had at least one opportunity to reveal at least one AC associated with each of the subgroups.

To illustrate this point with respect to ACs in category 1, this interviewer-cum-researcher, had ascertained that over the duration of the interviews, there were at least one opportunity given for any interviewee to reveal his/her ACs associated with perceptual thinking (i.e., to reveal at least 1 AC in sub-category i); similarly, there were also at least one opportunity to reveal ACs associated with 'one-factor only' type reasoning (sub-category ii); and likewise, there were also at least one opportunity to reveal ACs associated with 'anything goes' in a chemical reaction (sub-category iii).

201
9.2.2 RESULTS OBTAINED

Based on this procedure described above, the total number of ACs thus counted against each student at the U6 and L6 interviews is set out in Appendix I. The mean numbers of ACs in each of the 3 categories for each school and at each level are presented in Appendix J.

The overall pattern of the progression of the study sample can be seen in the 4 scatterplots at Appendix K.1 to K.4; where TOT-L-KE (total KE score at L6) had been used as a base measure, and which were carried out via Minitab software.

<table>
<thead>
<tr>
<th>Plot</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>K.1</td>
<td>is the plot of TOT-U-KE versus TOT-L-KE;</td>
</tr>
<tr>
<td>K.2</td>
<td>is the plot of T-PRO-KE versus TOT-L-KE;</td>
</tr>
<tr>
<td>K.3</td>
<td>is the plot of T-PRO-AC versus TOT-L-KE;</td>
</tr>
<tr>
<td>K.4</td>
<td>is the plot of T-PRO-AC versus T-PRO-KE.</td>
</tr>
</tbody>
</table>

The correlation coefficients of various measures of KEs and ACs are shown in the following table 9.4.

**TABLE 9.4**

<table>
<thead>
<tr>
<th></th>
<th>TOT-U-KE</th>
<th>TOT-L-KE</th>
<th>T-PRO-KE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOT-L-KE</td>
<td>0.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-PRO-KE</td>
<td>0.83</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>T-PRO-AC</td>
<td>-0.57</td>
<td>-0.39</td>
<td>-0.40</td>
</tr>
</tbody>
</table>

From the K.1 plot, and the correlation coefficient it can be seen that there is a fairly strong relationship between TOT-U-KE and TOT-L-KE; that students who scored well at the L6 level did tend also to score well at the U6 level.
From the K.2 plot and the correlation coefficient between T-PRO-KE and TOT-L-KE, no strong relationship could be seen. However, when the points are separated by schools as it could be in the plots K.5 to K.9, only in 1 school (i.e., school R) there is a strong relationship between T-PRO-KE and TOT-L-KE.

The following table sets out for each school the correlation coefficient between various progression related measures:

i. PRO-KE and TOT-L-KE
ii. PRO-AC and TOT-L-KE
iii. PRO-KE and PRO-AC

<table>
<thead>
<tr>
<th>School</th>
<th>PRO-KE vs TOT-L-KE</th>
<th>PRO-AC vs TOT-L-KE</th>
<th>PRO-KE vs PRO-AC</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.58</td>
<td>-0.80</td>
<td>-0.65</td>
</tr>
<tr>
<td>R</td>
<td>0.96</td>
<td>-0.71</td>
<td>-0.57</td>
</tr>
<tr>
<td>P</td>
<td>-0.19</td>
<td>-0.36</td>
<td>-0.32</td>
</tr>
<tr>
<td>E</td>
<td>-0.20</td>
<td>-0.66</td>
<td>0.36</td>
</tr>
<tr>
<td>S</td>
<td>-0.33</td>
<td>-0.30</td>
<td>0.24</td>
</tr>
</tbody>
</table>

The above table shows that only for school R (at significance level ≤0.7) there was a strong positive correlation between the students total KE score at the L6 level and their progression shown at the U6 level. For the other 4 schools, it appears that TOT-L-KE is not predictive of progression.

On the next measure of progression, change in AC (PRO-AC), for schools R, C and E there are fairly strong relationships between the change in ACs and TOT-L-KE, suggesting that students with high TOT-L-KE were more likely to show progression by abandoning their ACs.
The figures in the last column of table 9.5 shows that only for school C there is a fairly strong negative relationship between the abandoning of ACs and the progression in KEs, suggesting that as ACs are abandoned, more KEs tended to be acquired.

As mentioned in chapters 8 and 12, overall students' progression on KE scores tend to come from aspects B, prediction of overall energy change and aspect C, how the chemical reaction takes place. More specifically, increase in KEs were due to the shift from using perceptually dominated thinking and macroscopic explanations (eg shifting from the view expressed in AC B1a: that a reaction has to be overall endothermic if heat is needed to bring it about) to using conceptual thinking and explanations which invoke microscopic particles and processes (i.e., reasoning in terms of bond breaking and bond making, and so forth, see case I, chapter 12, and cases II and III at Appendix M).

To examine further the relationship between the KE and AC measures at the U6 and L6 levels, the correlation between them are set out in Table 9.6.

### TABLE 9.6
CORRELATION COEFFICIENTS AMONG KE AND AC MEASURES
AT U6 AND L6

<table>
<thead>
<tr>
<th></th>
<th>TOT-L-KE</th>
<th>TOT-U-KE</th>
<th>TOT-L-AC</th>
<th>TOT-U-AC</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOT-L-KE</td>
<td>1.00</td>
<td>0.55</td>
<td>-0.11</td>
<td>-0.42</td>
</tr>
<tr>
<td>TOT-U-KE</td>
<td></td>
<td>1.00</td>
<td>-0.17</td>
<td>-0.63</td>
</tr>
<tr>
<td>TOT-L-AC</td>
<td></td>
<td></td>
<td>1.00</td>
<td>0.57</td>
</tr>
<tr>
<td>TOT-U-AC</td>
<td></td>
<td></td>
<td></td>
<td>1.00</td>
</tr>
</tbody>
</table>

The above results in Table 9.6 suggest that while the highest values are the direct relationships between TOT-L and TOT-U for both the KE and AC indices separately, there is also a significant cross-relationship between the TOT-L-KE and TOT-U-AC; and between TOT-U-KE and TOT-U-AC (refer to figure 9.1 below). In order to explore such links more carefully, partial correlation coefficients were calculated (using the procedure given in Minium (1978) p. 611) to remove the indirect effect of any third variables on the links between the pairs. In most cases, there was little change in the pair correlation. The
exceptions were presented in Table 9.7 and interpreted as follows:

TOT-L-KE to TOT-U-KE: Taking out the effect of TOT-U-AC reduces r from 0.55 to 0.40.

TOT-L-KE to TOT-U-AC: Taking out the effect of TOT-U-KE reduces r from -0.42 to -0.11.

TOT-U-KE to TOT-U-AC: Taking out the effect of TOT-L-KE changes r from -0.63 to -0.53.

TOT-L-AC to TOT-U-KE: Taking out the effect of TOT-U-AC changes r from -0.17 to +0.30 (a second order partial correlation coefficient, giving the link between TOT-L-AC and TOT-U-KE with simultaneous allowance for both the TOT-L-KE effects and the TOT-U-AC effects still gives the correlation at 0.30).

Figure 9.1
Any interpretation in terms of causal links must be speculative. In any case, where one of the pair precedes the other in time, there is greater certainty, so it may be said here that:

* The TOT-L-KE score influences the TOT-U-KE score although some of this may be associated with its effect in reducing the TOT-U-AC score.

* The TOT-L-AC score influences the TOT-U-AC score.

* There is little influence between TOT-L-AC and TOT-L-KE.

* The TOT-L-KE score has little influence on the TOT-U-AC score once its effect on the TOT-U-KE is taken into account.

* The TOT-U-KE score seems to be enhanced if the TOT-L-AC score is higher, provided a correction is first made for the link between TOT-L-AC and TOT-U-AC.

* A higher TOT-U-KE score is associated with a lower TOT-U-AC score, although a small part of this may be due to the influence of TOT-L-KE on both.

A plausible but speculative hypothesis is that TOT-U-KE causes the TOT-U-AC effect, rather than vice versa. This implies a model in which improvement in identification of key elements in a scientific explanation (KEs) helps to reduce the alternative conceptions (ACs), whilst those with more ACs at the outset are likely to have more at the end, they are also more likely to have higher KEs scores at the end. This latter peculiar feature may arise because a larger number of these in the lower sixth may be an indication of a more active and inquiring approach. A further implication is that once a student has acquired a scientific or "science-like" framework with which they can be comfortable then they are able to quickly abandon their alternative frameworks and alternative conceptions.
TABLE 9.7
PARTIAL CORRELATIONS ON TOT-KE AND TOT-AC SCORES AT U6 AND L6

<table>
<thead>
<tr>
<th></th>
<th>partial correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOT-L-KE to TOT-U-KE (minus TOT-U-AC)</td>
<td>0.40</td>
</tr>
<tr>
<td>TOT-L-KE to TOT-U-AC (minus TOT-U-KE)</td>
<td>-0.11</td>
</tr>
<tr>
<td>TOT-U-KE vs TOT-U-AC (minus TOT-L-KE)</td>
<td>-0.53</td>
</tr>
<tr>
<td>TOT-L-AC vs TOT-U-KE (minus TOT-U-AC)</td>
<td>+0.30</td>
</tr>
</tbody>
</table>

9.3 PERSISTENCE OF ACs AT U6

This section examines tries to answer the questions:

* What were the ACs which were most easily abandoned by students?
* What were the ACs which were most persistent or not easily abandoned?
* Among the ACs which were not easily abandoned, which were the ones with the higher frequencies of occurrence?

In answering these questions, the data in chapters 4 to 7 were examined, to yield the following 4 groups, i, ii, iii and iv of ACs (see Appendix H for descriptions of ACs) which are highlighted in Table 9.8.

Group i Transient ACs or ACs most easily abandoned

These ACs are defined as those which were abandoned by at least half of those who held them at the L6, and which were held by at least 4 students at the L6.
Group ii  
**Persistent ACs**

These ACs are defined as those not abandoned by at least half of those who held them at L6, and which were held by at least 4 students at L6.

Group iii  
**Median frequency persistent ACs**

These ACs are defined as those were held by at least 12 (25%) students at both U6 and L6.

Group iv  
**High frequency persistent ACs**

These ACs are defined as those which were held by at least 24 (50%) students at both L6 and U6.

**TABLE 9.8**

<table>
<thead>
<tr>
<th>AC GROUPS AND THEIR PERSISTENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group i - transient ACs</td>
</tr>
<tr>
<td>A1a;A1e;A2a;B1a;D2b</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

From table 9.8 it can be seen that the high frequency persistent ACs (group iv) were those associated with the nature of bonding and bonds, and the driving force of chemical reactions. More specifically, they relate to confusion between ionic and covalent bonding; confusion about the bonding associated with reactions in solutions and heat energy input as the causal agent of chemical change.
Next in order of difficulty (group iii) seemed to be those associated with the nature of chemical bonds (bond breaking releases energy and so forth), the role of water in reactions in solutions; driving force and ACs related to the dominance of perceptual thinking such as the everyday meaning of burning, and wax in a burning candle only melts and not burns.

ACs which were most easily abandoned (in decreasing numbers of students who abandoned them) are those related to perceptually dominated thinking or the use of macroscopic explanations for overall energy change (B1a); substantialisation of heat/flame (A1a); anthropomorphic explanations of chemical change (D2b); that burning in limited amount of oxygen produces carbon monoxide instead of carbon dioxide (A2a); that burning always produce carbon dioxide (A1e). [It must be noted that in most cases, these are abandoned for views which are closer to scientific views but not necessarily coincident with scientific views, as illustrated in the case of student P2 above.]

The abandonment of ACs related to the use of perceptually dominated thinking and/or macroscopic explanations accounts (to some extent) for the higher progression in events 3 and 2 in Table 9.3. In event 3, students progressed through shifting from using macroscopic to microscopic explanations of the overall changes thus acquiring KEs in the process; and in event 2, they progressed from using perceptually dominated thinking to using conceptual thinking about the burning of candle wax.

9.4 Delineation and General Description of the Top and Bottom Groups of Students

The purpose of this section is to focus more closely on the reasons or factors of progression by comparing and contrasting two groups of students, viz. the group which showed the most progression and the group which showed the least progression. Based on the scatterplots (Appendix K.1 to K.4) and the individual scores of students, it was thought pertinent to examine one third of the sample more closely (i.e., the top and bottom one-sixth of the group) for possible reasons behind progression and non-progression. To examine more than a third would mean a smaller separation between the groups which might mean that the differences between them would be less pronounced.

209
To examine less than a third might mean that the result might not be representative of the sample.

The following table 9.9 sets out the U6, L6 and progression scores (U-L) of the top group of students (those who showed progression of at least 17 KEs, which is the cut-off point for the top one-sixth).

TABLE 9.9
TOTAL KEs SCORED AT U6 AND L6 INTERVIEWS, AND IMPROVEMENT IN THESE SCORES FOR TOP GROUP STUDENTS

<table>
<thead>
<tr>
<th>Student</th>
<th>U6-total KE</th>
<th>L6-total KE</th>
<th>(U6-L6)total KE</th>
</tr>
</thead>
<tbody>
<tr>
<td>R7</td>
<td>43</td>
<td>15</td>
<td>28</td>
</tr>
<tr>
<td>P4</td>
<td>38</td>
<td>13</td>
<td>25</td>
</tr>
<tr>
<td>R1</td>
<td>33</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>P18</td>
<td>33</td>
<td>14</td>
<td>19</td>
</tr>
<tr>
<td>S7</td>
<td>32</td>
<td>13</td>
<td>19</td>
</tr>
<tr>
<td>C8</td>
<td>31</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>P10</td>
<td>30.5</td>
<td>13.5</td>
<td>17</td>
</tr>
<tr>
<td>R5</td>
<td>29</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>Total KE</td>
<td>269.5</td>
<td>106.5</td>
<td>163</td>
</tr>
<tr>
<td>KE/student</td>
<td>33.7</td>
<td>13.3</td>
<td>20.4</td>
</tr>
</tbody>
</table>

Another way of viewing progression or improvement is to examine if there is a reduction in the number of ACs held by these students.

The number of ACs in each category type counted according to the procedure in section 9.2 are presented in Table 9.10.
From Table 9.10 the average reduction of 2 ACs per student, with the simultaneous increase of 20.4KE per student points to the progression made. Of the 16 ACs abandoned at the U6, 5 are of AC1 (naive chemistry); 8 of AC2 (chemical bonding) and 3 of AC3 (driving force). This again reflects that most of the progression made by the entire sample was associated with aspects B and C.

The following tables 9.11 and 9.12 likewise set out the corresponding data for the bottom group of students.
TABLE 9.11
TOTAL KEs SCORED AT U6 AND L6 INTERVIEWS, AND DIFFERENCE IN THESE SCORES FOR BOTTOM GROUP STUDENTS

<table>
<thead>
<tr>
<th>Student</th>
<th>U6-total KE</th>
<th>L6-total KE</th>
<th>(U6-L6)total KE</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>24</td>
<td>24.5</td>
<td>-0.5</td>
</tr>
<tr>
<td>S1</td>
<td>21</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>C16</td>
<td>9</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>C10</td>
<td>11</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>E5</td>
<td>12</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>E17</td>
<td>13</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>S2</td>
<td>15</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>P16</td>
<td>20</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>Total KE</td>
<td>125</td>
<td>114</td>
<td>11.5</td>
</tr>
<tr>
<td>KE per student</td>
<td>15.6</td>
<td>14.2</td>
<td>1.4</td>
</tr>
</tbody>
</table>

TABLE 9.12
NUMBER OF ACs, U6 AND L6, AND NO. AND TYPES OF ACs ABANDONED BY BOTTOM GROUP STUDENTS

<table>
<thead>
<tr>
<th>St</th>
<th>AC1-U</th>
<th>AC1-L</th>
<th>AC2-U</th>
<th>AC2-L</th>
<th>AC3-U</th>
<th>AC3-L</th>
<th>(U-L) AC</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>-2</td>
</tr>
<tr>
<td>S1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>-2</td>
</tr>
<tr>
<td>C16</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>+2</td>
</tr>
<tr>
<td>C10</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>+1</td>
</tr>
<tr>
<td>E5</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>E17</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>S2</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>+1</td>
</tr>
<tr>
<td>P16</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>-2</td>
</tr>
<tr>
<td>Tot</td>
<td>13</td>
<td>14</td>
<td>22</td>
<td>21</td>
<td>11</td>
<td>14</td>
<td>-16</td>
</tr>
<tr>
<td>Av</td>
<td>1.6</td>
<td>1.8</td>
<td>2.8</td>
<td>2.6</td>
<td>1.4</td>
<td>1.8</td>
<td>-2.0</td>
</tr>
</tbody>
</table>
From Tables 9.10 and 9.12, top group students generally abandoned more ACs than the bottom group. While on average each top group student abandoned at least 1 AC in AC2 category (ACs associated with the process of bonding), in contrast no ACs in this category were abandoned. (It must be noted that the ACs counted according to the procedure in chapter 8 are not exhaustive, as is explained in the same chapter.)

9.5 PATTERN OF PROGRESSION AMONG THE TOP AND BOTTOM GROUP STUDENTS - SIMILARITIES AND DIFFERENCES

The pattern of progression by event of the top group students are shown in the next Table, 9.13.

**TABLE 9.13**

PROGRESSION (U6-L6) SCORES IN TERMS OF NUMBER OF KEs BY EVENT FOR TOP GROUP STUDENTS

<table>
<thead>
<tr>
<th>Event/Student</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total (KE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R7</td>
<td>5</td>
<td>7</td>
<td>6.5</td>
<td>6.5</td>
<td>3</td>
<td>28</td>
</tr>
<tr>
<td>P4</td>
<td>3</td>
<td>7</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>R1</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>P18</td>
<td>3.5</td>
<td>5.5</td>
<td>4</td>
<td>2.5</td>
<td>3.5</td>
<td>19</td>
</tr>
<tr>
<td>S7</td>
<td>3.5</td>
<td>5</td>
<td>5.5</td>
<td>3</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>C8</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>P10</td>
<td>5</td>
<td>0</td>
<td>3.5</td>
<td>4.5</td>
<td>4</td>
<td>17</td>
</tr>
<tr>
<td>R5</td>
<td>4.5</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>0.5</td>
<td>17</td>
</tr>
<tr>
<td>Average</td>
<td>3.9</td>
<td>4.8</td>
<td>4.6</td>
<td>4.3</td>
<td>2.8</td>
<td>20.3</td>
</tr>
</tbody>
</table>

Table 9.13 shows that the greatest progression made by this group is in events 2 and 3, followed closely by events 4 and 1.

The corresponding figures of improvement by event for the bottom group are set out in the next Table 9.14.

213
### TABLE 9.14

**PROGRESSION (U6-L6) SCORES BY EVENT FOR BOTTOM GROUP STUDENTS**

<table>
<thead>
<tr>
<th>Event/Student</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total (KE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>2</td>
<td>0</td>
<td>-1</td>
<td>-1.5</td>
<td>0</td>
<td>-0.5</td>
</tr>
<tr>
<td>S1</td>
<td>-1</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>-0.5</td>
<td>0</td>
</tr>
<tr>
<td>C16</td>
<td>0.5</td>
<td>0</td>
<td>1.5</td>
<td>-0.5</td>
<td>0.5</td>
<td>2</td>
</tr>
<tr>
<td>C10</td>
<td>1</td>
<td>0</td>
<td>3.5</td>
<td>-1.5</td>
<td>-1</td>
<td>2</td>
</tr>
<tr>
<td>E5</td>
<td>1</td>
<td>0.5</td>
<td>2.5</td>
<td>-1.5</td>
<td>-0.5</td>
<td>2</td>
</tr>
<tr>
<td>E17</td>
<td>0</td>
<td>-1</td>
<td>2</td>
<td>1.5</td>
<td>-0.5</td>
<td>2</td>
</tr>
<tr>
<td>S2</td>
<td>-0.5</td>
<td>0</td>
<td>2.5</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>P16</td>
<td>0</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Average</td>
<td>0.4</td>
<td>0.1</td>
<td>1.5</td>
<td>-0.3</td>
<td>-0.3</td>
<td>1.4</td>
</tr>
</tbody>
</table>

From Table 9.14 it can be seen that there is little progression generally; with slightly more progression shown in event 3 than the other 4.

### TABLE 9.15

**PROGRESSION (U6-L6) SCORES IN TERMS OF NUMBER OF KEs BY ASPECT FOR TOP GROUP STUDENTS**

<table>
<thead>
<tr>
<th>Aspect/Student</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>Total (KE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R7</td>
<td>2</td>
<td>9</td>
<td>10</td>
<td>7</td>
<td>28</td>
</tr>
<tr>
<td>P4</td>
<td>1.5</td>
<td>8.5</td>
<td>15</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>R1</td>
<td>0</td>
<td>8.5</td>
<td>7.5</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>P18</td>
<td>5.5</td>
<td>2</td>
<td>11</td>
<td>0.5</td>
<td>19</td>
</tr>
<tr>
<td>S7</td>
<td>0</td>
<td>6.5</td>
<td>7.5</td>
<td>5</td>
<td>19</td>
</tr>
<tr>
<td>C8</td>
<td>0</td>
<td>7</td>
<td>6.5</td>
<td>4.5</td>
<td>18</td>
</tr>
<tr>
<td>P10</td>
<td>0</td>
<td>5.5</td>
<td>11.5</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>R5</td>
<td>0</td>
<td>8</td>
<td>5</td>
<td>4</td>
<td>17</td>
</tr>
<tr>
<td>Average</td>
<td>1.0</td>
<td>6.9</td>
<td>9.3</td>
<td>3.1</td>
<td>20.4</td>
</tr>
</tbody>
</table>

Av. as % of total KE

- 11%
- 46%
- 46%
- 31%

214
From Table 9.15, top group students made similar improvements on aspect B and C. The low improvement on aspect A is due to the fact that they had already acquired almost full KEs at the L6 (see chapter 7); while that for aspect D is due to their poor grasp of the concept of driving force even at the U6.

### TABLE 9.16

**PROGRESSION (U6-L6) SCORES IN TERMS OF NUMBER OF KEs BY ASPECT FOR BOTTOM GROUP STUDENTS**

<table>
<thead>
<tr>
<th>Aspect/Student</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>Total (KE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>0</td>
<td>0.5</td>
<td>-1</td>
<td>0</td>
<td>-0.5</td>
</tr>
<tr>
<td>S1</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>-3</td>
<td>0</td>
</tr>
<tr>
<td>C16</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>C10</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>E5</td>
<td>-1</td>
<td>1.5</td>
<td>1.5</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>E17</td>
<td>-1</td>
<td>1.5</td>
<td>1.5</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>S2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>P16</td>
<td>0</td>
<td>-0.5</td>
<td>2.5</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Average</td>
<td>-0.2</td>
<td>0.9</td>
<td>1.1</td>
<td>-0.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Av. as % of total KE</td>
<td>-2%</td>
<td>6%</td>
<td>5.5%</td>
<td>-4%</td>
<td></td>
</tr>
</tbody>
</table>

From Table 9.16 it can be seen that the bottom group, in contrast to the top group, made hardly any improvement on the aspects.

### 9.6 SOME POSSIBLE REASONS WHY TOP GROUP PROGRESS MORE THAN THE BOTTOM GROUP

This section examines the top and bottom groups in terms of the kinds of ACs held by both groups of students at the L6, and the extent to which these were relinquished or abandoned at the U6 level. For the purpose of discussion in this chapter and elsewhere in this thesis, an AC which is subscribed to or revealed by at least one top or bottom group student, at both U6 and L6 shall be referred to as a 'persistent' AC.
The search for persistent ACs among the top and bottom group students was carried out systematically by going through the list of ACs associated with each of the aspects A to D, described in chapters 4 to 7, and picking out ACs which were subscribed to by at least one top or bottom group student, at both U6 and L6.

Table 9.12 sets out the persistent ACs which were common to least half of either the top or bottom group; it also shows the number of students in each group which held the AC only at the L6, i.e., abandoned it.

**TABLE 9.17**

INCIDENCE OF COMMON PERSISTENT ACs IN TOP AND BOTTOM GROUPS AND INSTANCES OF ABANDONMENT

<table>
<thead>
<tr>
<th>Persistent ACs</th>
<th>Top (U+L)</th>
<th>Top (L only)</th>
<th>Bottom (U+L)</th>
<th>Bottom (L only)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B2a: chemicals give out energy</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>B3a: bond breaking release energy</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>B3c: energy needed to break and make bonds</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>C2a: confusion bet. ionic &amp; covalent bonding</td>
<td>2</td>
<td>5</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>C3a: ionic bonds still exist</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>C3b: preferential attract.</td>
<td>2</td>
<td>5</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>C3c: HCl split up evenly</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>C3d: H2O plays no sig. part</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>D1a: driving force is heat input</td>
<td>4</td>
<td>3</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>D1b: driving force is internal energy</td>
<td>3</td>
<td>0</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Total students</td>
<td>18</td>
<td>26</td>
<td>56</td>
<td>5</td>
</tr>
</tbody>
</table>

Note: There is no column corresponding to number of students who revealed an AC only at the U6 and not L6 because there was only two such instances.

From the above table, it can be seen that all 10 persistent ACs were common to between 4 and 8 bottom group students; this is in contrast with the top group. For the top group, with the exception of AC D1a, 'driving force is heat input', all the other 9 persistent ACs were common to between 1 and 3 students, i.e., less than half top group students.
From the figures at the bottom row of the table, a comparison between the incidence of the persistence of the ACs among, as well as the abandonment by, the 2 groups can be made. It can be seen that while the 10 ACs were persistent in 18 instances among the top group; they were persistent in 56 instances among the bottom group. Also the 10 ACs were abandoned in 26 instances by the top group students, and in only 5 instances by the bottom group.

More specifically, it can be inferred that the bottom group students could have been hindered in their progression in learning about the nature of chemical reactions by suffering from persistent ACs related to concepts such as: energy involved in bond breaking and making; bonding, especially the difference between covalent and ionic bonding; the solvation effect of water in the dissolution of ionic salts into free ions; the redox nature of acid-metal reaction, and the driving force of chemical reactions.

One possible explanation for the persistence of one cluster of ACs among the bottom group students (and not the top group) could be that many of the bottom group students (at least 4, see section 5.3, chapter 5) were viewing the chemical bond as a kind of physical link, a "joint of some sort" in the words of one student (ie it is substantialised as matter process), which requires energy both to break and to make (AC B3c). However, during the bond breaking process, energy is released (AC B3a). (It appears that in some cases, the bond is thought of as almost analogous to a physical bridge, which needs energy both to construct it and to start the process of taking it apart; and during the process when the bridge is falling apart, energy is released.)

The conception of a chemical bond as a physical link in the students' alternative frameworks also explains why ionic bond in the sense defined by the chemist could not be assimilated. This then results in the confusion between ionic and covalent bonding (AC C2a). It must be noted while some of the bottom group students could articulate that the bond comprises "a pair of electrons" (which in itself is at variance with the scientific view because of its incompleteness with respect to covalent bonds and it does not apply to bonds such as ionic ones), it seems to this interviewer-researcher that both views of the bond (ie as a physical link and as a pair of electrons) coexist in their conceptual frameworks.
This conception of the bond as a physical link also renders it difficult to understand how the link could be broken by the dissolving process (AC C3a). It also leads to the inference that heat is the active causal agent of chemical change since heat is both necessary and sufficient to break and make bonds (AC D1a).

Another alternative framework which seemed to be held by some of the bottom group students relates to the underlying idea that some chemicals, i.e., the reactive ones are capable of releasing their internal energy (AC B2a) which is then used to break and make bonds and resulting in chemical reactions (AC C3b and AC C3c). This means that internal energy of chemicals are viewed as the driving force (AC D1b). In this conception, then the solvent tends to be ignored or be regarded as passive.

It must be noted that while it appears from Tables 9.10 and 9.12, and 9.9 and 9.11 that at the L6, there were no significant difference between the top and bottom groups in terms of number of KEs scored and ACs counted.

However, it must be remembered that because the numbers of ACs counted and recorded according to the procedure in chapter 8 are not exhaustive, another count of ACs was done. This second counting was just a straightforward counting. Each time it was ascertained that an AC is held with respect to at least one event, it was counted against the student. Each AC is counted once even if it was used more than once, i.e., applied in more than one event.

The following table sets out the actual number of ACs thus counted for each student in the top and bottom groups.
TABLE 9.18

ACTUAL NUMBER OF ACs HELD BY TOP AND BOTTOM GROUPS AT U6 AND L6

<table>
<thead>
<tr>
<th>Top group</th>
<th>U-AC</th>
<th>L-AC</th>
<th>(U-L)</th>
<th>Bottom group</th>
<th>U-AC</th>
<th>L-AC</th>
<th>(U-L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R7</td>
<td>5</td>
<td>13</td>
<td>-8</td>
<td>E1</td>
<td>8</td>
<td>13</td>
<td>-5</td>
</tr>
<tr>
<td>P4</td>
<td>6</td>
<td>8</td>
<td>-2</td>
<td>S1</td>
<td>15</td>
<td>19</td>
<td>-4</td>
</tr>
<tr>
<td>R1</td>
<td>5</td>
<td>10</td>
<td>-5</td>
<td>C16</td>
<td>14</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>P18</td>
<td>6</td>
<td>13</td>
<td>-7</td>
<td>C10</td>
<td>22</td>
<td>20</td>
<td>+2</td>
</tr>
<tr>
<td>S7</td>
<td>8</td>
<td>11</td>
<td>-3</td>
<td>E5</td>
<td>15</td>
<td>13</td>
<td>+2</td>
</tr>
<tr>
<td>C8</td>
<td>14</td>
<td>13</td>
<td>+1</td>
<td>E17</td>
<td>7</td>
<td>15</td>
<td>-8</td>
</tr>
<tr>
<td>P10</td>
<td>5</td>
<td>19</td>
<td>-14</td>
<td>S2</td>
<td>15</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>R5</td>
<td>5</td>
<td>18</td>
<td>-13</td>
<td>P16</td>
<td>8</td>
<td>9</td>
<td>-1</td>
</tr>
<tr>
<td>TOT.</td>
<td>54</td>
<td>105</td>
<td>-51</td>
<td>TOT</td>
<td>104</td>
<td>118</td>
<td>-14</td>
</tr>
<tr>
<td>Av.</td>
<td>6.8</td>
<td>13.1</td>
<td>-6.4</td>
<td>Av.</td>
<td>13.0</td>
<td>14.8</td>
<td>-1.8</td>
</tr>
</tbody>
</table>

From table 9.18 it can be seen that while both groups had about the same number of ACs at the L6 level, students in the top group abandoned more ACs at the U6 level (see cases I in chapter 12 and case II in Appendix M).

The next Table 9.19 shows the science subject taken at GCSE by students in both top and bottom groups; and the grades scored by them.
An examination of the GCSE subjects and grades revealed that in the top group, 3 students took chemistry as a single science subject at GCSE, each scoring an 'A' grade vis-à-vis 2 bottom group students who scored a 'B' and 'C' between them. The rest of the students took coordinated science at GCSE. The 5 top group students scored 4'A's and 1'C'; the remaining 6 bottom group students scored 5'B's and 1'A'. The overall higher grades scored at GCSE suggest that the top group students might have stronger backgrounds or prior knowledge in chemistry than those in the bottom group, which in turn suggest that top group students having a more sound background in chemistry might benefit more from increased chemistry instruction; and would abandon ACs more quickly as more KEs learned. Whilst these results may be thought of as hardly surprising, they do raise the question as to whether or not some subjects (for example, chemistry) demand a relatively higher grade of entry than other subjects. This conjecture is discussed further under areas for further research in chapter 13.

Another factor which could explain progression or its lack is the school effect. As seen in previous chapters, schools R and P seemed to contribute significantly more to students' learning than the other three schools. As mentioned in Appendix L-5, this researcher noted that schools P and R seemed to provide a more supportive and challenging environment
for student learning; which could affect student motivation and confidence in learning which in turn affects the quality of learning outcomes.

The factors affecting progression discussed here are speculative, and needs to be more closely examined in future studies (see chapter 13).

Further discussion of the relationship between chemistry understanding and science subjects taken at GCSE is at section 9.8. Also more specific details on the relationship between the holding of ACs and the acquisition of KEs are presented in the case studies, I to IV, chapter 12 and Appendix M.

9.7 DISCUSSION REGARDING POSSIBLE REASONS FOR INCREASE IN ACs BETWEEN INTERVIEWS

As identified in 9.1 above, there were many cases identified where new ACs were revealed in the U6 interview that were not revealed at L6. These are not, in general, regarded as evidence of regression; rather they should generally be regarded as evidence of progression as the students experiment with new conceptual ideas and often fail to get the concept right during the early stages.

At one level, these increases reflect a move from the student simply not knowing and therefore not presenting the opportunity to reveal ACs to a position of offering theories and explanations which in many cases are erroneous as evidenced by the ACs identified.

At a more refined level, increases in revealed ACs reflect the transition from "naive" chemistry to "scientist's" chemistry as evidenced, for example, by the change from using perceptual/macroscopic to conceptual/microscopic reasoning. This change is illustrative of the everyday and scientific explanations of Brosnan (1992) whilst the process is akin to traversing the bridge between the student's world and the scientist's world as suggested by Black and Simon (1992).

This increase in ACs may be akin to the U-shaped type developmental curve identified by previous researchers (e.g., Strauss, 1977; Holding, 1987). Here students seemed to
have applied the new knowledge they have learned at the U6 to the wrong context and/or seemed to have abandoned concepts which have served them well at the L6. It seemed as though the new knowledge had not been properly differentiated from their existing knowledge and not properly integrated, and was allowed to colour or to disorientate their existing conceptual frameworks. From the perspective of Nisbet and Koss (1980), based on their "vividness criterion" it seemed that new knowledge is fresh in students' minds (ie stored in the short term memory, and thus easily accessed) and recalled in the process of explaining phenomena.

Examples of these could be seen in the case studies, I in chapter 12 and II in Appendix M. An instance of this was when the precipitation reaction involving aqueous sodium chloride and aqueous lead nitrate was no longer viewed as a simple ionic reaction between Cl\(^-\) and Pb\(^{2+}\) to form PbCl\(_2\) but as a nucleophilic reaction involving some partial positive charge on the 'Na' of NaCl which attacked the negatively charged nitrate.

From these instances, it could be seen often the process of acquiring new KEs is accompanied by the acquisition of new ACs, which in turn lead to more new ACs. What this means is that there is no simple direct relationship between KEs and ACs, ie it is not possible to infer that the acquisition of new KEs would naturally result in fewer number of ACs.

From another perspective, perhaps this increase in ACs or apparent regression which is seen in so many instances is the natural consequence of learning - of acquiring knowledge in unconnected bits and pieces in the early stage of learning (di Sessa, 1988), so that they often recall various different bits of knowledge at different times, presenting inconsistencies or apparent regression as in this case.

Another possibility is that the apparent regression could be the result of selective inattention - the fact that the interviewee has chosen to ignore old knowledge and to construct explanations based on new knowledge learned. As suggested by Reif and Larkin (1991), perhaps students do not appreciate the goals of science and hence do not appreciate the need to formulate a coherent explanation.
From yet another perspective, the apparent regression could perhaps be understood as the manifestation of the disequilibrium process, which is transitory to achieving accommodation and equilibrium again (Furth, 1981).

9.8 RELATIONSHIP BETWEEN CHEMISTRY UNDERSTANDING AND SCIENCE SUBJECTS STUDIED AT GCSE.

In view of the prevalence of the number of category 1 ACs (ie associated with naive chemistry and the possible linkage between the type of science subjects studied at GCSE and students' progression suggested in section 9.6, it is thought pertinent to examine if there is any significant difference in the number of ACs held in each category (in particular, in AC1 category - naive chemistry) between the 17 students in the study sample who took chemistry as a single science subject and the rest of the sample, ie 31, who took coordinated science. Thus, the one way analysis of variance is performed via Minitab software on the number of ACs in each category 1 to 3 by science subject taken at GCSE (ie chemistry as a single science subject versus coordinated science).

The mean number of ACs in each AC category held by each group of students at U6 and L6 and the p values of significance are set out in Table 9.20.

<table>
<thead>
<tr>
<th>Subj</th>
<th>AC1-U</th>
<th>AC1-L</th>
<th>AC2-U</th>
<th>AC2-L</th>
<th>AC3-U</th>
<th>AC3-L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chem (n=17)</td>
<td>0.71</td>
<td>1.12</td>
<td>1.59</td>
<td>2.12</td>
<td>1.65</td>
<td>1.76</td>
</tr>
<tr>
<td>Coord sc (n=31)</td>
<td>1.52</td>
<td>1.71</td>
<td>2.26</td>
<td>2.45</td>
<td>1.39</td>
<td>1.55</td>
</tr>
<tr>
<td>p</td>
<td>.002</td>
<td>.023</td>
<td>.025</td>
<td>.112</td>
<td>.141</td>
<td>.313</td>
</tr>
</tbody>
</table>

The data in Table 9.20 reveals that at both U6 and L6 levels, there was a significant difference (≤0.05) in the number of category 1 ACs (AC1) held by the 2 groups of
students. The smaller p value at the U6 also suggests that the difference between the 2 groups became greater with increased formal instruction.

This suggests that the students who took coordinated science at GCSE tended to have more ACs associated with naive chemistry compared to those who took chemistry as a single subject (This difference was even more obvious when the actual number of ACs are considered in place of these condensed ACs which had been counted according to the procedure set out in section 9.2)

The data also reveals while at the L.6 level, there was no significant difference between the 2 groups of students in terms of the number of category 2 ACs held; at the U6 level with increased formal instruction, the gap between them widened, so that the difference became significantly different. This is in line with the suggestion made in section 9.6 that with increased formal instruction, students with a stronger background in chemistry were more likely to abandon ACs (those associated with naive chemistry and with chemical bonds and the process of bonding).

It is interesting to note that students who did chemistry at GCSE had more category 3 ACs (ie those associated with driving force). This had been reflected in the interview process (and documented in section 7.3, chapter 7) where these students (more so than those who took coordinated science, who tended to say "I don't know" or who avoided the mentioning of the term 'entropy' completely) seemed to be more willing to speculate on driving force and the associated concept of entropy; thus revealing more new ACs associated with entropy.

The following Table 9.21 sets out the corresponding data on total KE scores at U6 and L6 (TOT-U-KE and TOT-L-KE), and progression (U-L) scores of the 2 groups of students, with p values of significance.
TABLE 9.21
MEAN TOTAL U6 AND L6 AND PROGRESSION SCORES IN TERMS OF KEs

<table>
<thead>
<tr>
<th>Subj</th>
<th>TOT-U-KE</th>
<th>TOT-L-KE</th>
<th>(U-L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chem (n=17)</td>
<td>26.2</td>
<td>15.1</td>
<td>10.9</td>
</tr>
<tr>
<td>Coord sc (n=31)</td>
<td>19.9</td>
<td>11.4</td>
<td>8.5</td>
</tr>
<tr>
<td>p</td>
<td>.009</td>
<td>.005</td>
<td>.216</td>
</tr>
</tbody>
</table>

The data in Table 9.21 reveals that the chemistry group already started with significantly higher scores at the L6 level. With formal instruction, both groups progressed (there were no significant differences in the progression scores) in parallel so that at the U6 there was still significant differences between their total KE scores.

What the analysis and discussion here seemed to suggest is that where chemistry had been taken at GSCE instead of coordinated science, more KEs and less ACs tended to be held at the U6. However, further research is needed to verify this suggestion.

9.9 SUMMARY OF CHAPTER

With 2 exceptions (one student who had clearly lost all interest in the subject and one who was exceedingly complacent and not perceiving a need to progress), all students made progress as measured by an increase in KE scores.

In general students were progressing from using naive reasoning to more scientific reasoning. Whilst many ACs were being abandoned, one consequence of this transition was the generation of new ACs as new concepts were incorrectly formulated or new knowledge was incorrectly assimilated into the students' own personal reference models.

This predilection to generate new ACs during the learning process highlights the need for more feedback between student and teacher in order to prevent new ACs holding back the student's progression and to prevent the generation of further ACs as the students conceptual model becomes further confused.
The major area that continued to cause problems at U6 level (as evidenced by persistent ACs) for these students was in understanding the detailed nature of chemical bonds, the confusion between ionic and covalent bonding and the energetics involved, and the driving force of chemical reaction. This point is discussed further in chapter 13.

A tentative relationship between progression and subjects studied a GCSE was revealed; this requires further empirical investigation to validate.
CHAPTER 10

CONSISTENCY AND INCONSISTENCY OF STUDENTS' VIEWS ACROSS EVENTS

10.0. INTRODUCTION

As discussed in chapter 3, the purpose of having a broad coverage in this study is to provide various opportunities for students to articulate their understandings of this very foundational area in chemistry and to enable examination of consistency of students' ideas across different contexts.

Research on students' consistency of ideas as discussed in chapter 2 has produced conflicting evidence. On the one hand, as reported by Song and Black (1991), there is considerable research evidence that performance in science related tasks is related to task context whilst, on the other hand, Driver (1989) in her review of this subject poses: "One open question is the extent to which children's conceptions are genuinely 'theory-like', that is, having a coherent internal structure and being used consistently in different contexts."

These two views need not be considered as separate views on the same continuum; the degree to which an AC will be used in a 'theory like' manner may be a reflection of the extent to which a student perceives one group of tasks to be of a common type whilst a second group of tasks may be perceived to form a second distinct type (whilst the scientist would declare all the tasks to be realisations of the same generic model).

The purpose of this chapter is thus to provide some evidence and insights on the consistency or otherwise of students' ideas across contexts. This will be based on analysis of U6 interviewees' responses on aspects B and D. The reason for focusing on the U6 responses only is on the basis that at the U6, with additional exposure to formal chemistry, students consistencies should be more pronounced and measurable. (However, future studies based on the L6 data collected could examine the pattern and progression in students' consistency over the period between the two interviews.) The reason for omitting students' responses on aspects A and C from this analysis is because of the more
event specific nature of the KEs associated with them, which render them unsuitable for this analysis.

Section 10.1 discusses consistency of students' ideas associated with aspect B, overall energy change.

Section 10.2 discusses consistency of students' ideas associated with aspect D, the driving force of chemical change.

Some conclusions are discussed in section 10.3

10.1 CONSISTENCY OR INCONSISTENCY IN RESPONSES ON ASPECT B, OVERALL ENERGY CHANGE

From a chemist's point of view, responses in all 5 events should be similar, i.e., each reaction is overall exothermic, the reason being that stronger bonds were being made than broken, so that energy released in bond making is more than enough to compensate for energy absorbed in bond breaking.

In examining the consistency of ideas across events with respect to aspect B, each student's U6 response in each event is placed into one of 5 categories according to the criteria shown in table 10.1.
TABLE 10.1
SUMMARY OF CATEGORIES AND CRITERIA USED FOR CONSISTENCY ANALYSIS FOR ASPECT B

<table>
<thead>
<tr>
<th>Category</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>&quot;science-like&quot; framework overall exothermic, more/stronger bonds made than broken.</td>
</tr>
<tr>
<td>ii</td>
<td>AC B3A overall exothermic, more bonds broken than made, ie direction of energy change misconceived.</td>
</tr>
<tr>
<td>iii</td>
<td>overall endothermic</td>
</tr>
<tr>
<td>iv</td>
<td>no energy change</td>
</tr>
<tr>
<td>v</td>
<td>no response, no chemical reaction, &quot;don't know&quot;</td>
</tr>
</tbody>
</table>

Note: "science like" means incorporating some or all aspects of the scientific view.

For examples of the allocation to categories, refer to the case studies in chapter 12 and Appendix M:
* cases I and III, events 1 to 5 - category i;
* case II, events 1,3,4,5 - category i; event 2 - category iii;
* case IV, events 1,3,4 and 5 - category ii; event 2 - category iii.

CONSISTENCY OF RESPONSES AT GROUP LEVEL

The following table 10.2 shows the number of students allocated into each of categories i to v by event. This table gives some indication of the consistency with which ideas in categories i to v were used across the 5 events by the group as a whole. However, it gives no indication of the consistency with which the different ideas in categories i to iv were used in different events by individuals (The question of consistency at the individual level is dealt later in this section).
Consistency on Aspect B: Distribution of Students by Event and by Category

<table>
<thead>
<tr>
<th>Category</th>
<th>Event 1</th>
<th>Event 2</th>
<th>Event 3</th>
<th>Event 4</th>
<th>Event 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>16</td>
<td>20</td>
<td>25</td>
<td>24</td>
<td>16</td>
</tr>
<tr>
<td>ii</td>
<td>7</td>
<td>19</td>
<td>19</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>iii</td>
<td>22</td>
<td>7</td>
<td>4</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>iv</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>v</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>

From Table 10.2, it can be seen that on aspect B, at best, between 40% to 50% of the group were using the "science like" framework (category i) across events 2, 3 and 4; and at best slightly less than 40% were using the alternative framework B3a (category ii) in events 2, 3 and 4.

It also shows that nearly half of the group thought the reaction in event 1 was overall endothermic for one reason or another.

The extent to which there is consistency of ideas across events is examined below.

Consistency of Responses Amongst Individuals

The consistency of responses at the individual level was measured by counting the number of students holding the same 'framework' (ie belong to the same category) across, firstly, the 5 events; and then across 2 subsets of reactions, viz. across events 1 to 3, the three combustion reactions and across events 4 and 5, the reactions in solutions. The results are presented in Table 10.3.
TABLE 10.3

CONSISTENCY OF STUDENTS USING IDEAS ASSOCIATED WITH ASPECT B ACROSS THE SET OF COMBUSTION REACTIONS AND REACTIONS IN SOLUTIONS

<table>
<thead>
<tr>
<th>Category</th>
<th>Events 2&amp;3 only</th>
<th>Events 1 to 3 only</th>
<th>Events 4&amp;5 only</th>
<th>All Events 1 to 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>20</td>
<td>11</td>
<td>14</td>
<td>7</td>
</tr>
<tr>
<td>ii</td>
<td>14</td>
<td>5</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>iii</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>iv</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total no.</td>
<td>37</td>
<td>19</td>
<td>24</td>
<td>11</td>
</tr>
</tbody>
</table>

In table 10.3, the term consistency means that a framework is used with a degree of commonality to explain the appropriate group of events.

From table 10.3, the following deductions can be made:

a) 37 students (77% of the total) were able to apply a framework (either scientific or alternative) consistently over the two 'flame' reactions in events 2 and 3. Of these, 19 (40% of the total) were able to extend their use of the framework over event 1, ie 40% of the students consistently used a common framework to explain combustion reactions.

b) 24 students (50% of the total) were able to apply a framework consistently over the two reactions in solution in events 4 and 5.

c) 11 students (23% of the total) were able to apply a common framework over all 5 events.

d) The equivalent percentages for application of a scientific framework are: 42% of students with respect to events 2 and 3, 23% of students with respect to events the combustion reactions in events 1 to 3, 30% of students with respect to the reactions in solution in events 4 and 231
5,
15% of students with respect to all 5 events.

In addition to the above, 4 students were identified who had no clear alternative frameworks at all, i.e. they revealed completely different ACs over all 5 events.

These results show that whilst, in general, frameworks are used consistently over events, their use is limited by what are perceived to the boundaries of commonality between types of events; for example, the burning of copper not always being seen as combustion in the same way as the two flames and the reactions in solution being seen as a different type of chemistry to combustion. This supports the view of Clough and Driver (1986) that "tasks which seemed similar to scientists may not appear that way to students".

10.2 CONSISTENCY OR INCONSISTENCY RELATED TO ASPECT D, WHY THE REACTION WAS THOUGHT TO HAVE TAKEN PLACE

On aspect D, as mentioned in chapter 7, there are a limited number of common frameworks identified, each associated with an AC, viz.:

D1a: heat as causal agent;
D1b: internal energy of chemicals;
D2a: difference in reactivity;
D3a: water as causal agent.

Besides these frameworks, there were a small number of responses which were closer to the scientific framework in that they incorporate some correct elements of the chemical thermodynamics involved, but which were somehow lacking in comprehensiveness or including some small points of confusion about the concept of entropy. These included responses such as:

* "becoming more stable" - (see case II, Appendix M);
* "heat, then becoming more stable";
* "increase in entropy of the system" (see case I, chapter 12);
"to have less entropy..more order".

For convenience these were grouped together as "science-like frameworks".

To examine the consistency of students' ideas with respect to the use of each of these frameworks, the number of students using each framework by event is presented in table 10.4.

<table>
<thead>
<tr>
<th>Framework</th>
<th>Event 1</th>
<th>Event 2</th>
<th>Event 3</th>
<th>Event 4</th>
<th>Event 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1a: Heat</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>D1b: Internal energy</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>D2a: Difference in reactivity</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>D3a: Water</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>'science-like framework'</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>no response, don't know, other</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>response</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The consistency of responses at the individual level was measured by counting the number of students holding the same 'framework' across, firstly, the 5 events; and then across 3 subsets of reactions, viz.

* across events 1 to 3, the three combustion reactions;
* across events 4 and 5, the reactions in solutions;
* across events 2 and 3, the two flames.

The results are set out in the following table 10.5.
The results in Table 10.5 shows that only 17 students (35%) appeared to be using the same framework across all 5 events; whereas across the 3 events where flames were present, the consistency increased to 100%. In events 4 and 5 which both involved solutions, probably because the similarity was not as obvious to the students as in the case of events 1 to 3, the consistency dropped to 71%.

On a broader level, the frameworks associated with ACs D1a, D1b, D2a and D3a could all be viewed as essentially the same, in that the underlying thinking is that there is an active causal agent in chemical change - in D1a, it is heat; D1b, it is the internal energy of chemicals; D2a, it is the differential reactivity or attraction between chemicals; and D3a, it is water, the solvent. Viewed on this broad level, it could be inferred that practically all the students except the 4 who did not have a chance to respond to event 5 were consistent across events.

It was interesting to note that in aspect D, there appeared to be a higher degree of consistency in the use of alternative frameworks than 'science-like' frameworks. This result contrasts to that found with aspect B where a higher proportion of students were seen to be using the accepted scientific view. As discussed elsewhere in this thesis, students performed consistently worse on aspect D and this appears to be related to the low level of emphasis placed on entropy by teachers. The majority of students therefore held only vague and largely pre-formal views on the matter of entropy; this finding appears to be
in line with the finding reported by Engel (1982) that the consistency in the use of alternative frameworks is more evident in phenomena where there are a limited number of frameworks and where these are intuitive in nature.

Among the reasons for the high degree of consistency in the use of frameworks with respect to aspect D was that the idea of an active causal agent (the experiential gestalt of causation, in the terms of Andersson, 1986b) had been inculcated very early in the students' everyday life. At the same time, there appeared to be no strong formal instruction to counter this idea. (That the aspect on driving force involving the concept of free energy and entropy had not been emphasised or had been regarded either as less important or beyond the grasp of the students had been suggested by some of the teachers involved.)

In contrast, there were no similar deeply-entrenched, intuitive frameworks associated with aspect B. At the same time, the scientific view which pertains to aspect B had been deemed as important by teachers (this point had been verified with the teachers concerned) and hence taught and emphasised throughout the A-level course. (In the study schools, as verified with the teachers, thermochemical calculations involving the heats of combustion of alkanes and heats of reactions in solutions had been covered early in the L6, and emphasised throughout all aspects of chemistry - organic, physical and inorganic.)

This means that the scientific view associated with aspect B had been accepted more widely by students. It was only in a minority of cases (4 students), where it seemed, because of the persistence of alternative frameworks (eg AC B3a) or preconceptions, this scientific view had not been received at all and these students used their own ACs consistently across the 5 events.

However, in a large number of cases (22 students), the scientific view appeared to be used in some events but not in others (eg there were 4 students who used the accepted frameworks in events 2, 3, 4 and 5 but not in event 1, where the reaction was thought to be overall endothermic because without heat, the reaction would not take place). This seemed to suggest that these 22 students were in a transitional state to using the accepted framework more consistently and widely. In the terms of Black and Simon (1992) they have embarked on the bridge which joins the pupils' country to the scientists' country. In
contrast the 4 students mentioned in the preceding paragraph had not yet begun the journey towards the scientists' country.

10.3 SUMMARY OF CHAPTER

In general, the results indicate that students were applying frameworks (whether scientific or alternative) reasonably consistently across groups of events that they perceived to be similar. What was clearly lacking was the scientists view of all of the events being regarded as realisations of the same underlying conceptual model. This supports the view that the students had not developed a sound understanding of the principles of chemical reaction and that their thinking was too easily directed by superficial perceptual clues.
CHAPTER 11

STUDENTS' LEARNING APPROACHES

A secondary objective of this study was to be able to understand the learning approaches of the individuals in the study sample and to endeavour to establish relationships between these and the students understandings of chemistry as revealed in the interview process.

Initial results were inconclusive and due to pressures of time in the main study this secondary objective was suspended with a view to re-establishing it as new project at a later date.

The approach adopted was the Biggs Learning Process Questionnaire with minor amendments and additions designed by this researcher to meet the specific needs of this study.

A full description of the background to the Learning Process Questionnaire together with its use in this study and results obtained are provided at appendix L; the principle findings achieved to date are summarised below.

The results from previous chapters 4 to 9 indicate that schools P and R seemed to be contributing more to student learning than schools C and E; while school S seemed to have intermediate influence on student learning.

The analysis of the data on the learning approaches based on Biggs' LPQ, showed inconclusive results. According to evidence from other studies (Biggs 1979, 1987; Watkins, 1983), students with surface approaches tend to produce low level learning outcomes while students with deep approaches tend to produce higher levels of learning outcomes (ie higher levels of understanding).

The results show that there were significant differences in the scores on surface
approaches by schools; with students in school C (one of the 2 weak schools) having the highest scores while those in schools R and E the lowest (Table L.4.1, Appendix L.4). This means that while the results for school C appear to be in line with the expectation that students high in surface approaches will tend to produce lower quality outcomes, the same could not be inferred of students in school E.

Furthermore, there were no significant differences between schools on the other 2 approaches (deep and achieving).

Results from the data analysis on students' perceptions of their chemistry classes appear inconclusive. There were no significant differences between the good schools R and P (and S to a smaller extent) on one hand, and the weak schools C and E on the other hand.

The overall picture seemed to be that from the students' perspectives, the schools had many similar points, viz.,

* they had been given a lot of notes by their chemistry teachers;

* they had ample opportunities to raise questions in class;

* they were asked questions which involved recall as well as higher order thinking skills in class;

* they were given assignments and homework which frequently or almost always involved individual work rather than pair or group work;

* they found discussion with friends an important avenue of learning chemistry.

From students' perceptions of their chemistry classes, there appeared to be no obvious clues as to why the progression in school C and E should be significantly lower than those in schools R and P. Perhaps a consideration of other factors such as prior achievement and school ethos might provide some clues.
The purpose of this chapter is to present a particular interview as a detailed case study to demonstrate a number of aspects of the data collected.

The case chosen is that of student R7, who was a student with an above average total L6 score (15KEs), and achieved the highest progression among the students (28KEs).

Three further case studies, II, III and IV, are included for completeness at appendix M.

The case studies demonstrate the following salient features of information collected:

- the progression made in terms of the increased richness and details in his explanations and the inclusion of more of the KEs of a scientific explanation; at the same time, while old ACs were abandoned, new ACs developed as new knowledge was either partially understood or applied in the wrong context;

- the regression in conceptualising of certain aspects;

- ACs arising from naive reasoning, confusion about the process of bonding and bonds; and ACs associated with driving force of chemical reactions;

- the use of incomprehensive or 'one factor only' type reasoning even at the U6 level or, in the terms of Rozier and Viennot (1991), the tendency to forget or ignore relevant variables in a multi-variable problem;

- the consistency and/or inconsistency in the use of conceptions across the events.

Throughout these case studies, student's verbatim responses are presented in italics.
The form of presentation of each case, either by event or by aspect, is chosen on a per case basis to best enable the researcher to illustrate the important points.
CASE I: STUDENT R7

(In this chapter the full descriptions of ACs referred to are at Appendix H.)

(Drawings are presented at appendix N1.)

(A verbatim transcript is presented at Appendix D, record sheets pertaining to the interview and showing analysis of responses, KEs scored and ACs revealed are at appendices E and F.)

R7 scored 2A's for coordinated science at GCSE, and he predicted that he would score an 'A' grade for A-level chemistry. His teacher also predicted same grade 'A'. He hoped to specialise in chemistry at the university.

Among possible reasons for his high progression are:

* his ability to abandon ACs associated with the process aspects of chemical reactions; such as B1a, C1a, C2a, C3a, C3b; and at the same time acquiring the relevant KEs;

* his ability to change from using predominantly perceptual thinking to conceptual thinking, which lead to increase in the number of KEs;

* his ability to shift from using macroscopic and/or anthropomorphic explanations to using microscopic and objective explanations;

* his interest and enthusiasm in chemistry.
Aspect A - Prediction of Type of Change

At the L6 level, he had no problems in predicting the change in all events except event 5, on which he predicted that there would be no chemical reaction because "it's something to do with the activity series...we use it to determine whether metals are going to react...sodium's pretty reactive...I don't think that's (meaning 'chemical reaction') going to happen".

Like 36 other L6 interviewees, he had seemed to have the misconception (AC C3b) that the activity series could be used to predict whether there would be a chemical reaction in event 5, a non-redox reaction. As discussed in section 6.3, chapter 6, this AC could be related to several possible related confusions such as AC C1a (see section 6.3, chapter 6):

* confusion between elements, mixtures and compounds. Similar confusions had also been found of younger students aged 15 and below (Briggs and Holding, 1985) - it seemed that students were thinking that the properties of sodium metal (its reactivity and so forth) still persists in the aqueous sodium chloride. In the terms of researchers such as Brosnan (1992) this is indicative of the use of common-sense (rather than chemist's) explanations of chemical change - where the properties of an object, in this case, aqueous sodium chloride, are regarded as "the same as those of the bits that make it up - not all of which may be visible". Thus, in this case students thought that the properties of aqueous sodium chloride are the same as the sodium and the chlorine bits. The difficulties that students have in grasping the idea of non-conservation of substance in chemical change had also been reported (Vogelegezang, 1987; De Vos, 1987a,b).

* he could be confusing between the element or substance, lead, and its particles - the lead ions, a problem which according to researchers like Selley (1978) is common in students and textbooks. This then could lead him to viewing lead ions in the system as having the same properties as metallic lead; which he thought was less reactive than sodium and hence incapable of displacing it from the solution, which led him to predict no chemical reaction.
Thus, because of these likely ACs, he was hindered from acquiring the KEs on the prediction of the type of change involved.

At the U6 level, he seemed to have abandoned these ACs, which allowed make to make the correct prediction and acquired the KEs involved. More specifically, his response was: "These two anions would swap so you end up with aqueous sodium nitrate and solid lead chloride..all group I nitrates are soluble."

Thus, on this aspect, the relationship between the holding of ACs and the acquisition of KEs had been illustrated.

Aspect B - Prediction on Overall Energy Change

On this aspect, again his L6 responses were largely vague and macroscopic, and revealed AC B1a, with is associated with the use of perceptually dominated thinking (Driver, 1985) which hindered him from acquiring the KEs. At the U6, he seemed to have abandoned this AC, and successfully acquired KEs associated with relevant aspects of the particulate model and the energetics involved. To be more specific, he showed progression by incorporating concepts of particles and relative bond strengths which were absent in his L6 discourse. In so doing, he made a lot of progression of terms of both KE increase and AC decrease.

For example, at L6 on event 1, his prediction was: "reaction is overall endothermic..takes in heat..because without heat, the reaction won't happen."

In this response, like a number of other interviewees, he seemed to be using predominantly perceptual thinking and holding to a misconception that if overt heat input is needed to bring about a chemical reaction, then that reaction must be overall endothermic (AC B1a). A similar misconception was reported among 15-18 year old students in studies by De Vos (1986), and Johnstone, MacDonald and Webb (1977). He seemed to ignore the concept of activation energy or energy needed to break existing bonds/structure, and seemed to be suffering from the misconception that because heat is needed to initiate a reaction, that reaction must be overall endothermic. This
misconception was quite common among the interviewees.

At the U6, on the same event, he predicted: "Overall exothermic. because you are creating a bond. energy is given out. yes, O-O bond need to break, you need energy to break a bond. bond breaking takes in energy, bond making gives out energy. Come to think of it, I don't think either the O-O bond or the Cu-O bond is particularly strong. so the net effect whether exothermic or endothermic isn't particularly large."

(This U6 response, like his other U6 responses on aspect B in the other 4 events was placed in category i, "science-like" framework, section 10.1, chapter 10 because it was a view closest to the scientific view and did not incorporate any obvious ACs, unlike those placed in the category ii framework mentioned in case IV, student C10.)

At this point, like many other interviewees, he displayed the tendency not to consider all factors involved in a problem or issue - he did not include consideration of the bonds in the other reactant, copper, which needed to be broken (AC B2b, section 5.3, chapter 5).

This led to prompting by the interviewer, who asked, "Are there any bonds which need to be broken in this copper foil?"

To which he then replied: "The bonding in metals is different because you haven't got electrons going round individual nucleus, you've got electrons floating around the whole metal nucleus. you need to put in energy to get the copper on its own. yes, you got to get copper a slight distance away from the main body of metal so that it can react on its own. it doesn't need to be a long way away. so there are two processes which require energy: affect the metallic structure in copper and split the O-O bond, create 2 oxygen atoms. if these then pull away 2 copper atoms from the metal and then produce 2 oxygen ions or radicals, whatever. I think it'd be overall endothermic but not significantly endothermic which is why you need to heat it to give it energy. if it were incredibly endothermic, it'd require a lot of energy. it won't happen at room temperature."

In spite of having been prompted to consider a different/third factor - bond breaking in copper - he was still using incomprehensive reasoning; he did not put together all three factors, i.e., bond breaking in copper and in oxygen gas as well as bond making in copper
oxide, in his reasoning (AC B2b, section 5.3, chapter 5). This tendency exhibited by him was common among the interviewees, and appeared to be supportive of the suggestion made by Rozier and Viennot (1991) that there are some tendencies in common reasoning which "aim at reducing the complexity of multi-variable problems". As pointed out by them, one main aspect of these tendencies involved treating a physical quantity which depends on several factors as if it were depending on only one factor, or forgetting about the other relevant factors.

The progression he made between the 2 interviews was quite obvious from his responses quoted above. When at the L6 level, he was not able to elaborate much on why he thought the reaction was overall endothermic, at the U6 level, his responses were rich and elaborate with details.

One possible reason why he thought the Cu-O bond was weak could be inferred from his initial U6 response when asked to predict what would happen to the copper foil if put in a very hot bunsen flame. His response was: "Just melt, no chemical reaction because the oxide is reduced easily...it'd decompose in heat back to copper and oxygen."

Later, after having been prompted to consider other metals like magnesium, he revised his view by saying that: "Yeah, copper oxide is easily reduced, but it'll just sit, won't spontaneously reduce...but if you pass hydrogen gas or methane...it will reduce to copper metal...it's not a difficult experiment, you don't need vast amounts of energy to reduce copper oxide to copper...but then it's not a very unstable compound going spontaneously from copper oxide to copper...most oxides of metals are quite stable 'cos you often get oxides on the surface of metals...aluminium, iron."

He seemed to have inferred that the Cu-O bond is not very strong based on the fact that it could be reduced easily by hydrogen or methane gas. In this inference, he seemed to reason rather incomprehensively or superficially, neglecting considerations of all the factors which led to the overall exothermicity of the energy change, which in turn arose from the formation of stronger H-O bonds in water, which drives the reduction of CuO to Cu.
The improved quality of his answers on aspect B can also be seen in the next example from U6, his response on the burning candle: "Overall exothermic. heat is given out from the burning of paraffin. it's like a balancing act 'cos you're breaking certain bonds. C-H bonds. and forming strong bonds in water and carbon dioxide which gives out more energy than breaking of weak bonds so the surplus net energy is given out as heat."

At the L6 level, he had said that the reaction was "overall exothermic", and the reason he gave was, "it gives out heat from the reaction"

Aspect C - How the reaction takes place.

On his aspect C, again, as in aspect B, he showed progression in his increased understanding of which particles and which processes were involved.

Eg i event 1

L6 response: "Copper molecules shaking around, more and more with heat, shake faster and faster, then they have so much energy that they bounce into oxygen molecules and they have so much energy that they stick together."

At the L6, his view of the process was rather vague; and did not include the concept of electrons; and there was the suggestion that he thought bond making requires energy (AC B3a). At the U6, his view of electrons and their role in bonding was quite sophisticated.

His U6 response was: "..you get. one cloud of electrons..(drawing a circle with 'Cu' written on its centre) Then you have this cloud of electrons coming around oxygen. oxygen starts off as 'O2' molecule, that is, bonded together, which break..have to create energy for oxygen to break, then you're left with an oxygen which is very small. oxygen is in group VI so it'll have 1 or 2 vacancies, depending on how it's split.easier to assume it's got 2 vacancies; then you'll have mutual attraction between copper and oxygen. because oxygen has 2 spaces, it'll be attracted by the electron cloud of copper and the electrons orbiting the copper..so they like going round copper..spherical shape..when oxygen gets close enough (drawing a partially completed circle with 'O' written at its centre, next to the first
circle representing copper with a cloud of electrons around it) then they're going to change their orbital and start orbiting the oxygen as well that's where they start to bond and make a bond. the electrons orbiting round both" (changing the circular shape around Cu to a dumb-bell shape with 'Cu' and 'O' at the centre of each lobe - see f1.1, Appendix N.1.2).

Like the vast majority of the other interviewees, he appeared to suffer from confusions between ionic and covalent bonding. Specifically, after having mentioned that the 2 electrons from copper formed the Cu-O bond, he went on to refer to it as a "sigma bond.. a single bond between Cu and O 'cos there's only one set of atoms that the electrons are coming from and bonding..only one bonding pair so it's called a sigma bond. Yes, copper contributes the electrons to form the sigma bond. oxygen doesn't contribute any electrons to the bond 'cos oxygen has the 2 spaces for the electrons to come in. Sometimes, copper and oxygen each contribute one electron to the bond. it depends."

The improved, rich and elaborate nature of his U6 response over that of the L6 one was evident. At the L6 level, he was unable to describe very specifically how the process of change was conceived; he was referring to molecules instead of atoms of copper, there was no reference made to bond formation; and he appeared to be suffering from the AC which was prevalent among the interviewees - that energy is needed for reactant particles to 'stick' together, i.e., energy or bond is needed to hold particles of reactants together to form new products (AC B3a). The prevalence of the view that energy is the causal agent of change has been suggested in other studies (Andersson, 1986b; Ogborn, 1990).

His U6 account, while not completely free from ACs, was much nearer to the scientific view. His treatment of the bonding process between copper and oxygen was quite typical of the interviewees in the sense that there was lack of comprehensive understanding of the nature of the bond or the attraction between the atoms involved. Like many other interviewees, he appeared to be confused or vague to some extent of the nature of the Cu-O bond. Like many of the other students, he did not conceptualised the Cu-O bond as anything more than the 2 electrons which are orbiting round the 2 atoms involved; which in this case was effectively shared between the Cu and O atoms. He did not articulate the scientific view that it is the electrostatic attraction between the shared electrons and the 2 nuclei which constitute the bond.
While his conceptualisation of the process was different to the conventional A-level view, which was articulated in the 'model' set up by the interviewer-researcher at Appendix C, it was not considered as invalid but transitional, having elements of both the scientific view and ACs or misconceptions. The conventional scientific response would, in most cases, start with considerations of the significant electronegativity difference between copper and oxygen, resulting in the transfer of electrons from copper to oxygen, leading to the formation of oppositely charged \( \text{Cu}^{2+} \) and \( \text{O}^{2-} \) ions. Electrostatic attraction between these ions then results in the release of energy and the formation of strong ionic lattice. A small degree of polarisation of \( \text{O}^{2-} \) electron charge by the \( \text{Cu}^{2+} \) could lead to a small amount of covalent character in the Cu-O bond.

The fact that ionic bonds usually possess some amount of covalent character and that most covalent bonds have ionic character meant that R7's treatment of the Cu-O bond from the view of covalency was not completely invalid. It was an alternative way of looking at bond formation processes.

His account while acceptable and commendable compared with numerous other accounts elicited in this study, also revealed likely ACs such as:

a) Possible confusion of covalent and ionic bond (AC C2a); as evident when he referred to the Cu-O bond being a sigma bond. The terms 'sigma' bond in chemistry is used in association with a covalent bond to describe the nature of the electron orbital overlap, whether it is an internuclear (sigma) overlap or a sideways (pi) overlap.

From his responses on aspect B quoted above, it could be inferred that he thought either oxygen ions or radicals could be produced as a result of the interaction between copper atoms and the oxygen molecules. Throughout his discourse on event 1, however, there was no mention of the formation of copper ions. From this omission and his mention of a sigma Cu-O bond, he seemed to think either that the bond was covalent or that there was more covalent character than ionic.

b) his mention of copper contributing 2 electrons to the bond might, on the other hand, be a reflection of the confusion of dative bond with covalent bond. In this
study, there were a number of other interviewees who conceptualised a bond, which they termed as a covalent bond, as being formed by one atom donating two (in some cases, only one electron) electrons to the overlap between the two atoms held by the bond. In other words, the meaning of sharing was given a slightly different meaning. It is one atom sharing its electron(s) with a second atom, with the latter atom not contributing anything to the bonding process. In effect, it seemed that a dative bond has been confused with a covalent bond; except that in the case of some interviewees, a covalent bond was misconceived of as comprising just one single electron being shared between two atoms.

Eg ii event 4

At the L6 his response in this event revealed several ACs, including 'the anything goes' view of chemical reaction mentioned in section 4.3, chapter 4; and ACs C1a, C2a and C3a.

Eg at the L6, he thought that aqueous HCl "might be ionic.. have a certain amount of H\(^+\) ions and Cl\(^-\).. because these charges are equal and opposite, they attract each other very strongly so you got very strong bonds..ionic bonds"

(He revealed AC C3a here, that there are ionic bonds existing H\(^+\) and Cl\(^-\) ions in dilute HCl, and on top of that he thought there are no bonds between the H\(^+\) ions and water molecules; also no bonds between Cl\(^-\) ions and water molecules. At the U6, as revealed from the extract below, he had abandoned this AC, and also showed understanding of the interaction between the proton and water molecules.)

His L6 response on the process: "...magnesium comprise atoms..molecules joined up like this (drawing 3 rows of circles, each with 'Mg' written at its centre and almost touching its neighbours on all sides)..lattice..sea of electrons (adding dots in the spaces between the 3 rows of circles)..each molecule [AC C1a: confusion between atoms and molecules] shaking about a little..with heat, they shake more and more until it breaks free..and able to join..will form..it should go to Mg\(^{2+}\) and 1 of them link up with 2 chlorines in the water forming MgCl\(_2\)."
Probed further on how magnesium go to Mg$^{2+}$, he responded: "magnesium must change into ions..ionise..but if you remove water..hydrogen will react with oxygen in air to form water..if you burn that off, evaporate..you'll be left with Mg$^{2+}$ and Cl$^{-}$ ions which form MgCl$_2$..maybe hydrogen will not react with oxygen because it requires a lot of energy..maybe it's just given off..Magnesium becomes Mg$^{2+}$ by losing 2 electrons..not sure where 2 electrons go to..don't think these electrons float around in liquid..I think they'll go on something and produce negative ions..maybe produce hydroxide ions..maybe some hydrogen react with an oxygen and 1 electron go there, forms hydroxide ion OH" [Note the 'anything goes' view of chemical reaction] which is soluble also."

His abandonment of the ACs identified was evident in his U6 response, which therefore accounts for the his acquisition in KEs:

His U6 response: "HCl is a strong acid 'cos got H which is very electropositive and Cl very electronegative so H$^+$ is almost on its own..actually it's H$_2$O$^+$ 'cos hydrogen has joined onto water and that acts as a very strong electrophile attacking..and Cl$^-$ wants to react [Note the anthropomorphism here - chloride ion wants to react] with magnesium 'cos magnesium very easily lose electrons and chlorine generally has a gap or space because it's in group VII..to lose an electron requires energy..so you got a sigma covalent bond between magnesium and chlorine (f4.1, Appendix K.1.2), showing a conventional dot and cross diagram, 3 intersecting circles in a horizontal row, the middle one with 'Mg' at this centre, the two at the side each with 'Cl' at its centre; each Mg-Cl intersection had a pair of electrons in it, represented by a dot and a cross; dot representing electrons from Mg, and cross an electron from Cl - f4.1, Appendix K.1.2)."

At this point, the interviewer queried, "Cl before reaction exists as chloride ions..with 8 outer shell electrons..it still wants to react with magnesium?"

He then said, "That's not right..I'm confused (cancelling out f4.1)..you have magnesium ion and chlorine ion because magnesium's position in the Periodic Table, it's up here..and chlorine is up here..generally the further the more likely to get an ionic compound..so MgCl$_2$ is not covalent..Mg's going to be 2+, 2 electrons short..loses 2 electrons to hydrogen 'cos if hydrogen is to form covalent bond it needs 2 electrons to form 1 H-H bond."
He then went on to explain based on the lattice energy concept why magnesium chloride remains in solution with "no physical bonds but attraction between the Mg\(^{2+}\) and Cl\(^-\) ions, in water MgCl\(_2\) dissolve because the energy, it's to do with this lattice energy basically, which is the energy it gets from being pulled together, that is, when 1 mole of Mg\(^{2+}\) ions and 2 moles of Cl atoms come together the energy they give off is lattice energy, there's also a certain amount of energy they give off when they dissolve in water, it's to do with interaction of water and individual ions, water has a charge on it, shape of the molecule leads to slightly negative and slightly positive bits (\(\text{O}^4.4, \text{O} & \text{H}\) on a V-shaped H\(_2\)O molecule have delta-ve and delta+ve charges respectively)...". He went on to explain in accurate detail the nature of interaction between the water molecules and the ions.

His initial U6 response quoted above showed at least 2 ACs which were common to the interviewees, viz., the conception that the key step was the formation of a bond between chlorine or (chloride ion) and Mg (AC C3a); and the confusion between ionic and covalent bonds (AC C2a).

However, while many of the other interviewees remained confused throughout the entire interview, he was quick to correct himself the moment he was reminded that the chlorine in fact exists as Cl\(^-\) ions in the reaction system. And while many other interviewees (even those in the top group such as case II, student P4), still insist that the reaction process must involve Mg giving electrons to Cl, and they had postulated that somehow Cl or Cl\(^-\) must "gave back" the 1 electron to the H or H\(^+\) ion, R7 was quick to realise that the more feasible step was for Mg to lose its electrons to H\(^+\) rather than to Cl or Cl\(^-\).

While at the L6 level he thought that there were no attractions and no bonds existing between ions and water molecules, at the U6 he was able to give a very comprehensive account of the solvation effect of water, together with a good discussion of the energetics involved.

At the L6 level, in the context of event 5, having said that water caused NaCl to dissolve and to split up into Na and Cl, he had said: "I don't know very much about that." It seemed that at the U6 interview, he had come to show the interviewer that he had rectified his lack of understanding about the solvation effect of water. (See part iii event
However, he did appeared to show some regression at the U6 interview when he predicted that in the absence of water, i.e., in a system containing pure HCl which is a gas and solid Mg ribbon: "There would be a similar reaction, except that you get a very violent reaction. Actual products depend on what's in excess. If excess HCl, MgCl₂ may do something with that. Oh! I don't see what it could do with HCl acid. Probably dissolve... reaction would be a lot more violent and give off a lot of heat 'cos it's exothermic."

Perhaps he thought that the lattice energy released was sufficient to break the covalent H-Cl bond? He seemed to have forgotten that some initial heat input would be needed to break some of the H-Cl bond in order to start the whole reaction going. Here, he seemed to be exhibiting again the 'one factor only' type limited reasoning.

His U6 answer was surprising because of 2 reasons:

a) He had postulated that the reaction involved electron transfer from Mg atom to H⁺ ion and he seemed to understand the energetics involved in bond breaking and bond making. He seemed to ignore or forget about this.

b) At the L6 level, when presented with the same question, his response was different. It was: "There would be no reaction because HCl needs to be ionised so that the reaction can occur." At the L6 level, he had postulated an electron process between Mg atom and an hydroxy 'OH' radical, and not a H⁺ atom. He also appeared to lack a sound understanding of the energetics involved by postulating that the hydrogen which was released actually reacts with oxygen from the air to form a hydroxyl group which then accepts an electron from Mg forming OH⁻ ion! Yet, he could infer that there would be no reaction if water is absent.

Among the possible reasons for his AC that there would be a violent reaction between Mg and HCl in the absence of water, was known as "vividness criterion" (Nisbett and Ross, 1980): it appeared that new knowledge associated with energetics (lattice energy and so forth) was still fresh in his mind and had been recalled given too much emphasis in his
conceptual scheme at the expense of old acquired concepts. Similar kinds of regression were found in a number of the other students including case II, student E1.

**Aspect D - Driving Force**

At the L6 level, he included 2ACs and no KEs in his explanations over the 5 events; because he, like the vast majority of the other interviewees, held the consistent (see section 10.2, chapter 10) view that the driving force in chemical reactions is some active causal agent (the experiential gestalt of causation, in Andersson's (1986b) terms). In events 1 to 3, it was heat input (AC D1a, section 7.3, chapter 7); for events 4 and 5, it was one of the chemicals (AC D2b, section 7.3, chapter 7), and his explanations were anthropomorphic:

Event 4: "the acid just wanting to react so it can form ions. chlorine wants to move from hydrogen to magnesium;"

and for event 5: "Metals are reactive. Sodium wants to be or combine with nitrate. it's happier with nitrate than chloride."

At the L6 level, his responses on the driving force in events 4 and 5 clearly showed that he had a poor understanding not only of the driving force but also of the process of the reaction. He seemed, to think, like many of the other interviewees that in the aqueous state, the ionic bonds between Mg²⁺ and Cl⁻ ions, and between Na⁺ and NO₃⁻ ions are unaffected by the solvent (AC C3a).

At the U6, he showed progression by moving from anthropomorphic explanations to more objective explanations, which included aspects of the KEs on entropy change (see also section 10.2, chapter 10), which he used consistently across the events.

However, as illustrated by the extracts from events 1 and 5, because he seemed to have acquired only bits of the relevant KEs (di Sessa, 1988), the result was partial understanding, and new ACs. More specifically, at the U6, he seemed to have abandoned his L6 ACs (D1a, D2b) and had grasped the idea of entropy increase as the driving force
of chemical change (new KE). At the same time, he also acquired the new AC (that the driving force of chemical change is entropy increase of the reaction system, which is contrary to the chemist's view that it is the entropy increase of the universe), which led to other new ACs (eg that the entropy of copper oxide is lower than those of copper and oxygen together).

Eg event 1: "..Driving force?..it's to do with the entropy of the system, that it's lower in copper oxide than between copper and oxygen. Entropy basically measures disorder of the system, the second law of thermodynamics [It is probably the third law he meant, not the second] says that disorder or entropy always increase so in any reaction the main driving force is the increase in entropy so this reaction happens with increasing entropy. Entropy of copper oxide must be higher than that between copper and oxygen 'cos entropy always increase."

Eg event 5: "The increase in entropy because sodium nitrate exist as Na⁺ and NO₃⁻ ion pairs, although you got the complication that it's in water..it's got a big lattice energy and it's higher than sodium chloride..sodium chloride has gone to sodium nitrate 'cos sodium nitrate have a bigger lattice energy than sodium chloride..chlorine is very very reactive...I have a firm belief that all reactions will increase in entropy so..if you got aqueous sodium nitrate, then there are more possibilities of random arrangement of sodium and nitrate within that solution so the entropy of the solution is increased quite a lot..also you may be losing some entropy because the entropy of lead chloride is lower than that of lead nitrate..the fact is that you've increased the entropy of the sodium compound by giving it more space to be randomly arranged."

This response again revealed that because he had misconstrued the second [third?] law of thermodynamics, he was further misled in trying to rationalise an increase in the entropy of the system after the precipitation had occurred. In actual fact, the entropy of the system had decreased, but it is heat released (which was almost imperceptible) which leads to an increase in the entropy of its surroundings.
He revealed 13 ACs at L6, 10 of which were abandoned at U6. At U6, he acquired 2 new ACs, which relates to the lack of understanding of the role of water as a solvent in reactions in solutions and to entropy. Both these ACs appeared to be transitional to the acquisition of scientific frameworks.

This case illustrates the various forms of progression (see chapter 9) in terms of the new scientific concepts (KEs) and links that are included in the student's responses.

It also illustrates how the crossing the bridge from the pupils' country to the science country (to use the metaphor of Black and Simon, 1993) is not an easy process; one could trip and slip over the stepping stones that have been laid down to assist one across - as could be seen here when R7 has only partially grasped the new concepts (new KEs) associated with entropy increase but had misconceived its context as that of the reaction system instead of the universe, i.e., the reaction system and its surroundings (new ACs). The result of acquiring new ACs associated with partial understanding was the development of more new ACs.

One reason, among other possible reasons, which could explain his high progression was in terms of his ability to abandon his old ACs (such as D1a, D2b) to acquire new KEs. This is to be contrasted with students like C10 who seemed unable to shake off her old
ACs, the result of which was low progression in terms of acquiring new KEs.

Admittedly, as revealed, he did acquire new ACs as he acquires new KEs, but these ACs relates to partial understanding or lack of differentiation of contexts, which could probably be easily corrected.
CHAPTER 13

CONCLUSIONS OF STUDY

This study set out to fill an identified gap in science education relating to the conceptions and understandings of A-level chemistry students. It had been identified that precious little work had been done to date to investigate the conceptions of science students who had undergone several years of formal domain-specific learning and had chosen to specialise in that domain with aspirations to continue science education to a higher level.

The study environment of understandings of the nature of chemical reaction was chosen because the concept of chemical reaction is not only fundamental to the subject of chemistry but also permeates it at every level.

The primary aims of the study were to

a) develop comprehensive insights into A-level students' understandings of the nature of some familiar, well-known chemical reactions

b) examine consistencies and inconsistencies in understanding across multiple events in order to test the depth of understanding

c) investigate patterns of progression in understanding over an extended period of continued formal study

The detailed findings of the study have been reported in the earlier chapters of this thesis; the purpose of this chapter is to take an overview of the findings in order to establish the common threads, to review the research methodology and to draw some conclusions that will form the basis for continued work in this area.

257
These conclusions are presented under the following four headings:

1) Discussion of the Study Results

2) Review of the Research Methodology

3) Significance of the Findings and Implications for Science Education

4) Discussion of Areas for Further Study

13.1 DISCUSSION OF THE STUDY RESULTS

13.1.1 OVERVIEW OF THE STUDY RESULTS

The study findings paint a somewhat depressing picture of a generally low level of understanding of this fundamental aspect of chemistry amongst a group of students of whom it might have been expected to be found a good level of understanding with perhaps specific areas of difficulty.

This picture is characterised by

a) The preponderance of perceptually dominated rather than conceptual thinking.

This is demonstrated in the large number of perceptually based ACs uncovered through the interview process. Some examples are:

* 27 students (56%) at L6 and 16 (33%) at U6 thought the wax in a burning candle is merely melting and not involved in any chemical reaction.
At A-level, one would expect these students to be able to conceptualise the burning candle as involving essentially the same combustion reaction as in the Bunsen flame. While many of the same students could describe the imperceptible methane gas in event 3 as reacting with oxygen in air to form carbon dioxide and water, they were misled by their visual perception when they saw the wick as 'being alight' but not the wax.

At the U6 level, 44 students (92%) still thought that an active causal agent is needed for chemical change. Among these, 39 (81%) thought that heat input is the active causal agent of chemical change.

At U6 level, having been exposed to concepts of driving force and entropy, one would expect these students to use conceptual thinking to explain driving force as involving the decrease in free energy or the increase in entropy of the universe. Yet these students seemed still to be thinking along the same lines as younger pupils eg the 8th grade students in the study by Novick and Nussbaum (1978), who did not think that a chemical reaction can occur if there were no external intervention such as heating. In the terms of Brosnan (1992) these students were using common sense explanations rather than a chemist's explanations of chemical change.

b) The very wide range of alternative conceptions about the nature of chemical reactions, including many of the naive conceptions reported in earlier studies amongst younger students (eg BouJaoude, 1991; Mehuet et al., 1985; Driver, 1985), were held by these A-level students.

These conceptions can be delineated into three broad categories which have been discussed in chapter 8 but can be summarised as

- ACs which reflect naive chemistry, such as substantialisation of heat; and carbon dioxide from the atmosphere being a reactant in burning systems.
It was surprising to this researcher to encounter so many naive misconceptions amongst A-level students who had done well at GCSE, chosen to study chemistry at A-level, and had aspirations to further study and/or employment in science related disciplines.

- ACs associated with the microscopic processes of chemical reaction, especially with the nature of chemical bonds and the direction of energy change involved.

- ACs associated with the driving force of chemical reactions, that is to say, why chemical reactions happen at all.

c) The persistence of many ACs despite appropriate topics being covered in the students' courses in the period between the two interviews. This finding is in line with previous studies (Gunstone and White, 1981; Clough and Driver, 1985).

d) The lack of scientific thinking amongst the students in terms of applying some general principles over multiple events. Instead, there was a tendency to view events within perceptual boundaries and to construct separate explanatory models for each separately perceived domain.

e) The preponderance of single factor reasoning rather than attempting to take into account a multiplicity of factors. It appeared that many students attempted to explain events with reference to only one, often narrow, idea rather than attempting to bring to bear the full range of chemical knowledge available to them. It seemed that, often, students were pre-occupied with their latest bit of knowledge which they then tried to deploy as some form of panacea.

f) The almost total lack of understanding about the energetics of chemical reactions:

- this study has found that very few of the students (not more than 10%)
interviewed voluntarily used concepts of chemical energetics in their reasoning about the microscopic processes associated with chemical change. Similar findings had been reported by Brook and Driver (1984) who found that very few of the students studied by them spontaneously used ideas about energy to explain physical phenomena presented to them.

- as suggested by De Vos and Verdonk (1986), and Cohen and Ben-Zvi (1992) cognitive learning difficulties associated with understanding the meanings of abstract concepts such as heat, temperature and bond energy, could result in many alternative conceptions.

g) In general, students scored well on the "what" of chemical reaction but poorly on the "how" and "why".

h) In general, progression between the lower and upper sixth form interviews, measured by an increase in the number of key elements recorded, tended to be matched by a corresponding decrease in the number of ACs held. However, there were many exceptions. These demonstrated students' ability to simultaneously hold scientific or "science-like" frameworks (ie frameworks which contained some but not all aspects of the scientific view) alongside alternative frameworks and suggest a dichotomy between school science and spontaneous knowledge, an observation also made by Pines and West (1986).

With such a picture it is hardly surprising that, even to A-level students, chemistry appears to be a difficult subject even to the extent of seeming mysterious (and perhaps close to alchemy) and that the subject appears to be increasingly unpopular amongst aspiring undergraduates.

The remainder of this section summarises the main areas of findings as a platform for considering the implications for science education and identifying areas for further related study.
13.1.2 PROGRESSION AND NON-PROGRESSION IN STUDENTS' CONCEPTIONS

Results discussed in Chapter 9 and elsewhere show that with increasing formal chemistry instruction, students could acquire elements of the scientific view while maintaining many of their own naive views. This is in line with findings reported in the literature (Gunstone and White, 1981; Gilbert, Osborne and Fensham, 1982).

For example, a number of the students did articulate the chemist's view that bond breaking requires energy. But on careful probing, the chemist's view had been shown to be superimposed on preconceptions that bond breaking results in the release of energy. Thus, according to some alternative frameworks, the process of bond breaking requires input of energy to initiate it or start it off; however, as the bonds break, they release energy. In other words, the energy input is conceived of as a kind of activation energy to initiate the bond breaking process. Once the bonds themselves begin to break, they then release energy - because bonds are made of energy, and by the principle of conservation of energy, the energy cannot just disappear when bonds break. Hence, it must be released.

Another example of the way in which the chemist's view had been superimposed on students' preconceptions is the view that the bond breaking process involves the absorption of energy and that bond making releases energy; but the energy which is released during bond making is the same energy which has been taken in during bond breaking which is no longer required.

In the study, progression made by students is seen mainly in terms of the provision of richer, more detailed accounts, which contain an increased number of the key elements (KEs) of a scientific explanation.

Between the two interviews, a number of students clearly shifted from a naive view of chemical change as resulting from one active agent (usually one of the reactants or heat,
which was often substantialised) acting on the (other) passive reactant(s) to the view of chemical change as the result of the interaction of equal partners. This view has also been discussed by Brosnan (1992) with reference to the characteristics of common-sense and chemist's explanations of chemical change.

In the same vein, a number of students also shifted from using anthropomorphic explanations, particularly with respect to aspect D, driving force of chemical change, to using non-anthropomorphic explanations (which were, however, still either incomplete or at variance with the scientific view). To what extent this abandonment of anthropomorphic reasoning can be viewed as progression is perhaps debatable. On one hand, the use of anthropomorphic reasoning could be seen as transitional to scientific reasoning, and therefore its abandonment can be viewed as progression. On the other hand, as pointed out by researchers such as Bentley and Watts (1991) who have documented examples of teleological and anthropomorphic reasoning by children and also in science textbooks, anthropomorphism is useful to both children and adults in explaining a variety of phenomena. In particular, they note that anthropomorphism is useful when "interconnectedness, not objectivity, humanness, not mechanistic approaches are the frameworks for examining and explaining phenomena around us."

A pertinent question here is, "To what extent should the practice (and learning) of chemistry/science be seen as objective and mechanistic by learners?" If it is to be seen as objective and mechanistic, then perhaps the use of anthropomorphic explanations should be discouraged. On the other hand, if it is to be seen as human and interconnected with other realms of life, including the everyday life, then perhaps the use of anthropomorphic explanations should not be extinguished? As mentioned in chapter 2, in this researcher's view, no forms of learning, including the learning of chemistry, can occur objectively, separate from the domain of attitudes, beliefs and feelings of the learner. The pursuit of science/chemistry itself is not detached from subjective elements of motives and drives. Perhaps, if the science/chemistry is seen as less mechanistic and more human, students might find it easier to learn? Perhaps as suggested by a number of researchers (eg Solomon, 1983; Brook and Driver, 1984) students should be encouraged not so much...
to change their conceptions but to distinguish between contexts and when particular conceptions are appropriate.

In terms of 'one factor only' type reasoning, even at U6, there were a number of students who tended to reason incomprehensively by not including all relevant factors in their explanations. This is probably indicative of their lack of formal reasoning ability, in line with findings in other studies, such as those by Buell and Bradley (1972) who found that a large proportion of the high school chemistry students studied by them were still not operating at the formal Piagetian stage. It might also be indicative of the tendency to forget or ignore relevant variables in solving a multi-variable problem as reported by researchers such as Rozier and Viennot (1991). In a small minority of the cases, it might even be a reflection of students' difficulties in verbalising their mental models comprehensively, a finding which was reported of younger students by Holding (1987).

This study has also uncovered a large number of instances where students seemed to show regression in their explanations or conceptions, which might be akin to the U-shaped type developmental curve identified by previous researchers (e.g., Strauss, 1977; Holding, 1987). Here students seemed to have applied the new knowledge they have learned at the U6 to the wrong context and/or seemed to have abandoned concepts which have served them well at the L6. It seemed as though the new knowledge had not been properly differentiated from their existing knowledge and not properly integrated, and was allowed to colour or to disorientate their existing conceptual frameworks.

Another possibility is that the apparent regression could be the result of selective inattention - or the suggestion by Nisbett and Ross (1980) that new knowledge, being fresh in the minds could be wrongly retrieved (in the place of older but more appropriate knowledge) to construct explanations, which need not, from the students' perspectives, be coherent because as suggested by Reif and Larkin (1991), students do not appreciate the goals of science; they do not appreciate the need to formulate a coherent explanation.
From another perspective, perhaps this regression which is seen in so many instances is the natural consequence of learning - of acquiring knowledge in unconnected bits and pieces in the early stage of learning (di Sessa, 1988), so that they often recall various different bits of knowledge at different times, presenting inconsistencies or apparent regression.

From yet another perspective, the apparent regression could perhaps be understood as the manifestation of the disequilibrium process, which is transitory to achieving accommodation and equilibrium again (Furth, 1981).

Indeed this researcher-cum-interviewer's heart goes out to students who found it all a confusing mass of isolated facts, and unable to make generalisations of the mass. Some students seemed unable to differentiate between concepts, between new things learned and old knowledge, and overgeneralised or applied new knowledge in a wrong context. Some seemed overwhelmed by the amount of learning they had to do at A-level compared with GCSE level. A few seemed bewildered having been told that what they had learnt previously at GCSE was a "whole load of rubbish".

Developing the analogy of crossing the bridge from the students' country to the scientists' country (Black and Simon, 1992), this research has identified two factors which could hinder students' progression: (1) the persistent ACs (many based on pre-formal knowledge) which could hold students back like elastic and (2) new (and hopefully transient) ACs which could trip the students up on the bridge.

In closely observing students' alternative conceptions this researcher is led to speculate that perhaps the longer an AC is held, the more deeply entrenched it becomes and therefore the more difficult it is to abandon it. Further research is required to develop this idea but, if it were demonstrated to be true then there would be implications for teaching.
A relationship between progression and the study of single science or co-ordinated science at GCSE has been established - this is discussed in detail under Implications for Science Education in section 13.3

13.1.3 CONSISTENCY AND INCONSISTENCY OF STUDENTS' CONCEPTIONS

In general, the results indicate that students were applying frameworks (whether scientific or alternative) reasonably consistently across groups of events that they perceived to be similar. What was clearly lacking was the scientists' view of all the events being regarded as realisations of the same underlying conceptual model. This supports the view that the students had not developed a sound understanding of the concept of chemical reaction and that their thinking was too easily directed by superficial perceptual clues.

Overall, it seemed that students tended to use different ACs for the same aspect or same concept on different events (and in certain events, even revealed views that were quite close to scientists' views). This inconsistency across events suggest that these students had not caught on to the idea of scientific reasoning to explain the generality of events. That younger pupils were unable to produce generalised explanations of phenomena had been reported by previous studies (Gilbert, Osborne and Fensham, 1982). However, here for students specialising in a scientific discipline, it is expected that they would have acquired the ability to think scientifically which should lead to the recognition of generality between events.

The fact that these students (aged 16-19) who had chosen to specialise in chemistry were still thinking event-specific like their much younger counterparts is a cause for concern; and all the more so as some of these students seemed set on pursuing science courses at the university and science-related careers in the world of work.
Some possible reasons for the apparent failure of school science to teach scientific reasoning are discussed by Reif and Larkin (1991). Among these are the lack of understanding among students of the nature of science and its goals, and their tendency to transfer everyday goals and everyday ways of thinking into the domain of science. Because everyday thinking only requires adequate but not maximal generality and consistency, they tended to view doing science as the same - not requiring maximal generality and consistency.

Another reason is linked to the nature of students' knowledge suggested by di Sessa (1988): students' knowledge of scientific concepts and principles are often fragmented and incoherent. This also means that it is difficult for them to learn and remember. Thus, not surprisingly, they often recall inappropriate bits and pieces of knowledge and apply them to wrong contexts which result in inconsistencies.

The findings both support the evidence reported by Song and Black (1991) that performance is related to task content and, to some extent, answer Driver's (1989) question by indicating that alternative frameworks are genuinely 'theory-like' in that they are used with a high degree of consistency within the boundaries of what the students perceive to be common types of events (for example 77% of the students used a framework consistently to explain the overall energy change associated with the two flame reactions). The findings further support the view of Clough and Driver (1986) "that tasks which seem similar to scientists may not appear that way to students".

13.1.4 CATEGORISATION OF STUDENTS' UNDERSTANDINGS

In chapter 8 a broad categorisation of the multitude of revealed ACs was presented and discussed (summary in 13.1.1 above). This categorisation was purely in terms of the students' demonstrable understanding of the chemical issues presented to them.
This researcher had set out with a constructivist-generative view of learning. However, during this study, she has been increasingly aware of the possibility of linkage between domain specific understanding and cognitive developmental levels as suggested by Gabel (1989) and Monk (1990, 1991). This linkage is suggested by a number of pointers, such as:

* The large proportion of students using perceptually dominated and/or single factor reasoning.

* The difficulties experienced by students in addressing the concepts of the microscopic level.

* The difficulties with which students were addressing concepts of energetics.

Thus, it is speculated that students' understandings could perhaps be viewed along the axes of the domain knowledge in chemistry and conceptual skills. Based on the limited breadth of this present study a first approximation suggests the following delineation of these axes:

The chemistry domain axis (y-axis) is delineated in terms of increasing complexity of the domain knowledge and broadly in line with the AC categorisation presented in chapter 8:

- naive chemistry

- the nature of chemical bonds

- energetics and entropy.

The conceptual axis (x-axis) is delineated in terms of the reasoning approaches identified
through this study, each unit of the axis representing progression towards the scientist's framework:

- using bits and pieces of unconnected information
- confusion between ideas and concepts
- theory-like ACs (alternative frameworks)
- scientist's framework

It is speculated that progression is dependent upon acquiring both further domain knowledge of increasing complexity along the y-axis and more refined conceptual skills along the x-axis.

It is further speculated that progression along the y-axis is dependent upon prior progression along the x-axis as each new cognitive or conceptual skill lays the foundation for the integration of further domain specific knowledge within the student's framework.

Clearly, further detailed research is required to test the relationship and dependencies between domain specific knowledge and cognitive skills, to scale and metricate the x and y axes and thence to provide proposals for the development of curriculum and teaching approaches.
13.1.5 WHY CHEMISTRY LEARNING IS SO DIFFICULT (INCLUDING SOURCES AND CAUSES OF ACs)

13.1.5.1 BASIC DIFFICULTIES

Almost everything within chemistry is based on an understanding of the microscopic world, the world of particles and their interaction, which cannot be experienced or felt or easily deduced from macroscopic phenomenon. This is in contrast to subjects like physics and biology where many of the topics are based on the macroscopic world and can be experienced and deduced from experience. The conceptual inexperienceable aspects of chemistry are especially difficult to learn in competition with perceptual thinking which is so much a part of everyday experience.

In this researcher's view, one reason why there seems to be so much confusion in the students' minds about key ideas in chemistry such as bonds, atoms and so forth is that concepts and models in the teaching process tend to be represented as factual and final rather than as they are - scientific notions or explanatory constructs which are subject to revision. It seems as though insufficient emphasis is provided to learners of the conceptual and conjectural nature of many of the ideas presented to them. For example, if the conceptual and conjectural nature of particulate ideas of atoms, molecules and ions are not understood by students, then it is not surprising that many alternative conceptions arise, such as those related to the attribution of macroscopic properties to microscopic particles and events.

Admittedly, the problems and challenges posed to the chemistry teachers in trying to carry learners forward from the macroscopic world of "as it is" to the microscopic world of concepts and conjecture are tremendous. For many teachers, it appears to be a challenge to have to present the microscopic world in terms of "this is what we believe" instead of presenting the world "as it is".
The conceptual leap from the macroscopic to the microscopic is further hindered by confusion in the use of words or terms which have a specific meaning in chemistry but may have a variety of meanings in other scientific disciplines, learning domains or everyday life.

A number of difficulties arising from such basic factors were identified in the study:

* The term "burning" is used in the everyday sense in various ways, such as catching fire or the application of (excess) heat and these meanings were not differentiated from its specific meaning in chemistry.

* The term "reaction" is used differently in everyday life as well as in subjects like physics; and again its various meanings appeared not to be differentiated in the thinking of the students.

* In everyday experience, energy input is needed to make things happen or to construct things - this leads to the view that heat is the causal agent of chemical change and the view that to make bonds, energy must be put in. The chemist's view is that bond making releases energy, increasing randomness (entropy) in the universe, and that it is the increase in entropy that is the reason why chemical reactions take place, which therefore seems completely contrary to the students' everyday perceptually dominated thinking and experience.

* Another origin for the AC that bond making requires energy seemed to be been linked in some way to anthropomophic or analogical reasoning: chemical bonding was conceived as in human terms, which seemed to lead to the idea that energy is required to form bonds, while energy is released when bonds are broken.

* The concept of increase in entropy as the driving force of chemical change is particularly difficult, since it is associated in the students' minds with the concept of stability, which in the common sense view (derived from everyday experience)
seems to be related to order and not randomness. Here, the problem of everyday language and scientific meanings are probably involved as well.

### 13.1.5.2 INCONSISTENCIES WITHIN CHEMISTRY AND BETWEEN SCIENCE SUBJECTS

A number of researchers (Fensham and Kass, 1988; Carr, 1987) have suggested that one of the reasons why students find science in general and chemistry in particular so difficult is the multitude of ways in which terms and definitions are used both within subject domains and across the sciences. This view has been upheld by this research.

Three examples demonstrate the point:

a) Students learn a number of apparently conflicting ideas about the concept of energy:

In physics, energy is seen as "the capacity to do work" or being needed to make things happen; in biology, energy is associated with food stored in plants (or "energy-rich" substances); in chemistry, energy is associated with the breaking and making of chemical bonds.

These different views appear to produce conflicts within students; for example, many students transfer the idea from physics that energy is required to make things and therefore formulate the concept that energy is required to make bonds; this is supported from biology lessons where they perceive energy that is stored as food in plants (or in "energy-rich" substances) as being analogous to the storage of energy in chemical bonds.
b) What was appropriate to explain phenomena in early chemistry instruction appears to have generated barriers to the learning of new, more complex ideas.

For example:

Students in their early chemistry instruction were taught the chemical equation
\[ \text{Mg} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2 \]
and taught that Mg displaces H from HCl to give MgCl\(_2\) as the product.

Whilst the above continues to be an adequate representation at the macroscopic level, it does not reflect the microscopic process which is taught at A-level and is represented by the following chemical system:

\[
\begin{align*}
2\text{HCl} & \rightarrow 2\text{H}^+ + 2\text{Cl}^- \\
\text{Mg} + 2\text{H}^+ + 2\text{Cl}^- & \rightarrow \text{H}_2(\text{g}) + \text{Mg}^{2+} + 2\text{Cl}^- 
\end{align*}
\]

In the study, many students could not abandon the view that, in solution, the Mg combined directly with the Cl.

c) Different representations of supposedly the same thing, eg redox reaction even within the subject.

For example, in physical and inorganic chemistry, the redox reaction (eg the event 4 reaction) is defined as involving the transfer of electrons from a reducing agent to an oxidising agent, as represented by a formulation of the type:

\[ \text{Mg} \rightarrow \text{Mg}^{2+} + 2\text{e}^-; \quad 2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2. \]

Whereas in organic chemistry redox reaction is usually defined and notated differently; and often with inadequate (or no) explanations given for the
differences:

\[
\begin{align*}
\text{CH}_3\text{-CH}_2\text{OH} & \quad \longrightarrow \quad \text{CH}_3\text{CHO} & \quad \longrightarrow \quad \text{CH}_3\text{COOH}
\end{align*}
\]

From the student's point of view, these are inconsistencies within the subject itself, which could result in the lack of appreciation of the need for generality and consistency in chemistry and/or the drawing of artificial boundaries around event types in the student's mind.

13.1.5.3 DISCREPANCIES BETWEEN SCHOOL SCIENCE AND ACTUAL SCIENCE (AND EVERYDAY LIFE)

Reif and Larkin (1991) analysed the differences between everyday life and science in terms of the goals and the cognitive means used for goal attainment. They suggested that students' lack of awareness of these differences can lead to widespread difficulties in learning science. They analysed these difficulties in terms of students' erroneous conceptions of the goals of science; their transfer of goals and ways of thinking which are effective in the everyday life to the domain of science. These ways of thinking devised by students in dealing with everyday life are inappropriate to science. In addition, they highlighted the discrepancies between school science and actual science. They suggested that students' lack of awareness of these differences can lead to widespread difficulties in learning science.

One example, quoted was that in everyday life, the goals are largely implicit and roughly relate to having a satisfactory life, various kinds of knowledge can be used as appropriate in different contexts without requiring great generality or needing global consistency. In contrast the goals of science pertains to attaining optimal prediction and explanation which means that there is a need for great generality and consistency, to ensure that a
small number of theoretical premises can lead to predictions about a multitude of phenomena. As pointed out by the researchers, "the central scientific goal of optimal prediction and explanation is a very ambitious extension of the more modest predictive and explanatory goals of everyday life".

Not surprisingly, students tend to transfer everyday goals into science learning, and they tend to view scientific knowledge predominantly as a valuable collection of facts and formulae rather than as a conceptual structure useful for making predictions.

In addition science courses often do not foster the scientific goal of understanding, or may even pervert it. Many encourage and reward the reproduction of memorised knowledge, rather than the ability to make diverse inferences leading to scientific understanding. Furthermore, when dealing with time pressures imposed by school examinations and workloads, many students (indeed a number of the interviewees explicitly told the interviewer they had no time at A-levels to deal with concepts that they did not understand, hence, they resorted to memorising them) believe that they cope better by memorising facts rather than engaging in the longer, tedious reasoning processes needed for proper understanding of science concepts and principles.

Another source of difficulties in learning chemistry/science is related to the discrepancy between school science and actual science, a point also made by Reif and Larkin (1991). To quote one example, in the context of school science, errors are perceived as sources of punishment and embarrassment, whereas in actual science, they are sources for progress.

13.1.5.4 DISCONTINUITY BETWEEN CHEMISTRY LEARNED AT LOWER LEVELS AND AT A-LEVEL

Besides the various sources of difficulties discussed above, another source of students' difficulties in learning A-level chemistry it seemed, according to this researcher, come
from the discontinuity in students' learning experience between lower level chemistry, including GCSE, and A-level. Much of what students learn at the lower levels appeared inconsistent to what they learn at A-levels, and in fact as found in this study some students were told that what they had learned at GCSE was a "whole load of rubbish". The following are some examples:

a. At lower levels, they learned that dissolving is a physical change. At the higher levels, some textbooks and teachers believe that it is a chemical change but some other textbooks and teachers still maintained that it is a physical change (The difficulty has been discussed in section 8.6.)

b. At lower levels, the ionic bond between sodium and chlorine is often represented in a manner which suggests a one to one correspondence (the "pseudo-molecular" presentation of the ionic bond, in the terms of Taber, 1994). This appears to be further reinforced in the use of formulae (such as 'NaCl') and chemical equations (such as NaCl+H₂SO₄ = NaHSO₄ + HCl), without, it appeared, adequate emphasis of the mole concept. At A-level, it seemed they needed to unlearn this or to learn that there is no one to one correspondence in ionic bonds; in other words, ionic bonds, unlike covalent bonds, extend in all directions (ie non-directional, whereas covalent bonds are directional) and that each sodium ion is bonded ionically not just to one chloride ion but to a large number of chloride ions at the same time, and likewise for the chloride ion. It was clear through the interviews that the majority of the students, had not unlearn the concept of a one to one correspondence in ionic compounds.

c. At lower levels, they learned (and write equations which show) that a metal like magnesium would displace hydrogen from dilute HCl and form magnesium chloride. But A-levels they were supposed to learn that, at the microscopic level, the chloride ions do not take part in the reaction at all, they are 'spectator ions'.
d. At lower levels they learned about valency but at A-levels, they were told "valencies are banned" (to quote the words of one student); instead they were to use oxidation numbers.

e. At lower levels they learnt that chemical reactions are irreversible, but at higher levels, they were told that in fact most chemical reactions are reversible and in theory all are reversible.

Thus, it appeared that the issue of progression in chemistry learning - or the different levels of thinking and explanations which are necessary at each stage of learning had not been well articulated, at least from the students' perspectives; which resulted in discontinuity (from the students' perspectives) in the students' chemistry education which could pose severe learning obstacles.

13.2 REVIEW OF RESEARCH METHODOLOGY

On retrospection, there is no doubt in this researcher's mind that the choice of the interview method had been a good one. The method generated a wealth of insights into students' conceptions which would have been unavailable through, for example, pencil-paper techniques.

It is this researcher's view that the choice of a wide range of events and the open interview style have been fully vindicated by both the breadth and depth of information gathered, which would have been difficult to achieve with other approaches. In particular, the wide range of events has provided insights into how these students perceive different chemical events and formulate and apply their alternative frameworks and conceptions.
This researcher challenges on two points the view of Monk (1994) that the interview-
about-events is "too high-powered" a microscope.

Firstly, while agreeing with Monk on the usefulness of surveys in providing patterns of
cognitive processing at the macroscopic level, it needs to be pointed out that in education,
we are dealing with individuals - each of whom is unique, with unique world views and
ways of conceptualising, which could only be accessed by personal, individual "high
powered" interview method and not impersonal surveys and questionnaires.

Secondly, the analogy can be drawn between the use of 'open' and 'closed' questions in
any form of information collection. The interview-about-events is very much the 'open'
form of questioning, enabling the respondent the greatest freedom to express views
without artificial constraints - thus providing the opportunity to garner the widest
understanding. The pencil-paper questionnaire, on the other hand, is a comparatively
'closed' form of questioning - which could be used to seek clarification of detail once
overview understanding has been achieved.

In this researcher's view therefore, the interview method when used with sensitivity and
expertise, will be one of the most basic and important methods of deriving understandings
about students' conceptions and progression. For specific tasks or concept areas, it could
perhaps be combined with other paper-pencil techniques such as questionnaire surveys,
word association, concept mapping or semantic networks, and might prove to be even
more effective and useful.

The major challenge for the future is to be able to develop the technique for use in a wide
variety of science education environments in line with the specific objectives of particular
research programmes. For example, in order to metricate the progression model postulated
in section 13.1.4 will require the revision of the interview schedule in order to gain
further insights into the relationship between conceptions and cognitive or conceptual
skills.
13.3 SIGNIFICANCE OF THE FINDINGS AND IMPLICATIONS FOR SCIENCE EDUCATION

This study had succeeded in developing a wealth of new insights regarding the nature of A-level students' difficulties and problems in understanding the concept of chemical reaction as well as in learning chemistry in general.

The study has revealed that students who have achieved good grades at GCSE and who had chosen to specialise in chemistry were still using naive ideas and reasoning and did not seem to have acquired a deep understanding or the use of scientific reasoning and explanations. It has shown how many of the various ACs found in younger students, even those who have had little exposure to formal chemistry, are also found in older students who have had much more exposure to formal chemistry. It shows that science/chemistry instruction, despite having access to much research material on the subject, appears to be having little impact in addressing students' deep-rooted ACs.

It also explored the various reasons for these students' difficulties with understanding chemistry and using scientific reasoning, among which are the apparent discontinuity experienced by students between the lower levels, up to GCSE, and A-levels; and the fact that school science differs from actual science and the everyday life.

There are two particular insights gained from the study which require further rigorous investigation because of their potential impact on science education. In both cases, the insights, which are founded on the empirical evidence gleaned, support commonly held anecdotal views.

Firstly, there is clear empirical evidence that students who had studied chemistry as a separate/single science subject at GCSE performed better against a number of the measures used in this study. For example, these students (ie those who studied chemistry as a single subject at GCSE) scored significantly higher on the KE measures at both
upper and lower sixth forms. More significant is the finding that students who had taken coordinated science (ie double certificate in science at GCSE) held significantly more alternative conceptions (and in particular those associated with naive chemistry) at both lower and upper sixth forms than their single chemistry counterparts. These results suggest that coordinated science is a less adequate platform for the rigour and depth of A-level chemistry study.

Secondly, the finding that many students were able to simultaneously hold scientific (or "science-like" frameworks) and alternative frameworks suggests that students may be rote-compartmentalising information solely for the purpose of passing public examinations; and that the public examinations are not testing students' deep understandings. Indeed, some students volunteered that they simply memorised difficult information and formulae that they were unable to fully comprehend simply to get themselves through the examination; time did not permit the luxury of gaining a more in-depth understanding.

The major underlying concerns for chemistry education from these findings are:

a) The lack of ability to use generalised explanations across a multiplicity of events and the "anything goes" thinking about chemical reactions. This lack of scientific reasoning suggests a matching lack of appreciation of what science learning and practice is about, and indeed a lack of understanding of the goals of science itself; a somewhat surprising finding from specialist science students.

b) The lack of a coherent understanding of the process issues of chemical reaction particularly with respect to understanding of the whole area of area of chemical bonds and chemical energetics despite the emphasis on both topics within the curricula and classroom practice. There is a clear and urgent need to address the problem.
c) The very shallow understanding that students have of the driving force of chemical reaction especially with respect to the concept of entropy. It is this researcher's view that this topic is largely being glossed over in A-level courses and leaving students with little formal basis for understanding why chemical reactions should take place at all. Whilst entropy is recognised to be a difficult concept to integrate into existing frameworks, it is this researcher's firmly held conviction that the understanding of driving force is key to a predictive view of chemistry without which chemistry can appear to be little more than modern-day alchemy.

Some issues facing chemistry education which are highlighted by this study are at the heart of the debate between the "Alternative Conception (AC) Movement" and the "Cognitive Developmentalist" position:

i) At what age should students be taught various chemistry concepts such as the particulate model (including various kinds of particles and their chemical interaction to form new kinds of particles) - which is the fundamental basis of chemistry learning? The various confusions associated with aspects of particles and their chemical interaction prevailing among the A-level students raise questions about the effectiveness of their past learning, and perhaps, teaching as well.

ii) Is there a limit to students' ability to understand such concepts as suggested by Monk (1990, 1991) and Adey (1992) working from a Cognitive-Developmentalist framework?

iii) Can students be taught to construct concepts which are more in line with scientists' frameworks, without at the same time having their cognitive processing capacities raised?
As discussed by Adey (1992), both the views of the AC Movement and the Cognitive Developmentalist Position on learning and development need to be taken into consideration. This researcher therefore proposes a programme of research to identify the nature and extent of any causal relationship between students' cognitive development and their ability to assimilate the advanced chemistry concepts related to the particulate model, and the energetics of chemical reaction. Effectively, the objective of such a programme should be to rigorously test Monk's (1990, 1991) suggestions of a good fit between the quality of students' conceptualisations and their cognitive developmental levels, and should test this researcher's suggested model as articulated in section 13.1.4. above.

13.4 AREAS FOR FURTHER STUDY

As was identified from the literature review, there has been precious little research to date in this area of A-level students understanding of chemical reactions and this study has only been able to scratch the surface. However, sufficient insights have been generated to enable a number of lines of further study to be proposed. These are presented below in no particular order of significance or priority.

1) There is a need for more empirical research to validate this researcher's findings that suggest GCSE coordinated science is a less appropriate platform for the rigours of A-level study.

2) There is a need to establish the nature and extent of any causal relationship between students cognitive development and their ability to acquire domain specific knowledge. A proposed study programme would involve mapping the students' stage of cognitive development (to be determined by using tests such as those developed by Wylam and Shayer, 1980) onto the nature or quality of conceptualisations, pre- and post-instruction, to examine the linkage between conceptual development/change and cognitive developmental stage. If indeed a
definite linkage between conceptual development/change and cognitive developmental stage was established, then it would suggest that future research should include intervention programmes such as CASE (Cognitive Acceleration through Science Education) (Adey and Shayer, 1990) for these students.

3) In the light of the rather tentative findings related to gender effect (see section 4.3, chapter 4) and school effect (see chapter 11), future studies could examine these two effects and their interaction on students' conceptions in this area.

4) The dominance of alternative conceptions (ACs) associated with bonds and bonding and driving force identified in significant numbers of students across schools in this study seemed to point to some weakness in the teaching context. In the light of a number of studies in the literature which showed that teachers or university graduates also hold ACs about various aspects of science/chemistry, one area of further research would be to conduct a similar study involving teachers as well as their students, to examine if there is any significant correlation between students' understandings and ACs and those of their teachers.

5) Another area for further study is a comparison study with parallel data derived from Singapore samples; in which case, the data and findings together with the analytical model (developed in terms of the various key elements, KEs expected in a scientific response) derived in the present study would also be further re-examined, in the light of new data collected from A-level chemistry students in Singapore, who follow the same syllabus as students in school C, i.e., the Cambridge Syllabus 9250. Perhaps future studies could look into how different educational culture and environment affect students' understanding in this essential conceptual area in chemistry. In relation to this, perhaps the understandings and ACs of teachers and students from different countries and educational cultures could be investigated to examine how they compare and contrast with each other. For example, comparative data could be obtained by using the same interview schedule and technique to interview teachers and students from U.S., Asia,
Australia and continental Europe. Any significance difference in the findings should point to contributory factors present in a particular environment or educational culture and could benefit and inform chemistry/science curriculum planning at the international level.

6) While this study had been useful in terms of providing some interesting data on different type of schools through the inclusion of a fairly large sample which span five schools, it is felt that further study which involved more intensive and closer monitoring of the development in students' understandings over time (i.e., with increasing exposure to formal chemistry instruction) would provide additional information on how individual students learn or make progress on specific concepts and topics.

7) From this study, perhaps future studies should map students' conceptual trajectories (Driver, 1989) using similar research technique but involving a smaller number of students who should be randomly chosen. Their conceptualisations on specific concepts or topics should be examined at more frequent intervals and over a longer period of time. These students should be interviewed, using essentially the same interview format each time, perhaps once a half-term, instead once a year (as in this study), over the two sixth form years (instead of over one year). Perhaps only one event should be used at each interview, to ensure that there would be in-depth probing and ample time for students to articulate their understandings. Also perhaps the event used at each interview should be different each time, so that while the contexts appear to be different, essentially the same underlying concepts in terms of identified key elements (KEs) are being investigated.

Where progression in understanding or where ACs are abandoned or revealed, the student could then be prompted and encouraged to reflect on the factors and trajectories of change. The information thus gained would then throw light on how students learn or mislearn, and on possible answers to questions which are
perennial concerns of educators and educationalists. Such longitudinal studies should also prove useful in helping to determine which prerequisite concepts students should acquire in order to build on their prior knowledge base. It should yield useful information not only on what concepts to teach, but also the order or sequence in which concepts should be developed for optimum understanding.

8) In a similar vein, a longitudinal study with more frequent interviews could be deployed to test how new ACs are generated and discarded as students move, in the analogy of Black and Simon (1992), over the bridge from the students' country to the scientists' country. Such a study could address issues of persistence as well as transience in alternative frameworks.

9) This study has only explored progression in a very limited way; having used the interview method to collect essentially two snapshot views of the conceptions of a cohort of 48 students; with the snapshots separated by a period of about one school year. Future studies to document students' progression in conceptualising chemical reactions, however, could involve larger cohorts of students in extended longitudinal studies, where a mixed of various data collection techniques, such as combination of written tests and interviews, could be used. The use of complementary written tests and interview methods would mean that there could be breadth as well as depth of coverage on students' ideas.

10) A secondary objective of this study had been to measure students' learning motives and approaches and to attempt to correlate these approaches to the levels of understanding as measured in terms of KEs. Whilst some work was carried out, the initial results were inconclusive and lack of time prevented further investigation. This researcher feels that there is much potential for science education in gaining a clearer understanding of students' motives and approaches and their relationship to understanding and academic performance.
13.5 CONCLUDING REMARKS

This study has provided invaluable insights into the understanding of the fundamental processes of chemical reaction among A-level students, many of them aspiring to progress into higher education or into science related careers.

The study has shown that, contrary to what might have been expected (or hoped), such students have not only a relatively low level of understanding about the nature of this core aspect of the study of chemistry but also fail to seek the scientists' view of a generalised model to explain a multiplicity of events.

The study has identified some specific areas for further investigation both in the short term to validate initial findings and in the longer term to provide a better understanding of the needs for science (and in particular, chemistry) education.

At one level, it could be viewed that these older students represent but a continuation of the spectrum of alternative frameworks discussed in earlier research based on comparatively younger age ranges. On the other, one has to pose the question of cognitive ability being the limiting factor to understanding. Whilst the balance between the two views remains open, this researcher has shifted from a being a 'constructivist-generativist' to being a 'conservative constructivist' through to duration of the study. It seems to this researcher that whilst learning can be accelerated within the context of a dynamic and developing framework, the individual's level of cognitive development could represent a barrier (which is not immovable) to the full and useful integration of advanced concepts into existing frameworks. Further research is clearly called for, if we, as science educators are not to fail future generations of potential scientists, our society and ultimately ourselves.
APPENDIX A

SOME COMPARATIVE DATA ON THE STUDY SCHOOLS

To provide some idea of how the schools compare in terms of public examinations results and absentee rates, the following Table 3.2 sets out some figures which were extracted from the Daily Telegraph 24 November 1993.

<table>
<thead>
<tr>
<th>School</th>
<th>% with ≥5 GCSEs grades A-C</th>
<th>Average points score of students entered ≥2 A/AS</th>
<th>% students absent without leave ≥1 half days in year</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>83</td>
<td>11.6</td>
<td>14</td>
</tr>
<tr>
<td>E</td>
<td>46</td>
<td>17.7</td>
<td>4</td>
</tr>
<tr>
<td>P</td>
<td>100</td>
<td>20.5</td>
<td>1</td>
</tr>
<tr>
<td>R</td>
<td>not available</td>
<td>13.4 (768 candidates)</td>
<td>not available</td>
</tr>
<tr>
<td>S</td>
<td>not available</td>
<td>12.6 (193 candidates)</td>
<td>not available</td>
</tr>
</tbody>
</table>

According to the Daily Telegraph 24 November 1993, the highest score achieved among the sixth form and education colleges was an average score of 21.4 (which meant that school P's results were almost on a par with the top sixth form college), and the average score of all A-level candidates was 14.7.

The following table Table 3.3 sets out the A-level Examination Syllabuses which were followed by students in the five schools.
### TABLE A.2

**A-LEVEL EXAMINATION SYLLABUSES AND CHEMISTRY CURRICULUM TIME**

<table>
<thead>
<tr>
<th>School</th>
<th>Examination Syllabus</th>
<th>Curriculum Time (information from teachers concerned)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Cambridge U. Syllabus 9250</td>
<td>5 one-hr periods per week, of which two are double for practical work and for extensive tutorial work</td>
</tr>
<tr>
<td>E</td>
<td>Nuffield Chemistry</td>
<td>8 periods a week, with integrated practical and theory lessons, each period 35-40 minutes</td>
</tr>
<tr>
<td>P</td>
<td>London U. Syllabus 9080</td>
<td>5 theory and 3 practical lessons a week, each period 35-45 minutes</td>
</tr>
<tr>
<td>R</td>
<td>Nuffield Chemistry</td>
<td>5 one-hour periods a week, with integrated practical and theory lessons</td>
</tr>
<tr>
<td>S</td>
<td>London U. Syllabus 9080</td>
<td>3 double periods, i.e., 6 periods a week, each 45-50 minutes, with integrated practical and theory lessons</td>
</tr>
</tbody>
</table>
APPENDIX B

THE INTERVIEW SCHEDULE

Events to be used as foci for discussion:

1. hot copper in air
2. burning candle
3. bunsen flame
4. magnesium-dilute HCl interaction
   (4b: copper-dilute HCl interaction)
5. aqueous sodium chloride-aqueous lead nitrate interaction
   (5b: aqueous copper sulphate-aqueous sodium chloride interaction).

Aspects to be focused on:

A. prediction of type of change (i.e., reactants and products);
B. prediction of overall energy change (i.e. exothermic or endothermic);
C. how the change happened (i.e., how the change process is conceived);
D. why the change happened (i.e., driving force of change).

While the general coverage in all events is the same, being focused on the 4 aspects A to D, there are some minor variations in the form of questions across events, which can be seen in the following detailed scheme. Also for events 4 and 5, where time permits, parallel events (i.e., 4b and 5b) and questions (such as "What if water was absent...") were used to provide another avenue for eliciting students' ideas on related issues, as well as to provide for consistency checks in the students' responses.

Event 1: hot copper in air

A.

"This is a piece of copper foil. What do you predict would happen if it is put in a very hot bunsen flame?"

If a chemical change is predicted: "What do you think are the reactants involved? And what products?"

"On what basis have you made your prediction?"

If a chemical change is not predicted, go on to the subsequent events, till after event 5 has been covered, then return to perform the experiment for the student. When s/he observed that a chemical change has occurred, then proceed with subsequent aspects B to D. Throughout all the other events, this same practice was followed.
B.  
"What do you predict is the overall energy change involved? Explain your answer in terms of the processes which you think are taking place at the microscopic level."

C.  
"How do you imagine the change taking place at the microscopic level? Give as detailed an account as possible, how you imagine the change taking place."

If the interviewee still has difficulty answering: "Suppose we have with us now a special machine which enables us to 'see' the tiniest of particles and suppose we are now looking at the change as it is occurring. Describe what you imagine you would see, i.e., give a step-by-step account of what you think you would 'see'."

D.  
"What do you think is the driving force of the change?" ("Why do you think the change took place?")

Event 2: burning candle

A.  
"Do you think there are chemical reactions taking place in the flame?"

If answer is 'Yes': "What do you think are the reactants involved? What are the products?"

B.  
"What do you think is the overall energy change involved? Explain your answer in terms of the processes which you think are taking place at the microscopic level."

C.  
"How do you imagine the reaction(s) taking place?"

D.  
"What do you think is the driving force for the reaction(s)?"
Event 3: Bunsen flame

A.

"Do you think there are chemical reactions taking place in the flame?"

If answer is 'Yes': "What do you think are the reactants involved? What are the products?"

B.

"What do you think is the overall energy change involved? Explain your answer in terms of the processes which you think are taking place at the microscopic level."

C.

"How do you imagine the reaction(s) is taking place?"

D.

"What do you think is the driving force for the reaction(s)?"

Event 4: Magnesium-dilute HCl interaction

A.

"Here is a piece of magnesium ribbon. What do you predict will happen if it is dropped into this beaker of dilute hydrochloric acid solution?"

If a chemical change is predicted: "What do you think are the reactants involved? And what products? What form (physical state) do the products take?"

"On what basis have you made your prediction?"

B.

"What do you predict is the overall energy change involved? Explain your answer in terms of the processes which you think are taking place at the microscopic level."

C. (part 1)

"How do you imagine the change taking place at the microscopic level?"

D.

"What do you think is the driving force for the change?"
C. (part 2)

"If no water is present, i.e., magnesium ribbon is added to a gas jar containing pure hydrogen chloride, which is a gas, what do you predict will happen?"

"What do you think is the part played by water?"

(The ideas elicited here supplements those elicited under aspect C (part 1), how the process of change is imagined; and is used as a parallel item to cross-check the consistency of ideas.)

Event 4b: copper-dilute HCl interaction

(This event is to be discussed only after event 5 had been discussed, i.e., only if there is sufficient time leftover. Again the ideas elicited here supplements those elicited in event 4.)

A.

"What do you predict will happen if copper, instead of magnesium, is added to dilute HCl solution?"

If a chemical reaction is predicted: "What are the reactants involved? What are the products?"

If no chemical reaction is predicted: "Give reasons for your answer."

Event 5: aqueous sodium chloride-aqueous lead nitrate interaction

A.

"What do you predict will happen if this lead nitrate solution is added to this beaker of sodium chloride solution?"

If a chemical change is predicted: "What do you think are the reactants involved? And what products? What form (physical state) do the products take? On what basis have you made your prediction?"

If a chemical change is not predicted, perform the experiment for the student. When s/he observes that a chemical change has occurred, then proceed with the following aspects B to D.
B. "What do you predict is the overall energy change involved? Explain your answer in terms of the processes which you think are taking place at the microscopic level."

C. (part 1)

"How do you imagine the change taking place at the microscopic level?"

(Where the student has difficulty imagining the initial state of the reactants, depending on the time available, the interviewer, presented them with some solid NaCl, asked them to make a drawing showing its microscopic structure, and asked them to make a second drawing showing the result of dissolving it in water.)

D.

"What do you think is the driving force for the change?"

C. (part 2)

"If no water is present, i.e., finely powdered lead nitrate is mixed with finely powdered sodium chloride, what do you predict will happen?"

"What do you think is the part played by water?"

(The ideas elicited here supplements those elicited under aspect C (part 1), how the process of change is imagined; and is used as a parallel item to cross-check the consistency of ideas.)

Event 5b: aqueous sodium chloride-aqueous copper sulphate interaction

(This event is to be discussed only after event 5 had been discussed, i.e., only if there is sufficient time leftover. Again the ideas elicited here supplements those elicited in event 5.)

"What do you predict would happen if I repeat the experiment, using copper sulphate solution instead of lead nitrate solution?"

If a chemical reaction is predicted: "What are reactants? What are products? What forms would products take? What is the driving force for the change?"
This appendix defines the key elements (KEs) in the expected response under each aspect A-D and each event 1-5.

A: Prediction about type of change
B: Prediction about overall energy change
C: Process imagined through the special machine
D: Driving force of the change

For each aspect, based on a scientist's interpretation of syllabus coverage at A-level and discussion with some of the teachers concerned (some of the teachers in the five schools were more friendly and open than others), key elements (KEs) in the responses are defined. Each response is then coded according to whether the defined key elements are included. For every key element included, '1KE' or 'one key element' is assigned. Where a significant part of the key element is included, '0.5KE' or 'half a key element' is assigned.

ASPECT A

The expected responses revolve around knowing that a chemical change is involved, and being able to identify the reactants and products involved. For events 1 to 3, students are expected to know that oxygen in air, which is invisible, is one of the reactants involved in the chemical changes.

The key elements in the expected response for each event vary slightly, since the amount of information given to interviewees vary slightly according to events.

For example, in event 1 'hot copper in air', the response to aspect A was elicited by the trigger question, "What do you predict would happen if this piece of copper metal is put in a very, very hot bunsen flame?" Here a response such as "heated copper would react with oxygen in hot air/oxidise to produce a deposit/layer/coating of black copper oxide" is regarded as indicative of sound understanding at A-level. The key elements in the expected response are:

1. besides copper, oxygen is the other reactant
2. the main product is copper(II)oxide

While attempting to maintain consistency in the categorisation of the same aspect across the 5 events, it is recognised that in some cases this is not entirely possible. For example in event 4 (also in event 5) under aspect A, the 2 reactants involved, magnesium ribbon and aqueous HCl (event 5: aqueous lead nitrate and aqueous sodium chloride) are given in the trigger questions. In these 2 cases, identification of reactants are not considered as key elements in the expected responses. For example, a response which is indicative of
sound understanding to the trigger question, "What do you predict would happen if a piece of magnesium ribbon is added to dilute HCl?" at this level is probably along these lines: "Magnesium would react with the acid producing a solution of MgCl₂ and H₂ gas would be given off". Here since the 2 reactants involved are given, they are not expected to be included in the students' responses. Thus while the identification of reactants involved are relevant and necessary in events 1, 2 and 3 since these are not given or obvious, the same is not necessary in events 4 and 5. Instead for these 2 latter events, the physical states or forms of the products are relevant and important. For example, if the physical states of the 2 reactants in event 5 are both given as aqueous solutions, then it can be inferred that a sound understanding of the precipitation reaction involved is lacking. Similarly, in event 4, a lack of sound understanding can also be inferred if the physical state of magnesium chloride is given as an insoluble solid. Thus the physical states of products are included as key elements in the expected response of the latter 2 events but not the first 3.

Where appropriate, if only part of a key element is included, then a fraction such as half or 0.5 of a key element is counted.

**Aspect B**

Prediction on overall energy change, includes essentially 3 key elements:

1. Heat is released when new bonds/structure are made [Type of bonds, whether ionic or covalent are included under aspect C, and hence not expected here. However, where type of bond is given under this Aspect ie B, the information is coded under Aspect C. Where some but not all, the different bonds made were mentioned, 0.5KE is assigned.]

2. Heat is taken in to break existing bonds/structure [Again the type of bonds broken are not expected. Instead, only the identification of which bonds are broken is sufficient.]

3. Relative strengths of bonds and structure made and broken which dictate the overall energy change ie direction of energy change, whether exothermic or endothermic.

**ASPECT C**

Process imagined "through the special machine", includes essentially 4 key elements:

1. Identifying microscopic particles involved, and their collisions [If reacting particles are identified without mentioning collisions between them, 0.5KE is assigned. If collisions between particles are mentioned but particles are either not specified or incorrectly identified, 0.5KE is assigned.]

2. Breaking of bonds [If this is only considered in one reactant, 0.5KE is assigned.]
ASPECT D

The driving force of the chemical change: All chemical reactions are manifestations of the tendency toward maximum total entropy or toward increased dispersal of matter and energy in the system as well as its surroundings. Reactions occur through a combination of kinetic and thermodynamic factors i.e., they involved both thermodynamically and kinetically favourable conditions. Carbon in the presence of oxygen is thermodynamically unstable with respect to the compound carbon dioxide because the enthalpy content of the latter is much lower compared to the sum of enthalpies of C and oxygen. Yet, at ordinary conditions, the chemical reaction between C and oxygen does not take place because of the high energy barrier or activation energy required for reaction i.e., the reaction does not take place because of unfavourable kinetic conditions. On the other hand, if heat is applied to overcome the energy barrier, then the reaction becomes both kinetically and thermodynamically feasible, and a reaction takes place. Thus there are essentially 2 key elements in the expected response, the kinetic and the thermodynamic factors:

1. The tendency towards kinetic stability
2. The tendency towards thermodynamic stability

In the remainder of this appendix is given the required answers for all aspects in each of the five events. Each event/aspect is coded as follows: the code on the left-hand side, comprising a number from 1 to 5 and a letter from A to D indicates the Event and Aspect referred to. E.g., '1A' refers to Event 1, Aspect A; '4C' refers to Event 4, Aspect C. Key words or phrases in the expected response are underlined.

1A:

2 key elements

KE1. Copper oxidises or reacts with oxygen in air: if only Cu or O₂ is mentioned, then 0.5KE is assigned

KE2. Main product is CuO: no penalty for wrong formula of the oxide
IB:

3 key elements

KE1. new ionic bonds/lattice structure in copper oxide are made, which is accompanied by release of energy. [The type of bond made is not expected to be mentioned. Any information given here about the type of bond made whether ionic or covalent is analysed as part of the response under Aspect C. If bond making is mentioned and direction of energy change is incorrect ie bond making is associated with energy absorbed instead of energy released then 0.5KE is assigned.]

KE2. bonds in reactants, copper metal and in oxygen gas, are broken, which requires energy input. [If bond breaking is mentioned only in one reactant and/or if bond breaking is thought to be exothermic, then 0.5KE instead of 1KE is assigned.]

KE3. because the bonds/structure made are stronger than bonds/structure broken, there is net energy given off ie there is more energy given off during bond/structure making than is taken in for bond breaking.

Since copper oxide is essentially an ionic compound, the response should mention the contribution of lattice energy of copper oxide to the overall exothermicity. Where only the new bond made but not lattice energy is mentioned, '0.5KE' instead of '1KE' is scored.

IC:

4 key elements

KE1. collisions between reacting particles, oxygen molecules/atoms and copper atoms

KE2. bond/structure breaking in O=O gas and in copper metal

[If bond/structure breaking is mentioned in only one reactant, then 0.5KE is assigned.]

[Responses which included explanation to the effect that bond breaking is the result of fruitful collisions and the attainment of activation energy to overcome the energy barrier would indicate a deeper understanding]

KE3. forming of ionic bond or transfer of electrons from copper atoms to oxygen molecules/atoms resulting in the formation of Cu²⁺, rupture of O=O bond and O²⁻ ions; no reasons need to be given as to why the electron transfer should be from copper to oxygen.

[It is considered not necessary to mention the exact number of electrons transferred; also responses that did not mention of the formula for copper oxide or included the wrong formula for copper oxide are regarded as acceptable. However, where there is no mention of electron transfer or where electrons are thought to be transferred from oxygen to copper, then 0KE is assigned.]
KE4. **electrostatic attraction between oppositely charged ions** resulting in some formation of **lattice** structure on the surface of the metallic structure.

[If attraction between copper and oxygen ions were mentioned but not the formation of lattice structure, then it is deemed as incomplete and is assigned 0.5KE instead of 1KE. If the nature of the attraction is not mentioned or wrongly conceived such as magnetic forces, but the term lattice structure is mentioned then 0.5KE is assigned.]

[More in depth discussion could include mention of polarisation, such as 'as Cu²⁺ ion moves closer to the O²⁻ anion, it begins to distort the latter's electron distribution, and the Cu²⁺ ion is beginning to recover a significant share of its lost electrons. At this stage the ionic bond takes on some of the character of a covalent bond.']

1-5D [the same across all 5 events]:

2 key elements

KE1. Availability of energy to overcome the **energy barrier** or **activation energy**.

[Where activation energy is not mentioned, ie only heat supplied is mentioned without any elaboration, then 0KE is counted.]

KE2. Increase in the total entropy of the system and its surroundings or decrease in **enthalpy** of the system.

[Responses which mentioned becoming more stable without mentioning either decrease in enthalpy or increase in entropy are considered as including only a part of a key element and are counted as 0.5KE instead of 1KE. Responses which mentioned changing from reactive to less substances without mentioning enthalpy/entropy changes are counted as 0KE.]

2A:

2 key elements

KE1. Wax is burned, oxidised or reacted with **oxygen** [If wax is considered as not involved in chemical change, but wick and oxygen are, then 0.5KE is counted. If both oxygen and wax are thought not to be involved 0KE is assigned. Similarly in responses which mentioned both wax and wick as not involved in chemical change but oxygen is involved 0KE is counted.]

KE2. Main products are soot or **carbon**, CO₂ and H₂O. [If only one of the products is identified, then 0.3KE is counted.]

[Responses which mentioned carbon dioxide, carbon monoxide, water and hydrogen as products are counted as including 2KEs and 1AC ie AC A3c].
2B:

3 key elements

KE1. **New bonds C=O and H-O bonds are made** which is accompanied by **release of energy**.
   
   [If bond making is mentioned in only one reactant, 0.5KE is counted. If the direction of energy change is misconceived 0.5KE is counted.]

KE2. **Existing bonds in wax and oxygen are broken** ie C-C and C-H bonds in wax which is essentially a paraffin, and O=O bond in O₂, which **requires energy input**.
   
   [If bond breaking in only one reactant is mentioned, then 0.5KE instead of 1KE is counted. Again if the direction of energy change is misconceived, 0.5KE is counted.]

KE3. Because **bonds made are stronger than bonds broken**, there is net energy given off ie **more energy is given off in bond making than absorbed in bond breaking**.

2C:

4 key elements

KE1. **collisions** between reacting particles ie **wax and oxygen molecules/atoms**.

KE2. **bond breaking in oxygen and wax molecules** (as a result of fruitful collisions and the availability of activation energy.)

   [If bond breaking is considered to occur only in one reactant and not both, ie either in wax or in oxygen but not in both, then 0.5KE instead of 1KE is counted. Responses which showed awareness that bond breaking is neither complete nor extensive, ie some C-C bonds are not broken, resulting in carbon or soot and other smaller hydrocarbons as possible products are indicative of greater understanding.]

KE3. **Bond making, mainly C=O and H-O bonds**

KE4. **Discrete molecules** of CO₂ and H₂O are formed.

3A:

2 key elements

KE1. **CH₄ is oxidised** ie O₂ is involved in chemical interaction. [No credit is given for naming methane as a reactant since this, including its chemical formula is given.]
KE2. Main products are \( \text{CO}_2 \) and \( \text{H}_2\text{O} \)

[Responses which mentioned carbon dioxide, carbon monoxide, water and hydrogen as products are counted as including 2KEs and 1AC ie AC A3c].

3B:

3 key elements

KE1. New \( \text{C} = \text{O} \) and \( \text{H} - \text{O} \) bonds made which is accompanied by release of energy

KE2. Existing bonds in \( \text{CH}_4 \) ie 4 \( \text{C} - \text{H} \) bonds and \( \text{O} = \text{O} \) bonds broken which requires energy input

KE3. Because bonds made are stronger than bonds broken more energy is given out in bond making than absorbed in bond breaking

3C:

4 key elements

KE1. Collisions between reacting particles, \( \text{CH}_4 \) and \( \text{O}_2 \) molecules

KE2. Bond breaking or splitting in oxygen and methane molecules (as a result of the collision and the activation energy provided by the bunsen flame)

KE3. Bond making, \( \text{C} = \text{O} \) and \( \text{O} - \text{H} \) bonds

KE4. Discrete molecules of \( \text{CO}_2 \) and \( \text{H}_2\text{O} \) are formed

[Responses which mentioned that incomplete combustion where there is limited supply of oxygen result in mainly soot and water vapour instead of \( \text{CO}_2 \) and \( \text{H}_2\text{O} \) indicate a deeper level of understanding; but no additional KEs are counted.]

4A:

2 key elements

KE1. Magnesium chloride and hydrogen gas are formed
KE2. MgCl₂ is soluble, aqueous

[In a number of cases where after predicting that aqueous magnesium chloride and hydrogen gas would be formed, the student went on to discuss and suggest (in their response aspect C), that the hydrogen released would react with oxygen from the air and so forth (see Appendix D; also case 1, chapter 12), 2KEs are still counted. The only difference is that ACs are counted as well.)

4B:

3 key elements

KE1. Formation of H-H bonds and ion-solvent bonds between Mg²⁺ and water molecules, both processes resulting in energy being released

KE2. Existing bonds in Mg metal as well as ion-solvent bonds between H⁺ and water molecules must be broken which requires energy input.

KE3. Because stronger bonds are made than broken more energy is given out in bond making than absorbed in bond breaking

4C:

4 key elements

KE1. Collisions between reactant particles ie hydrated H⁺ ions and Mg atoms

KE2. Bond breaking within metallic structure and hydrated H⁺ ions

KE3. Electron transfer between Mg and H⁺ ie Mg → Mg²⁺ + 2e; 2H⁺ + 2e → H₂

KE4. Formation of H-H and ion-solvent bond between Mg²⁺ and water molecules

5A:

2 key elements

KE1. Name the 2 products formed correctly ie lead chloride and sodium nitrate

KE2. Lead chloride is formed as a precipitate, sodium nitrate is formed in the aqueous state
5B:

3 key elements

KE1. **New bonds/structure within PbCl₂ are made** which is accompanied by release of energy, lattice energy.

KE2. **Existing ion-solvent bonds between Pb²⁺ ions and H₂O molecules, also between Cl⁻ ions and water molecules must be broken** which requires energy input.

KE3. Because bonds/structure made are stronger than bonds broken more energy is given out in bond making than absorbed in bond breaking.

5C:

4 key elements

KE1. Reactant substances are dissociated into **free ions** in solution ie ionic bonds have been more or less broken by the solvation effect of water.

KE2. **Fruitful collisions between hydrated Pb²⁺ and hydrated Cl⁻ ions** result in bond/structure forming.

KE3. **Breaking of ion-solvent bonds within hydrated Pb²⁺ and Cl⁻ ions** either before or during the reaction.

KE4. **Formation of crystal lattice** structure of PbCl₂.
APPENDIX D

VERBATIM TRANSCRIPT FOR STUDENT R7 ILLUSTRATING THE SCORING OF KEs AND ACs

(The figures referred to in this transcript are on the set of drawings made by this student, which are presented at Appendix N.1.1; the specific KEs and ACs scored are summarised in the record sheet at Appendix E.1. The number of KEs and ACs scored are set up in Appendix F.)

I: Now, Thomas, this is a piece of copper foil. What do you predict will happen if I were to put it in a very, very hot flame?

R7: Er.. I think it'll probably burn.. to form an oxide with the oxygen in the air.

I: Aha.. what do you mean when you say burns.. something burns?

R7: Well, burns.. as I understand it means it combines with oxygen to..erm.. or decomposes.. something like that.

I: Decomposes.. Can you say a bit more about decomposing..

R7: Decomposing is like breaking down into smaller things.. something like a carbonate which might decompose down into carbon dioxide and other products.

[AC A1b: everyday understanding of burning as application of heat, decomposition]

I: Ah.. then in what form do you think the copper oxide will exist?

R7: Er.. I think copper oxide is a solid, black powder.

[Aspect A: 2KEs - 1 for knowing oxygen and copper are reactants; 1 for product copper oxide. Note: KEs co-existing with AC A1b]

I: And then how do you imagine the process taking place? You know, the change from copper to copper oxide..

R7: Er.. well, when I heat it up, I think it'll probably be.. start to glow at first.. and.. erm.. then it'll start to look as tho' soot or something is formed on it.. on the outside.. starts to oxidise.. and then it'll start to become very flaky.. and then it'll crumble away.
And then if you were looking at the burning copper thro' a microscope, let's say we have a very, very powerful microscope that will allow us to see, you know, the smallest of particles, what do you think you will see happening..what do you imagine you will see happening?

R7: *Er..well, what you see is the copper particles..copper molecules......*

[AC C1a: confusion between atoms, molecules, etc.]

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......which start shaking around and as you give more and more heat, they shake faster and faster and faster and they have so much energy that they would bounce into oxygen molecules and they have so much energy they stick together.

---

[C = 1.5KE, collisions between reactant particles; 0.5KE for mentioning reactant particles. AC B3a suggested: bond making requires energy.]

---

I: Ah..

R7: (laughed) *something like that.*

I: What do you predict is the overall energy change?

R7: *Overall endothermic..takes in heat..because without heat, the reaction won't happen.*

[Aspect B = 0KE; B1a: a reaction must be overall endothermic if heating is needed. Note: Here AC prevented acquisition of KEs]

I: And what do you think is the driving force for this change or this chemical reaction?

R7: *Er..well, it's the heat that you give to the copper, in which case they have energy, so they are able to combine with oxygen.*

I: Why do you think this reaction happens at all..

R7: *Because of the heat..the heat drives it.*

I: Aha..so you see heat as the driving force. On what basis have you made these predictions?

R7: *Erm..well, when you heat something up okay, it gets hot, and I mean, when you got this copper on its own, and you are not giving it heat, it isn't oxidising but when you give it heat, you're not really changing anything else..it does start to oxidise, so the thing which changes is the heat and so that must produce the reaction.*
[EVENT 1 - 3.5KEs, 5ACs]

I: Now, let's next talk about a burning candle. Do you think there chemical reactions taking place in the flame? (lighting the candle)

R7: *Em*. well, I think the wax is burning but quite slowly. So it's probably burning to...wax, I think is carbohydrates or..hydrocarbon.. so it's going to give off. well, it will give off carbon, which is probably what's making the string black...and it will also give off hydrogen perhaps, and carbon dioxide, and maybe some water.

I: What do you think are reactants...and products involved..?

R7: *Er*. I'm not quite sure what the formula of wax is, but it will be some sort of..hydrocarbon, when it's heated up..in the presence of heat, it produces carbon, *em*. H₂O, and H₂.

I: Aha..again how do you imagine this change taking place? Okay, you say that you think wax is a hydrocarbon, so..why not let its formula be like..CₓHᵧ since you don't know the numbers of atoms of carbon or..atoms of hydrogen..and then okay, so we have a CₓHᵧ molecule of wax..Now what do you imagine happening to this CₓHᵧ as the chemical reaction goes on?

R7: *Em*. well, I think some of the..is it alright if I write here..(writing 'CₓHᵧ' and then drawing fig 1)...if you imagine it..it's sort of like.. branches of carbon with hydrogens coming out..probably it doesn't look like this.. but, I'd imagine it to have something like this..er..they'll get energy because of the heat..it's burning..the H's will join up to each other and.. *em*. fly off and form separate H₂ molecule and you might get things like hydrogen combining with oxygen...

I: Where does the oxygen come from?

R7: From the air.

I: Ah..

R7: So if hydrogen combines with oxygen, you get some water produced and in the same way with carbon you might get carbon dioxide produced or carbon monoxide...things like that..and some of the wax..this is probably quite a complicated hydrocarbon and it might be broken down into er..smaller hydrocarbons..so you get something like that (drawing fig 2, the full structural formula of ethane.)

[Aspect A:2KEs; AC A3c: burning of alkanes produces carbon monoxide and hydrogen]

I: Can you say a bit more about the effect of heat on this molecule..
R7: On.

I: On the wax molecule...the effect of heat...

R7: Erm...well, the heat cause bonds between the atoms to...weaken because the atoms themselves are shaking about more and more and...so this weakens the bonds between them...which means it's easier for them to break away and so when they have got enough energy, they do that.

[Aspect B: 1KE heat breaks bonds]

I: Ahm...can you say a bit more about bonds...which bonds here..

R7: Erm...bonds...I'm not sure about those in the hydrocarbons...but...erm...they're...they're forces holding the molecules together because of the forces that the actual atoms have...so many protons and electrons...those forces can interact with each other...to push to repel each other or pull them together so...erm...there might be a very strong force pulling them together but you are giving the molecule so much energy that they'll overcome that force and pull away from each other..

I: Aha...can you say a bit more about bonds...what about bonds in the reaction process..?

R7: Erm...I don't know.

[Aspect C: 1KE for mentioning bond breaking, although there seemed a lack of understanding of the nature of bonds; also confusion between intra- and inter-molecular bonds, AC C2b.]

I: What do you predict is the overall energy change?

R7: Exothermic...it gives out heat from the reaction.

I: Why do you think it's overall exothermic..

R7: Heat is produced from the burning.

I: What do you think is the driving force of this reaction..

R7: Erm...I think again it's heat again.

I: Why do you think the reaction happen at all..

R7: Heat drives the reaction...if there's no heat, reaction will not take place.

[SUMMARY EVENT 2 - 4KEs, 2 new ACs]
Okay, you think it's heat again. Now we shall have another flame. This bunsen flame: do you think there are chemical reactions going on in the flame?

R7: *Emm...*it's quite similar to the wax, except you're burning a different hydrocarbon...*emmm*...this one is quite visible...so it's producing some kind of soot...probably carbon but now when you put oxygen in there (seeing that I have adjusted the airhole to fully open) it burns to produce different products...so..

I: Aha...so you think they are quite similar..

R7: They are quite similar...It's just that this one is probably more efficient...well, now it burns with a fiercer flame...bunsen flame's methane...they're chemically quite similar...it's just *emmm*...wax is basically a bigger molecule than methane...they are made up in the same way...same products...carbon dioxide and water..

I: How do you imagine the process of this reaction...between methane and oxygen..

R7: Heat weakens the bonds...the carbon and hydrogen...come apart...then combine with oxygen...forms carbon dioxide and water...similar process to the wax.

I: What do you think is the driving force for reaction...burning of methane...?

R7: *Emm...*well, it's heat...I think the heat...er...causes it to combust so that's what makes it burn but because it's flammable...that...*emmm*...that means that it will burn as well.

I: You said the heat causes it to combust...what do you mean by combust?

R7: Burn.

I: So combustion and burning is the same?

R7: I think there is a slight difference...but...I'm not really sure what it is.
Okay, now we shall talk about another reaction. This is a piece of magnesium ribbon. What do you predict will happen if I drop it into this dilute hydrochloric acid solution?

R7: *Ern.. the magnesium will react with the hydrochloric acid and it will form magnesium chloride, I think and hydrogen.. yah.*

I: And in what form will magnesium chloride and the hydrogen be?

R7: *Er.. hydrogen will be a gas, and magnesium chloride, I think, will be soluble.*

[Aspect A: 2KEs]

I: On what basis have you make your predictions?

R7: Er.. I think I have done the experiment before.

I: *What do you predict is the overall energy change?*

R7: Er.. I think it's overall exothermic..

I: *What are your reasons for saying it's overall exothermic.*

R7: Because it's a very vigorous reaction. It's giving out a lot of energy and that energy is converted to heat.

I: At the microscopic level, can you account for why this reaction is overall exothermic..

R7: The reaction itself.. the magnesium is very reactive.. and so is the acid.. when they come together.. that's where heat is given out.

[Aspect B: 0.5KE for predicting the correct energy change]

I: Then what do you think is the driving force for this reaction?

R7: *Same as the previous three reactions; the heat.*

I: Can you say a bit more about the heat..

R7: *Heat absorbed from the surroundings.*

I: How do you imagine the reaction taking place.. can you try to give a step by step account of how you imagine the reaction taking place?
RT: I think it's because of the sort of make up of the atoms of hydrochloric acid and magnesium that, erm, that they are very willing to react with each other and, so, er... they do it vigorously.

I: Okay, you talk about the make up of the atoms in hydrochloric acid and magnesium. Okay, so can you say a bit more about what you imagine the atoms... the particles at the microscopic level is like. Okay, let's start with the acid first.

RT: Acid... hydrochloric acid... it should be one atom of hydrogen joined to one atom of chlorine.

I: Can you make drawings to illustrate what you mean.

RT: Acid should have this H-Cl molecule (writing a 'H' joined to a 'Cl' by a single line).

I: And what does this line represent... this line between hydrogen and chlorine.

RT: It represents a bond between them.

I: Aha... so you are saying that in this hydrochloric acid solution, the hydrogen is joined to the chlorine?

RT: Erm... I'm not actually sure whether it's joined... it might be ionic... in which case it have a certain amount of hydrogen which has a, I think it's a one minus... or one plus... it's one plus... yeah, you have a hydrogen with a one plus charge... an ion... sorry... which is an atom with electrons added or taken away... to give it a, what's called a stable configuration similar to that of a noble gas and chlorine ion which is one minus and because these charges are equal and opposite, they attract each other very strongly and so you've got very strong bonds holding them together.

I: And what would you call this bond?

RT: Ionic bond.

I: Ionic bond... and then besides these hydrogen ions and chloride ions... what other particles would there be?

RT: Erm... well, there'll be protons and neutrons in the nucleus and electrons on the outside.

I: [He seemed to be interpreting my question differently.]
I: Aha...okay...besides that, like this is made by dissolving the hydrogen chloride in water right...so do you expect to see some water particles there?

R7: Erm...there will be...but the water molecules would be separated from the hydrochloric acid molecules.

I: So what is your picture then...of how...of the relative arrangement of the water molecules and the hydrogen chloride? How do you imagine them to be put together then?

R7: Erm...well, that's what I imagine...you might have a water molecule here...a hydrogen chloride molecule here and it would go round...sort of like that...I think there'd be more water molecules to hydrogen chloride...molecules...(drawing fig 3) so something like that.

I: Just now you were saying that in the acid the hydrogen chloride probably split up into ions...now you are talking about molecules...are they the same?

R7: No, I think...You don't have that (cancelling off fig 3 above)...You're going to have...erm...an H+ ion and the Cl- ion and they are not necessarily going to be attracted to the water [AC CIII: lack understanding of ion-solvent attraction] and you are going to have an H2O molecule because water doesn't form its bonds in this way...it forms it in another way...like shells of electrons...and so you get a molecule of H2O...(drawing fig 4) and other molecules... here and...here and mixed around here, you can have H+ ions...and Cl- ions.

I: So now you are saying that there is probably no bonds between the hydrogen ions and the chloride ions?

R7: Erm...not when they are in water.

[Aspect B: 0.5KE]

I: Not when they are in water...Do you think there are any bonds between the water molecules and the hydrogen ions?

R7: No.

I: And then between the water molecules and the chloride ions?

R7: I don't think so.

I: You don't think there are any bonds whatsoever?

R7: Erm...I don't know...there might be but I don't think...I don't think there are...

[AC: There are no concept of ion-solvent interactions at all.]
How about between the water molecules themselves. Between this water molecule and this water molecule (pointing to two different but neighbouring molecules in fig 4) are there any forces of attraction...any bonds?

Er..there should be...I think.

Okay, then what is your picture of magnesium ribbon? At the atomic level, what does magnesium ribbon look like?

Erm..I think you're going to have lots of magnesium atoms...er..joined up like this (drawing fig 5), and so on..a lattice or something like that...and around them you're going to have a sea of electrons...because it's a metal and that's what I understand...all molecules are moving except at absolute zero. Each molecule would be shaking about a little bit and the more you heat, the molecules would shake about more and more.

[Note again AC C1a: confusion between atoms, molecules and ions.]

Okay then how do you picture this magnesium in this state changing into magnesium chloride and hydrogen gas?

Erm..as you heat up they shake more and more until it breaks free...and it's able to join...it will form, let me think, it should go to Mg$^{2+}$ and one of them will link up with a chlorine in the water...link up with two of them and you'll have MgCl$_2$ magnesium chloride.

Heat up...

Yes, it takes in heat from the surroundings..

You're saying that magnesium 2+ is linked up to the chloride ions in this aqueous solution?

Erm..they won't actually...not while they are aqueous...solution...they'll just...the magnesium will just change into ions...ionise...yah.. change into this (pointing to the Mg$^{2+}$ which he has written on paper) But if you..were to..remove...I think, the water in there I think the hydrogen reacts with the oxygen in the air to produce water..and so if you were to burn that off, evaparate it probably, you're left with magnesium and chloride ions which would form magnesium chloride.

You're saying that the hydrogen that is given off will react with oxygen in the air to produce water, some of which is found in the test tube here..

Yah, I think so, yah. Or it might not react..erm..I don't know hydrogen actually...it could be given off.
283 I: Which is more likely?

284 R7: I mean.. I think it's more likely to be given off actually.

285 I: So you don't think it's likely to react with oxygen from the air..

286 R7: Erm.. I don't know.. I think it's because it needs quite a lot of energy to do that, and it hasn't got that energy.

288 I: It needs a lot of energy to react with oxygen.. what do you see is the role of energy there..

290 R7: I'm not very sure..

291 I: Aha.. and can you enlighten me a bit more on how the magnesium changes from neutral atom to Mg^{2+}?

293 R7: Erm.. it loses two electrons.

294 I: Ah.. what happens to the two electrons?

295 R7: Er.. (laughed) I'm not very sure.. they.... (long pause) erm.. I think they'll produce.. erm.. other ions as well which the electrons will go. See when you make a negative ion, you've got to add electrons and so the electrons are going towards making negative ions.

299 I: Ahm.. negative ions.. you mean..

300 R7: I think it will be.. I'm not sure what.. probably hydroxide ion.. (long pause)

301 I: Say a bit more.. hydroxide ion..

302 R7: Erm.. I don't know.. maybe some of the hydrogen might react with an oxygen and an electron to go to.. erm.. hydroxide.. ion.. I'm not very sure.

304 I: You're saying that hydroxide ions are produced as well.

305 R7: I think so. Yeah.

306 [Note AC A3: 'anything goes as long as the elements are in a soup.]

307 [EVENT 4 - 3.5KEs; 1 new AC]

308 I: Okay, then what do you think happens if copper is used in place of magnesium. In other words, we add this acid to the copper, do you think there will be a chemical reaction?
311 R7: Erm..I think there will but it will take a lot longer because copper isn't so
312 reactive as magnesium. Erm..I'm not too sure why that is..I think it's because
313 the way its electrons are arranged in its shell in the atom itself..sort of lends
314 itself to it staying where it is..not reacting very much. If you were
to..maybe..heat it and then put it into hydrochloric acid, because it will have
315 more energy, it might react then.
316
317 [Note again his AC that heat supplied will drive reaction, AC D1a.]
318 I: What do you think is the driving force for this Mg-dilute HCl reaction?
319 R7: Erm..probably the acid..erm..it's just wanting to react..so they can form ions..
320 I: Just wanting to react..
321 R7: Erm..I don't think they are stable sort of..in each other's company..can't have
322 magnesium being stable when it's with hydrochloric acid..the..chlorine wants
to move from the hydrogen to magnesium.
323
324 [Aspect D: OKE, AC D2b: anthropomorphic explanations for driving force.]
325 I: I thought you said that the chlorine and the hydrogen are already separated in
326 the acid..
327 R7: Er.yah, but ..er..
328 I: And then in this solution...are the magnesium and the
329 chlorine..chloride..separated?
330 R7: Er.I'm not sure...they might be attracted to each other but erm..not join..
331 I: Can you say it again..go through what you think occurs step by step.
332 R7: Well..I think probably in hydrochloric acid..you've hydrogen ions and chlorine
333 ions..and I think when they..before it's made up..you've got erm..hydrogen
334 chloride and you add to water so..and what happens is that the bond between
335 the two atoms sort of breaks..and so they're free from each other.[Aspect C:
336 1KE].but I think they still remain quite close to each other and erm..you add
337 magnesium..and the magnesium reacts to produce the magnesium ion..and
338 possibly some other ions, maybe hydroxide ions or something like that..and
339 this magnesium ion then swaps places with the hydrogen ion and you get
340 something like that (writing 'Mg2+2Cl-').
341 I: Can you say a bit more about how you think water breaks the bonds in HCl?
342 R7: Erm.I don't know..I just..erm..I remember that when you add certain
343 substances to water, they break down into their ions.
Okay..I have some solid sodium chloride here. What do you predict will happen if I take some solid sodium chloride here and I add water to it?

It'll dissolve.

Aha..what do you mean by dissolving..

Erm..the..what do I mean by dissolving..Well, what I think, is splitting up into sodium and chlorine..and each of them can itself turn into an aqueous state because it's no longer solid..it's split up.........

Can you say a bit more about how you think water might cause this splitting up...

Erm..

What is it about water that cause this..

Don't know.

Okay, never mind. Then what is your picture..Okay, can you draw your mental picture of solid sodium chloride..what it looks like..and then draw another picture of what you think it looks like in water, after it's dissolved in water.

Erm..(drawing fig 6)..they all join to each other like this and it's sort of in a quite rigid frame..it's sort of cube type of thing.

Are these neutral atoms? (noting that he has merely written particles as 'Na' and 'Cl', i.e. without pluses and minuses signs.)

No, these are all ions so 2-, 2+, 2-, 2+ (adding '2+' to 'Na' and '2-' to 'Cl'), 2- and 2+ and so on and ..they sort of join up like that in a cube shape..it's crystalline..and when it goes into water..erm...I think it separates out into the two separate ions..though I don't really know very much about that.

So in the water would there be any attraction between these sodium and the chloride ions?

I don't know.

Will there be any bonds between them?

I don't think there would. But I'm not sure.

And then where would the water be..in relation to these ions?
R7: It's just all mixed around with it, because the water is neutral and the ions are charged...so it might join together...or be sort of attracted to each other but I'm not sure.

I: You're saying that something neutral could be attracted to something that is charged?

R7: Yeah...the substance wants to become neutral...neutrally charged again...I think...er...I don't know...I just know that charged substances or anything attracts a neutral...like if you charge a balloon, it can stick on the wall because it's charged and the wall is neutral.

I: Aha...aha...okay, right...then what do you predict will happen if I add lead nitrate solution to this sodium chloride solution?

R7: Erm...I don't know...one of two things, nothing would happen or er...the metals [Again AC Clα: confusion between elements and their compounds] would swap over basically...to form lead chloride and sodium nitrate.

I: So what determines whether they will swap over? What determines whether there will be a reaction?

R7: Erm...I think it's something to do with the activity series...we use it to determine whether metals are going to react.

I: Aha...so in this case let's see...why don't you write it down and then try to predict...This is sodium chloride...right...sodium chloride, aqueous, then plus lead nitrate aqueous...

R7: ...(writing 'NaCl(aq) + Pb(NO₃)₂')...erm...well, sodium's pretty reactive actually...I don't think that's going to happen...to be honest [AC C3b]

I: So you think there is not going to be a reaction?

R7: Erm...I don't think there will be...

I: Alright...I'm going to put some sodium chloride solution in this test tube and then add this lead nitrate solution...

R7: Yeah...(noting the white precipitate) Well, what's happened is that you've got lead chloride and sodium nitrate.

I: So what is it we are seeing now?

R7: Well, there...you've got a...well, that's a solid in there...which is the lead chloride, because lead chloride is insoluble...because it won't ionise...when it goes into solution...and so it sort of remains as it is...it's a solid but it's er...suspended in the solution.
You said that the lead chloride won't ionise...that means it doesn't exist as ions, does it, in the solid?

R7: *Erm...I don't know...it just won't ionise. It won't ionise when it goes into solution.*

I: So by saying that something would not ionise, you are saying that it would not exist as ions...is that what I'm understanding you...

R7: *I think so...yah...I don't know...It just is insoluble...substance.*

I: So what is your mental picture of lead chloride then? How do you picture lead chloride?

R7: *Erm...I don't know...It might be sort of you have...erm...a lead nucleus here and chlorine nucleus here and they've got electrons spinning around it...so if you see diagrammatically, they might be...sharing some electrons...(drawing fig 7) so they each become stable in configuration.*

I: Aha...so they are not ionic..

R7: *Er...I don't think so...no, in this case.*

I: Then in this case what do you think is the driving force?

R7: *Erm...it's because I think lead's...It's because the metals are reactive...lead is reactive, sodium is reactive...I think the sodium want...er...wants to be with the nitrate...and...because the sodium wants to combine with the nitrate...it's happier with nitrate than chloride...*

[Note AC D2b again]

I: How do you think the process is like...suppose we are looking at the reaction as it is occurring through our very powerful microscope which enable to see the tiniest of particles..

R7: *Erm...they are in ions...but I'm not too sure...how they react...*

I: What do you predict is the overall energy change..

R7: *Not sure about this one...*

I: Okay...Let's suppose that instead of adding lead nitrate solution, I add copper sulphate solution to sodium chloride solution. What do you predict will happen?
Enn.. (writing 'CuSO4 + NaCl →'). Enn.. I think it would probably stay as it is actually.. er.. I don't know.. I haven't.. I can't remember coming across sodium sulphate or copper chloride.. I don't know if they exist.

I: Right, this is copper chloride actually (holding up the bottle of aqueous copper chloride). So there is.. copper chloride does exist. And sodium sulphate does exist too.

R7: *Yah, I think they exist.. but I don't know.. I don't think they'll react.*

I: You don't think so..

R7: I'm pessimistic.. it might do.. I don't know.. it depends whether sulphate.. it wants to be with the sulphate or chloride.. or I don't really know.

I: I see.. aha.. then what do you mean by a chemical reaction?

R7: *Enn.. a chemical reaction is when chemicals or compounds combine or change to produce sort of.. new chemicals or compounds and.. there is actually something going on.. but is not like water turning into steam or something like that which is physical reaction.*

I: Okay, never mind.. let's talk about the magnesium reaction again where heat was produced. Where do you think the heat could come from? Adding the dilute HCl to magnesium ribbon.. and getting heat and hydrogen plus magnesium chloride.. where do you think the heat comes from?

R7: *Enn.. well.. when they react, they give out energy and that energy is transferred to heat.*

I: When things react, they give out energy...

R7: *Er.. some give out energy.. some need energy to react.*

I: Aha.. why the difference..

R7: Er.. I don't know.. it's like going uphill or going downhill.. that sort of thing. Sometimes.. some reactions go uphill.. so you need energy, you need heat to make them work, and some reactions go downhill, and so.. er.. they've got surplus energy, so gives out heat.

I: Aha.. can you say a bit more about this going uphill and downhill.. where do you think is the cause or origin of this energy.. or what cause some reactions to be on the top of the hill..
R7: Erm...I'm not sure...erm...I think certain elements react very vigorously...like fluorine is a very active gas...erm...but why I'm not too sure...I mean I know it's got something like seven electrons in its outer shell and so...erm...I think that makes it volatile...it would react quite easily...but certain elements like er...a noble gas is very hard, almost impossible to get them to react...because they are very stable...I'm not sure.

I: So where do you think the energy comes from? Like the energy in that reaction between magnesium and HCl.

R7: Erm...I think it's just the energy that's contained in the atoms themselves...because I don't know...

I: Is there a common driving force behind chemical reactions?

R7: Erm...I think it's just energy basically...either energy from heat or energy because it's moving or just energy mainly.

I: Okay, this is the absolute last question: You know in this reaction between magnesium and the acid, does water play any part in the reaction?

R7: No, I don't think so. I think the HCl needs to be in water so it's ionise or something so the reaction can occur.

I: I see...and then in the reaction between sodium chloride and lead nitrate...would the reaction take place if there was no water?

R7: Erm...I don't think so.

I: For what reason?

R7: Erm...I think it's because they are not ions...they're sort of like atoms joined together and there isn't any sort of incentive for them to react.

I: Okay, thank you very much.

(The interview which was about 90 minutes duration ended here. It was longer than usual because he was free in the subsequent hour and was willing to allow me to continue beyond the scheduled time of one hour.)

[SUMMARY EVENT 5 - 0KE, 1 NEW AC]
APPENDIX E.1

RECORD SHEET SHOWING WHICH KEs AND ACs ARE COUNTED

[The sample record sheet here records the specific KEs and ACs identified in the interview transcript in Appendix D in the columns which pertains to 'L' ie L6.]

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Notes on E1 Record Sheet

1st column: refers to event number;
2nd column: refers to specific KEs as set out in Appendix C;
3rd column: refers to 'specific KEs counted in the response under aspect A at L6';
4th column: refers to 'specific KEs counted in the response under aspect A at U6' and so forth.

If a particular KE is included in a student's response, then 'yes' is entered.
If part of the KE is included, then '½' is entered.

The rows corresponding to 'AC' record the specific ACs revealed by specific AC codes, a description of which is at Appendix H.
APPENDIX E.2

RECORD SHEET SHOWING WHICH KEs AND ACs ARE COUNTED FOR CASE I, STUDENT R7

[The sample record sheet here records the specific KEs and ACs identified in the interview transcript in Appendix D in the columns which pertains to 'L' ie L6. The 'U' ie U6 entries are based on the U6 interview, which are described in case I, chapter 12.]

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Notes on E2 Record Sheet

1st column: refers to event number;
2nd column: refers to specific KEs as set out in Appendix C;
3rd column: refers to 'specific KEs counted in the response under aspect A at L6';
4th column: refers to 'specific KEs counted in the response under aspect A at U6' and so forth.

If a particular KE is included in a student's response, then 'yes' is entered.
If part of the KE is included, then '½' is entered.

The rows corresponding to 'AC' record the specific ACs revealed by specific AC codes, a description of which is at Appendix H.
APPENDIX F
RECORD SHEET SHOWING NUMBER OF KEs AND ACs COUNTED

[The sample record sheet here records the number of KEs and ACs identified in the interview transcript in Appendix D.]

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NOTATION:

(X,Y) where X = No. OF KEs, and Y = No. OF ACs included in the response under a particular aspect and event.
**APPENDIX G**

**TABLE G.1**

U6 AND L6 KE SCORES AND PROGRESSION SCORES (U-L) FOR ASPECT A ACROSS EVENTS FOR EACH STUDENT

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331
APPENDIX H

CATEGORISATION OF ACs, THEIR DESCRIPTIONS AND FREQUENCIES

Category 1: ACs associated with naive chemistry, which encompasses the following 3 subcategories, to which are allocated the groups identified under aspects A to D in chapters 4 to 7.

sub-category i. ACs associated with perceptual thinking (groups A1 and B1);

A1a: substantialisation of heat; heat or flame is seen as a substance, more specifically, it is seen as a reactant or the active agent of chemical change

A1b: the conception of burning as catching fire or simply, as heating, the application of heat; oxygen may or may not be involved as a reactant; if oxygen is involved, its role was either unclear or misconceived; and the result of burning is not necessarily a chemical change.

A1c: metals do not burn

A1d: wax does not burn, only melts

A1e: burning always results in carbon dioxide being produced

A1f: role of solvent is unknown - chemicals dissolve in each other

B1a: a reaction must be overall endothermic if heat/heating is needed; conversely, if heat is not needed, then the reaction must be exothermic and spontaneous

sub-category ii. ACs associated 'one factor only' reasoning (group B2);

B2a: a reaction is overall exothermic because heat is given out from the excitement of electrons/molecules; a reaction is overall exothermic because chemicals give out energy

B2b: overall there is no energy change if the number of bonds broken equals number of bonds made; a reaction must be overall endothermic if one of the bonds to be broken is very strong; a reaction must be overall exothermic if one of the products is very stable (or
more stable) than one of the reactants

B2c: confusions between kinetic and thermodynamic stability eg a reaction is overall endothermic if a solid (wax) is being changed into a liquid and a gas (water and carbon dioxide) because gas is less stable than liquid which is less stable than a solid; bunsen flame releases more energy than a candle flame because a reactant in gas form has a lot of energy; a gas (like methane) is unstable so it is more easily broken down by oxygen than solid wax

sub-category iii. ACs associated with 'anything goes as long as the elements are in the soup' (groups A3 and A4).

A3a: when oxygen in air is used up in burning, then carbon dioxide is used instead of oxygen

A3b: carbon dioxide, as well as oxygen or instead of oxygen from the air is involved as a reactant in burning

A3c: burning alkanes such as methane results in carbon monoxide (instead of and carbon dioxide); hydrogen (instead of and water vapour)

A3d: Other examples of 'anything goes as long as the elements are in the soup' eg hydrogen evolved in Mg-HCl interaction reacts with oxygen in air to form hydroxyl group or water, etc.

A4a: copper when heated in air forms copper oxide and soot

Category 2: ACs associated with the process of bonding and the nature of bonds, which subsumes the following 3 subcategories, and the associated groups.

sub-category i. ACs associated with misconceived ideas about the nature of bonds and wrong direction of the energy change involved in bond breaking and bond making (group B3);

B3a: bonds release energy when broken, absorb energy when made; energy is needed to form bonds; bonds store energy; energy holds or binds atoms together; the bond is basically energy which holds atoms together
B3b: energy given off during bond making is energy which was put in to break bonds which it no longer needs

B3c: energy is required to break and to make bonds

B3d: a covalent is weaker than ionic or metallic bond

sub-category ii. ACs associated with various confusions, between particles and substances, and different types of bonds (groups C1 and C2);

C1a: confusion between elements, mixtures and compounds; particles and substances; oxidation numbers and electrical charges; electronegativity/electropositivity and electrical charges

C2a: confusions between covalent and ionic bonding, which are manifested in various forms

C2b: confusion about various types of bonds, intra- and inter-molecular bonds, Van der Waals bonds, etc.

sub-category iii. ACs associated with reactions in solutions (group C3).

C3a: dissolved substances eg HCl, NaCl form separate ions (or molecules) with ionic (or covalent) bonds still there, ie ions are not free (or water breaks inter- but not intra-molecular bonds in dissolves)

C3b: events 4 and 5 are seen as involving the displacement of something less reactive by something more reactive or seen as preferential attraction - magnesium bonds with chlorine and displaces hydrogen; attraction between sodium and nitrate breaks lead-nitrate bond

C3c: in the aqueous medium, H-Cl bond undergoes homolytic fission, ie when the H-Cl bond breaks, H comes off with 1 electron and Cl with 7 electrons in their outermost shells respectively; Mg loses electrons to Cl forming Mg-Cl bond in solution

C3d: water, the solvent, in event 4 and/or event 5 plays no significant part; reaction is faster or the same if water is absent
Category 3: ACs associated with driving force, which subsumes the following 3 subcategories and associated groups:

**sub-category i.** ACs which show ideas of conservation and have some scientific basis, and arising mainly from the lack of understanding about the driving force (group A2);

**A2a:** when alkanes burn, if the oxygen supply is insufficient, carbon monoxide instead of carbon dioxide will be formed, and/or hydrogen gas instead of water vapour

**sub-category ii.** ACs associated with the idea of energy input as the driving force (group D1);

**D1a:** driving force is heat input; heat is the causal agent of chemical change

**D1b:** driving force is internal energy of chemicals or the energy and power between the bonds

**sub-category iii.** ACs associated with relative reactivity or preferential attraction; or with water, the solvent (groups D2, D3 and D4).

**D2a:** driving force is the difference in reactivity or charge or electronegativity or competition between two things for something else

**D2b:** anthropomorphic explanations such as chemicals wanting to react to form full shells or just wanting to combine with one substance more than another because it is happier that way

**D3a:** water, the solvent is the driving force

**D4a:** the entropy of a system depends on the number of products vis-a-vis the number of reactants (i.e., there was no concept of the entropy dependence on the physical states)

**D4b:** driving force is to decrease the entropy of a chemical system

**D4c:** driving force is to increase the entropy of a chemical system
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APPENDIX I

NUMBER OF ACs BY STUDENT BY SCHOOL BY INTERVIEW, COUNTED ACCORDING TO PROCEDURE GIVEN IN SECTION 9.2, CHAPTER 9 (ie LIMITED TO MAXIMUM OF 9 PER STUDENT)

<table>
<thead>
<tr>
<th>Student</th>
<th>U-total AC</th>
<th>L-total AC</th>
<th>(U-L)AC</th>
<th>Student</th>
<th>U-total AC</th>
<th>L-total AC</th>
<th>(U-L)AC</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>E2</td>
<td>7</td>
<td>6</td>
<td>+1</td>
</tr>
<tr>
<td>C6</td>
<td>5</td>
<td>3</td>
<td>+2</td>
<td>E6</td>
<td>3</td>
<td>5</td>
<td>-2</td>
</tr>
<tr>
<td>C8</td>
<td>5</td>
<td>6</td>
<td>-1</td>
<td>E10</td>
<td>3</td>
<td>4</td>
<td>-1</td>
</tr>
<tr>
<td>C10</td>
<td>8</td>
<td>7</td>
<td>+1</td>
<td>E1</td>
<td>3</td>
<td>5</td>
<td>-2</td>
</tr>
<tr>
<td>C12</td>
<td>7</td>
<td>7</td>
<td>0</td>
<td>E3</td>
<td>6</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>C14</td>
<td>7</td>
<td>5</td>
<td>+2</td>
<td>E5</td>
<td>6</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>C16</td>
<td>7</td>
<td>5</td>
<td>+2</td>
<td>E7</td>
<td>3</td>
<td>4</td>
<td>-1</td>
</tr>
<tr>
<td>C18</td>
<td>7</td>
<td>7</td>
<td>0</td>
<td>E11</td>
<td>4</td>
<td>5</td>
<td>-1</td>
</tr>
<tr>
<td>C20</td>
<td>4</td>
<td>5</td>
<td>-1</td>
<td>E17</td>
<td>6</td>
<td>7</td>
<td>-1</td>
</tr>
<tr>
<td>E19</td>
<td></td>
<td></td>
<td></td>
<td>E19</td>
<td>4</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Total AC</td>
<td>53</td>
<td>48</td>
<td>+5</td>
<td>Total AC</td>
<td>45</td>
<td>52</td>
<td>-7</td>
</tr>
<tr>
<td>Average AC per student</td>
<td>5.9</td>
<td>5.3</td>
<td>+0.6</td>
<td>Average AC per student</td>
<td>4.5</td>
<td>5.2</td>
<td>-0.7</td>
</tr>
<tr>
<td>Student</td>
<td>U-total AC</td>
<td>L-total AC</td>
<td>(U-L)AC</td>
<td>Student</td>
<td>U-total AC</td>
<td>L-total AC</td>
<td>(U-L)AC</td>
</tr>
<tr>
<td>---------</td>
<td>------------</td>
<td>------------</td>
<td>--------</td>
<td>---------</td>
<td>------------</td>
<td>------------</td>
<td>--------</td>
</tr>
<tr>
<td>P2</td>
<td>4</td>
<td>6</td>
<td>-2</td>
<td>R2</td>
<td>5</td>
<td>7</td>
<td>-2</td>
</tr>
<tr>
<td>P4</td>
<td>2</td>
<td>4</td>
<td>-2</td>
<td>R4</td>
<td>5</td>
<td>8</td>
<td>-3</td>
</tr>
<tr>
<td>P6</td>
<td>3</td>
<td>4</td>
<td>-1</td>
<td>R6</td>
<td>5</td>
<td>6</td>
<td>-1</td>
</tr>
<tr>
<td>P8</td>
<td>2</td>
<td>3</td>
<td>-1</td>
<td>R1</td>
<td>3</td>
<td>6</td>
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<td>P10</td>
<td>3</td>
<td>6</td>
<td>-3</td>
<td>R5</td>
<td>3</td>
<td>6</td>
<td>-3</td>
</tr>
<tr>
<td>P12</td>
<td>4</td>
<td>6</td>
<td>-2</td>
<td>R7</td>
<td>3</td>
<td>5</td>
<td>-2</td>
</tr>
<tr>
<td>P14</td>
<td>6</td>
<td>6</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P16</td>
<td>4</td>
<td>6</td>
<td>-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P18</td>
<td>3</td>
<td>5</td>
<td>-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P20</td>
<td>5</td>
<td>5</td>
<td>0</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total AC</td>
<td>36</td>
<td>51</td>
<td>-15</td>
<td>Total AC</td>
<td>24</td>
<td>38</td>
<td>-14</td>
</tr>
<tr>
<td>Average AC per student</td>
<td>3.6</td>
<td>5.1</td>
<td>-1.5</td>
<td>Average AC per student</td>
<td>4.0</td>
<td>6.3</td>
<td>-2.3</td>
</tr>
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</table>
### APPENDIX I (CONTINUED)

<table>
<thead>
<tr>
<th>Student</th>
<th>U-total AC</th>
<th>L-total AC</th>
<th>(U-L) AC</th>
</tr>
</thead>
<tbody>
<tr>
<td>S2</td>
<td>7</td>
<td>6</td>
<td>+1</td>
</tr>
<tr>
<td>S4</td>
<td>5</td>
<td>4</td>
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<td>+1</td>
</tr>
<tr>
<td>S8</td>
<td>4</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>S10</td>
<td>6</td>
<td>8</td>
<td>-2</td>
</tr>
<tr>
<td>S12</td>
<td>4</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>S14</td>
<td>4</td>
<td>5</td>
<td>-1</td>
</tr>
<tr>
<td>S16</td>
<td>7</td>
<td>8</td>
<td>-1</td>
</tr>
<tr>
<td>S18</td>
<td>6</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>S20</td>
<td>5</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>S1</td>
<td>5</td>
<td>7</td>
<td>-2</td>
</tr>
<tr>
<td>S7</td>
<td>5</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>S11</td>
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<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Total AC</td>
<td>70</td>
<td>73</td>
<td>-3</td>
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<tr>
<td>Average AC per student</td>
<td>5.4</td>
<td>5.6</td>
<td>+0.2</td>
</tr>
</tbody>
</table>
APPENDIX J

MEAN SCORES OF ACs COUNTED BY PROCEDURE IN SECTION 9.2, CHAPTER 9
BY AC CATEGORY AND BY SCHOOL

<table>
<thead>
<tr>
<th>School</th>
<th>AC1-U</th>
<th>AC1-L</th>
<th>AC2-U</th>
<th>AC2-L</th>
<th>AC3-U</th>
<th>AC3-L</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>2.1</td>
<td>2.1</td>
<td>2.3</td>
<td>1.8</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>R</td>
<td>1.2</td>
<td>1.7</td>
<td>1.3</td>
<td>2.5</td>
<td>1.5</td>
<td>2.2</td>
</tr>
<tr>
<td>P</td>
<td>0.6</td>
<td>1.1</td>
<td>1.5</td>
<td>2.2</td>
<td>1.5</td>
<td>1.8</td>
</tr>
<tr>
<td>E</td>
<td>1.0</td>
<td>1.2</td>
<td>2.1</td>
<td>2.5</td>
<td>1.3</td>
<td>1.5</td>
</tr>
<tr>
<td>S</td>
<td>1.3</td>
<td>1.5</td>
<td>2.5</td>
<td>2.6</td>
<td>1.6</td>
<td>1.5</td>
</tr>
<tr>
<td>p</td>
<td>.002</td>
<td>.088</td>
<td>.053</td>
<td>.048</td>
<td>.804</td>
<td>.216</td>
</tr>
</tbody>
</table>

MEANING OF ENTRIES IN THE COLUMNS:

AC1-U: No of ACs in category 1 (ACs associated with naive chemistry) at U6;

AC1-L: No of ACs in category 1 at L6;

AC2-U: No of ACs in category 2 (ACs associated with the process of bonding and chemical bonds, the role of solvents, etc) at U6;

AC2-L: No of ACs in category 2 at L6;

AC3-U: No of ACs in category 3 (ACs associated with driving force of chemical change) at U6;

AC3-L: No of ACs in category 3 at L6.

The data shows that on AC1 (naive chemistry) school C was the only school where there was no reduction in the number of ACs held per student. In the other four schools, there appeared to be a reduction in the number of category 1 ACs. Also the reduction seemed greater in schools R and P than in schools E and S.

On AC2 (ie pertaining to the process of chemical change) again school C was at odds with the other 4 schools. At the U6 level, while in the other 4 schools, there was a reduction in the
number of ACs in AC2, in school C, there was an increase. At the same time, the reduction in the number of AC2 was greatest in school R, followed by school P, then schools E and S.

On AC3 (ACs in category 3, i.e., those which pertain to driving force of chemical change, there were no significant difference between the five schools. However, there appeared to be a slightly bigger reduction in the number of AC3 held by students in school R compared to those in the other four schools.
APPENDIX K1

PLOT OF TOT-U-KE VERSUS TOT-L-KE

```python
plot c12 c13
```

<table>
<thead>
<tr>
<th>TOT-U-KE</th>
<th>TOT-L-KE</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.0</td>
<td>10.5</td>
</tr>
<tr>
<td>14.0</td>
<td>17.5</td>
</tr>
<tr>
<td>21.0</td>
<td>24.5</td>
</tr>
</tbody>
</table>

343
APPENDIX K.2
PLOT OF T-PRO-KE VERSUS TOT-L-KE

\text{B > plot c94 c13}

\begin{center}
\begin{tabular}{c}
\text{-PRO-KE-} \\
\text{20+} \\
\text{10+} \\
\text{0+} \\
\hline
\text{7.0} & \text{10.5} & \text{14.0} & \text{17.5} & \text{21.0} & \text{24.5}
\end{tabular}
\end{center}
APPENDIX K.3

PLOT OF T-PRO-AC VERSUS TOT-L-KE

```
B > plot c96 c13

- 2.0+  *
- PRO-AC- *
- 0.0+ 2 3 2 2 2 *
- *
- -2.0+ 2 3 *
- *
- -4.0+ *
- *

---+-----+-----+-----+-----+-----+-----+-----
  7.0 10.5 14.0 17.5 21.0 24.5
```
APPENDIX K4

PLOT OF T-PRO-AC VERSUS PRO-KE

B > plot c96 c94

- 2.0+ * * *
- -
- PRO-AC-
  2 ** *
- -
0.0+ * 3 * * * * * * *
- -
- -
- * 3 * 2 * ** *
- -
- -
- -2.0+ * * * * * * * * *
- -
- -
- -4.0+ * 2 *
- -
+----------------------------------------+T-PRO-KE
 0.0  6.0  12.0  18.0  24.0  30.0

346
APPENDIX K.5

PLOT OF T-PRO-KE VERSUS TOT-L-KE FOR SCHOOL C

Note: School C

* * *
6.0 7.5 9.0 10.5 12.0 13.5

>retrieve 'bdwk001'
WSHEET SAVED 7/30/1994
APPENDIX K.6

PLOT OF T-PRO-KE VERSUS TOT-L-KE FOR SCHOOL R

B > Note: School R
B > plot c94 c13

T-PRO-KE

7.5 9.0 10.5 12.0 13.5 15.0

TOT-L-KE

24.0+

16.0+

8.0+

348
APPENDIX K.7

PLOT OF T-PRO-KE VERSUS TOT-L-KE FOR SCHOOL P

B > Note: School P
B > plot c94 c13

24.0+ *
16.0+ *
8.0+ *
0.0+ *

7.5 10.0 12.5 15.0 17.5 20.0 TOT-L-KE
APPENDIX K.8

PLOT OF T-PRO-KE VERSUS TOT-L-KE FOR SCHOOL E

% > Note: School E
% > plot c94 c13

---

T-PRO-KE
---

7.0+  *  *  *
---

3.5+  *  *
---

0.0+  *
---

TOT-L-KE
7.0  10.5  14.0  17.5  21.0  24.5
APPENDIX K.9

PLOT OF T-PRO-KE VERSUS TOT-L-KE FOR SCHOOL S

% > Note:  School S
% > plot c94 c13

\[ \text{TOT-L-KE} \]
\[ 6.0 9.0 12.0 15.0 18.0 21.0 \]

\[ \text{T-PRO-KE} \]
\[ 21.0+ \]
\[ 14.0+ \]
\[ 7.0+ \]
\[ 0.0+ \]
APPENDIX L

INVESTIGATION OF LEARNING APPROACHES OF THE STUDY SAMPLE

This appendix provides information on the work carried out on students' Learning Approaches as part of this study.

The information is provided as follows:

Appendix L.1 Review of studies on students' learning approaches with particular emphasis on Biggs' learning process questionnaire

Appendix L.2 Method of the Learning Process Questionnaire

Appendix L.3 The Learning Process Questionnaire with covering letter to the respondent

Appendix L.4 Findings based on the Learning Process Questionnaire

Appendix L.5 Analysis of Variance on Surface Approach (SA), Deep Approach (DA) and Achieving Approach (AA)

Appendix L.6 Profiles of study schools

Appendix L.7 Summary
The literature review on students' alternative conceptions studies seemed to point to one depressing fact, that each year students could do well according to conventional examination standards, including those at the university level, but they still harbour their naive views or misconceptions on topics that they were supposed to have learned. And this problem is not limited to learning in the natural sciences. Hallden (1986) and Hounsell (1984) for instance, reported persistent misconceptions held by school and university students regarding the nature of history as a subject, which was manifested in their written assignments. Dahlgren (1984) reported that a number of successful university economics students stubbornly believed that the price of a commodity is determined by its cost of production, rather than the interaction of demand and supply.

It seems that such students can be found at "all levels of educations and in nearly every subject", and that "some now teach other students" (Ramsden, 1988). It seemed that something has gone wrong with learning! It seemed that not only is there a need to look at the specific kinds of difficulties and misconceptions that students harbour, but there is also a need to look at how students approach learning and other factors that impinge on the outcomes of learning.

Research on students' approaches at the higher level (high school and beyond) has concentrated on describing from the perspective of the student. This research has been carried out from two main perspectives, i.e., psychometric and phenomenographic. The psychometric approach has used questionnaires and multi-variate techniques to identify and describe various learning approaches in terms of motives and strategies adopted by students in various contexts (e.g., Entwistle and Ramsden, 1983; Biggs, 1987). The phenomenographic approach on the other hand is based on qualitative analyses of student interviews about the way they handle their specific learning tasks, and qualitatively describe students' different approaches to study.

Researchers in both groups have identified significant relationships between students' learning approaches and the quality of what they learn. Thus working from the qualitative perspective Marton and Saljo (1976a,b) have shown that surface approaches lead to poorly structured and low level outcomes, whereas deep approaches then to lead to high levels of understanding.

At the same working from the psychometric perspective, Entwistle and Ramsden (1983)
have also reached similar findings; more specifically they show that the level of students' prior knowledge and factors associated with course and departmental structures and teaching influence the way students go about their learning and subsequently the levels of understanding. Thus, it has been found that an individual student may adopt different learning approaches in the learning of different subjects/courses, depending on their perceptions of what the subject or course is about and the expectations of teachers and assessors.

In this section of the review, background will be provided of the Biggs' LPQ, which has been selected as the instrument to identify students' learning approaches, so that the relationship between students' learning approaches and depth of understanding as determined through analysis of interviews could be examined.

One way of understanding student learning is provided by the '3P' model of learning, 'presage (or input), process and product (or output)', first outlined by Dunkin and Biddle (1974) in the context of classroom interaction, and elaborated by researchers such as Biggs (1978, 1985, 1987, 1989) (Figure 2.1).

The presage factors exist before the student enters the learning situation, and are of two kinds, i.e., the personological factors which comprise enduring personal characteristics such as cognate abilities and prior knowledge and the situational factors which are in the control of the institution and the teacher, i.e., the teaching context, and includes variables such as course structures, evaluation procedures and methods of teaching, and so forth.

The process factors make up the "learning process complex", which comprises three basic approaches to learning, each approach comprising a motive and a related congruent strategy.

The 3P model thus depicts a cycle of events, in which student characteristics, the teaching context and students' learning processes are related to learning outcomes. It represents an interactive system with the components at presage, process and product levels tending to be in equilibrium, and with the entire system being affected by changes to any one component. In effect, it means that the interaction of all components needs to be taken into account if improvement in learning is aimed for.

However, this section of the literature review is concerned mainly with the process factors of the 3P learning model; and more specifically with student approaches to learning.

In the literature on this area of student learning, writers have each referred basically to two different approaches: for example, Ausubel (1968) referred to rote and meaningful learning; Pask (1976) referred to serialist and holistic learning; Biggs and Telfer (1987) referred to generic and surface coding; Entwistle, Hanley and Hounsell (1979) referred to understanding and reproductive learning; Marton and Saljo, (1976a, 1976b) to deep level and surface level; (Schmeck, 1983) to deep processing and fact retention; (Biggs
and Rihn, 1984) to internalising and utilising dimensions.

These dual views suggest that there is support for the view adopted in this study - that there are three main students' learning approaches.

A number of studies have shown that conceptions of learning influence how students approach their learning tasks (Marton and Saljo, 1984; van Rossum and Schenk, 1984). For example, if learning is viewed essentially as the accretion of facts and procedures to one's repertoire, then a surface approach tends to be adopted in learning tasks. On the other hand, if learning is viewed as a way of interpreting the world through the developing of insights into subject matter, and new ways of thinking about reality, and personal growth, then a deep approach to learning tend to be adopted (Entwistle, 1988; Marton, 1988; van Rossum and Schenk, 1984).

The relationship between academic motivation and scholastic achievement is well-established.

There is evidence that conceptions of learning and approaches to learning are related to motives (e.g., Marton et al., 1984; Entwistle and Ramsden, 1983; Laurillard, 1984; Fransson, 1977). These studies have shown that the intentions and motives that students have influence the way they go about the business of learning tasks, i.e., they adopt a learning strategy which is in accordance with their motive.

The combination of motive and strategy, designated as an 'approach' to learning, three of which - deep, surface and achieving - have been identified by a methods which are based on information processing models of learning, and which used factor analysis techniques, and have been replicated several times (Biggs, 1978, 1979, 1987; Entwistle and Ramsden, 1983; Watkins, 1983). Two of these three approaches, viz., the deep and surface approaches are very similar to those identified by Marton and his colleagues (Marton and Saljo, 1976a,b, 1984), who had approached the problem from a phenomenographic perspective and who used qualitative analysis of interviews with students.

Biggs (1987, 1993) provides a good description and discussion of the three approaches as measured in the two related learning approach inventory designed, constructed and validated by him, viz., the SPQ (the Study Process Questionnaire which is used to determine learning approaches of tertiary level students) and the LPQ (the Learning Process Questionnaire, the parallel version of the SPQ, which is used to determine the learning approaches of secondary students). Each approach is a composite of motive and strategy.

The surface approach (SA) is based on extrinsic motivation. Affectively there are two inter-related surface motives (SM); pragmatic ones such as seeing school learning as a means towards some other end, like obtaining a job, and a more immediate negative motive of avoiding failure, seen in relatively high levels of test anxiety. In the absence
of any more positive reasons for learning, learning strategies are centred around avoiding failure but doing as little work as possible. Thus, the learner tends to be syllabus bound, learning what s/he really needs to, and with a view of reproducing the material rather than transforming and internalising the material.

The deep approach (DA) is based on interest in subject matter (DM). The learner is interested in the subject matter and sees the task as interesting and focuses on the underlying meaning rather than the literal aspects. The task components are integrated with each other and with other tasks. The learner reads widely, discusses with others and may 'play' with the task, theorising about it and forming hypothesis about how it relates to other known or interesting items.

The achieving approach (AA) is based on a particular form of extrinsic motive: the ego-enhancement that comes out of visibly achieving, and in particular through high grades. The related strategies refer to organising time, work space, syllabus coverage in the most efficient way (usually known as 'study skills'). The learner adopting an achieving approach sees high grades and marks as important, is competitive about obtaining them, sees it as important to be self-disciplined, neat, systematic, and plans ahead, allocating time to tasks according to their 'importance'.

Table L.1 summarises the three learning approaches in terms of the relevant motive-strategy combination.

<table>
<thead>
<tr>
<th>Approach</th>
<th>Motive (M)</th>
<th>Strategy (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>extrinsic: avoid failure but don't work too hard</td>
<td>focus on selected details and reproduce accurately</td>
</tr>
<tr>
<td>Deep</td>
<td>intrinsic: study to satisfy curiosity about topic</td>
<td>maximise understanding; read widely, discuss, reflect</td>
</tr>
<tr>
<td>Achieving</td>
<td>achievement: compete for highest grades</td>
<td>optimise organisation of time and effort ('study skills')</td>
</tr>
</tbody>
</table>

Adapted from Biggs (1987) p.11.

While at any given time, deep and surface approaches are mutually exclusive, an achieving approach may be linked to either surface deep approaches. Surface-achievers, for example, may systematically rote learn selected detail to attain high grades. Deep-achievers on the other hand, are organised and strategic in their search for meaning and high grades.
This model of learning in terms of motives and strategies is a particular instance of Mischel's (1973) description of how people behave in terms of their encoding strategies and self-regulatory systems. A student's encoding strategy of the learning context, or institution as a whole, is represented by his/her motives (to achieve high grades, to gain qualification, to pursue academic interests or any one or a combination of these). Similarly, a student's self-regulatory systems are represented by the strategies adopted (reproducing limited content, etc.). The kind of reflective self-awareness that is implied here is referred to as 'metacognition', or 'knowledge concerning one's own cognitive processes and products... (and) the active monitoring and sequential regulation of these processes in relation to cognitive objects or data on which they bear' (Flavell, 1976, p.232) while the way the individual interprets his/her own motives is a 'metamotivational state' (Apter, 1982, p.39). Thus, it can be seen that there is a 'psycho-logic' in how individuals construe their role in a situation, and in their decision to do something about it.

Marton and Saljo (1976a, 1976b) working from a phenomenographic perspective, also identified two learning approaches, deep and surface, which correspond very closely to those discussed in Biggs' framework.

In addition, the Biggs' learning model also finds support in other independent studies. An example is the work of Hackman and Taber (1979) who found their clusters of students to comprise three major groups: pragmatic careerists, self-directed scholars, and competitive leaders, which seemed to parallel respectively the surface, deep and achieving approaches in Biggs' model.

Another model which is closely akin to Biggs' model is that of Entwistle, who used similar multi-dimensional analysis and whose Approaches to Study Inventory (ASI) addresses Pask's (1976) leaning styles (Entwistle and Brennan, 1971; Entwistle and Wilson, 1977; Entwistle and Ramsden, 1983).

In particular, in a study (Entwistle, Hanley and Hounsell, 1979) 800 students in two English universities were surveyed using the Entwistle's ASI. Data were factor analysed, which yielded three second-order factors, referred to by the researchers respectively as understanding, reproducing and achieving. Understanding involves the search for meaning, and is related to intrinsic motivation; reproducing involves rote-memorising of information and is related to fear of failure and extrinsic motivation; and achieving a high degree of self-confident and ruthless organisation. The resemblance to the Biggs' model seems remarkable.

In a subsequent study Ramsden and Entwistle (1981) using the same instrument, ASI, responses from 2208 students from 66 academic departments in six disciplines in British tertiary institutions were collected and then factor analysed. This time four factors were found, the same three as listed in the earlier study, and an additional 'disorganised and dilatory' factor.
Watkins (1982) administered Entwistle’s ASI to 540 Australian university students and identified three factors, one deep, and two surface (disorganised and organised). The components of the achieving factor were dispersed over the other three. In another study with 300 Australian students, Watkins (1983) obtained a similar result, but regarded his results as generally supporting 'the meaning/reproducing/achieving model of the study process complex' (p.29). Further support for the existence of these learning orientations among Australian students was provided by Watkins and Hattie (1980), Hattie and Watkins (1981), O'Neil & Child (1984) and Entwistle and Kozeki (1985).

Thus it seems that the three factor approaches-to-learning models are well supported by large scale empirical studies such as those quoted in the preceding sections, although the precise nature of the factors will vary according to the instruments (some ASI items were very similar to those in the SPQ, but others were quite different), the samples and the method of factor analysis used (Biggs, 1993). But, this is not to say that these are the only three approaches. Entwistle and Watkins in the above mentioned and other studies have each referred to a "disorganised and dilatory factor" while Taylor (1984) from a different perspective refers to what may be construed as the same three approaches of Biggs (SA, DA and AA) plus four others including a "social" approach.

Examples of studies which have used either the Biggs' SPQ or LPQ and which report that surface approaches are correlated low level outcomes while deep approaches are correlated with high level outcomes are Biggs (1979, 1987a; Watkins, 1983, Trigwell and Prosser, 1991a).

Examples of other studies which have used the Biggs' LPQ to understand the relationship between students' learning outcome and learning approaches are Hegarty-Hazel and Prosser, 1991a, b; Leong, 1990; K.Tang (1991); T. Tang (1991), Hattie and Watkins (1981); Watkins and Astilla, 1982.

CONCLUSION FROM THIS REVIEW

The above mentioned studies show some of the history and current research aimed at understanding students' learning approaches. It also gives the background to the Biggs' Learning Process Questionnaire (LPQ) which is used in this study to to attempt to understand the study students' learning approaches and its relation to learning outcome in terms of understanding of the nature of chemical reactions.
APPENDIX L.2

METHOD OF THE LEARNING PROCESS QUESTIONNAIRE

L.2.1 Background

From Appendix L.1, the studies reviewed have shown that among other factors, students' perceptions of the learning situations and task context impinged on the way they go about learning, and hence how well they learn (Marton and Saljo, 1984, Entwistle and Ramsden, 1983, Biggs, 1987).

Admittedly, in the search for clues to understand how students learn or not learn, it would be useful not just to know the students' perceptions of their chemistry classes but also other information such as the effectiveness of the teaching, the characteristics of the interaction between the teacher and the students, the aims and expectations that the teacher has for each learning situation and so forth. Among other things, it would be pertinent to test if there is congruence between the teachers' aim and expectations with the actual situation itself, as well as with the students' interpretations of the learning situation. However, in this study because the main focus had been on the developing of insights into the nature of students' conceptions; and because of practical constraints (such as those related to time constraints, and of getting the teachers' concurrence to allow this researcher to observe an appropriate number of chemistry classes), only two variables in the learning situation have been explored. These are: students' learning approaches and students' perceptions of their chemistry classes. Information on these variables were gathered by means of the learning process questionnaire (see Appendix L.3: The Learning Process Questionnaire). This questionnaire employs a 5 point Likert scale, ranging from 1 to 5.

The first 36 items of this questionnaire which were aimed at evaluating students learning approaches in terms of learning motives and strategies, were taken from the Biggs' Learning Process Questionnaire (LPQ), which had been extensively validated (see section L.1). No modifications were made to the borrowed items except for one case, namely item 25, where the first two words 'I think' were added, because the form or style of item 25 seemed to be slightly at odds with the rest of the 35 items, without the two added words.

The last 14 items on students' perceptions of their chemistry classes were designed by this researcher and validated by two experts.
L2.2 THE ADMINISTRATION OF THE LEARNING PROCESS QUESTIONNAIRE

The learning process questionnaire was given to each interviewee at the end of the upper sixth interview session, together with a covering letter (see Appendix 4) and a stamped self-addressed envelope. Each interviewee was again assured of the confidentiality of his/her responses to the questionnaire; the fact that it was necessary to mark each questionnaire by a code in order to facilitate the matching of questionnaire responses with interview data was explained. That it was imperative for each interviewee to complete and return the questionnaire to the interviewer was also emphasised.

As requested by the researcher, 44 out of the 48 students completed and returned the questionnaire within a few days. Only 4 students needed to be reminded by telephone to complete; who subsequently returned the questionnaire. Thus, all 48 questionnaires were duly completed and returned.

L2.3 VALIDITY AND RELIABILITY OF THE BIGGS' LEARNING PROCESS QUESTIONNAIRE (LPQ)

The Biggs' Learning Process Questionnaire (LPQ) was the culmination of research which extended over a period of nearly 20 years. Its validation and use (together with that of its parallel version, the SPQ or Study Process Questionnaire, for use with tertiary students) was documented in Biggs (1987), and summarised in section L.1.


The test-retest reliability correlations for Year II (that is, lower sixth form) students, available from two independent studies ranged from 0.49 to 0.72 in one study and from 0.60 to 0.70 in the other. These figures were considered as highly satisfactory, indicating that students did display a measure of stability in their motives and strategies (Biggs, 1987).

The last 14 items were constructed by this researcher were validated by two experts in the field of education and teacher training, who also crossed-checked the interpretation of these items to ensure their reliability.
L2.4 ANALYSIS OF DATA FROM THE LEARNING PROCESS QUESTIONNAIRE

The 6 sub-scales on the Biggs' LPQ, are presented in the following section, the first item Q1 on the questionnaire contains a statement which pertains to the first sub-scale, SM (Surface Motive); the second item Q2 pertains to the second sub-scale, SS (Surface Strategy); the third item Q3 pertains to the third sub-scale, DM (Deep Motive); the fourth item Q4 pertains to the fourth sub-scale, DS (Deep Strategy); the fifth item Q5 pertains to the fifth sub-scale, AM (Achieving Motive); and the sixth item Q6 pertains to the sixth sub-scale, AS (Achieving Strategy), then the cycle repeats itself, with the seventh item Q7 pertaining to the first sub-scale, SM and so forth.

Table L.2 summarises the computation of the various sub-scales which are based on Q1 to Q36 of the questionnaire (see Appendix L.3 for the full questionnaire, which includes the covering letter to the respondent). The more detailed description of the computation process is then presented in the few paragraphs.

<table>
<thead>
<tr>
<th>NAME OF SUB-SCALE</th>
<th>COMPUTATION OF SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM (Surface Motive)</td>
<td>Q1 + Q7 + Q13 + Q19 + Q25 + Q31</td>
</tr>
<tr>
<td>SS (Surface Strategy)</td>
<td>Q2 + Q8 + Q14 + Q20 + Q26 + Q32</td>
</tr>
<tr>
<td>SA (Surface Approach)</td>
<td>SM + SS</td>
</tr>
<tr>
<td>DM (Deep Motive)</td>
<td>Q3 + Q9 + Q15 + Q21 + Q27 + Q33</td>
</tr>
<tr>
<td>DS (Deep Strategy)</td>
<td>Q4 + Q10 + Q16 + Q22 + Q28 + Q34</td>
</tr>
<tr>
<td>DA (Deep Approach)</td>
<td>DM + DS</td>
</tr>
<tr>
<td>AM (Achieving Motive)</td>
<td>Q5 + Q11 + Q17 + Q23 + Q29 + Q35</td>
</tr>
<tr>
<td>AS (Achieving Strategy)</td>
<td>Q6 + Q12 + Q18 + Q24 + Q30 + Q36</td>
</tr>
<tr>
<td>AA (Achieving Approach)</td>
<td>AM + AS</td>
</tr>
</tbody>
</table>

The scores on each sub-scale was thus obtained by summing up the scores on each item which pertains to it. As the maximum score on each Likert type item is 5 and the minimum score is 1, this means that the maximum score on each of the motive or strategy sub-scales is 5x6 or 30 and the minimum is 1x6 or 6.

The sum of each pair of congruent motive and strategy scores yielded a score on the corresponding approach sub-scale. For example, the Surface Approach (SA) sub-scale
score was obtained by adding the scores on the Surface Motive (SM) and Surface Strategy (SS) scores; the Deep Approach (DA) sub-scale score is obtained by adding the scores on Deep Motive (DM) and Deep Strategy (DS) sub-scales; and the Achieving Approach (AA) sub-scale score is obtained by adding the scores on the Achieving Motive (AM) and Achieving Strategy (AS) sub-scales.

The items Q37 to Q50 were examined individually and then together to build up a snapshot idea of the kinds of perceptions that the students had of their chemistry classes.
APPENDIX L3

THE LEARNING PROCESS QUESTIONNAIRE WITH COVERING LETTER TO THE RESPONDENT

Date:

Dear _______________

Thank you very much for the many interesting ideas and precious time you have given in the interviews.

As mentioned before, this research looks at not only students' ideas about Chemistry but also attitudes and ways of learning the subject.

As a further contribution to the research, it would be most helpful if you could make just a little more of your valuable time available to complete the attached questionnaire.

It is a simple questionnaire, not about your knowledge of Chemistry, but about how you learn Chemistry.

I would be most grateful if you could return the completed questionnaire WITHIN THE NEXT FEW DAYS to:

Miss Hong Kwen Boo
William Goodenough House
Mecklenburgh Square
London WC1N 2AN

I am enclosing a stamped addressed envelope.

Thank you very much again.

Yours sincerely,

H.K. Boo
APPENDIX L.3 (CONT.)

THE LEARNING PROCESS QUESTIONNAIRE (LPQ)

This questionnaire contains a number of questions about your attitudes towards your studies and your usual ways of learning in school.

There is no RIGHT way of going about your learning. It all depends on what suits your own style and the subjects you are studying. The following questions have been carefully selected to cover most aspects of your schoolwork and your answer to each question is important. If you think your answers to a question would depend on the subject being learnt, give the answer that would apply to learning Chemistry at A-level.

HOW TO ANSWER

For questions 1-49, there is a row of numbers ranging from one to five:

1  2  3  4  5

A response is shown by circling the number which is closest to the way you want to respond.

The numbers stand for the following responses:
1 - this statement is NEVER or ONLY RARELY true
2 - this statement is SOMETIMES true
3 - this statement is true about HALF THE TIME
4 - this statement is FREQUENTLY true
5 - this statement is ALWAYS or ALMOST ALWAYS true

EXAMPLE

I study best with the radio on.

If this is almost always true of you, you should circle 5, thus:

1  2  3  4  5

If you only sometimes study well with the radio on, you should circle 2, thus:

1  2  3  4  5
Underline the number that best fits your FIRST reaction - don't spend a long time on any question, and answer every question.

For question 50 there is a slightly different form of response which is explained on the last page of this questionnaire.

Do not worry about what you think your teachers or anyone else might want you to say. Your answers are CONFIDENTIAL.

Thank you very much for your help and co-operation.
LEARNING PROCESS QUESTIONNAIRE

1. I chose my present subjects mainly to help me get a good job when I leave school, not because I'm particularly interested in them.

   1 2 3 4 5

2. I find that my school work can give me a feeling of real satisfaction.

   1 2 3 4 5

3. I try to obtain high marks in all my subjects because of the advantage this gives me in competing with others when I leave school.

   1 2 3 4 5

4. I tend to study only what's set; I don't do anything extra.

   1 2 3 4 5

5. While I am studying, I try to think of how useful the material that I am learning would be in real life.

   1 2 3 4 5

6. I regularly take notes from suggested readings and put them with my class notes on a topic.

   1 2 3 4 5

7. I am upset by a poor mark on a test and worry about how I will do on the next test.

   1 2 3 4 5

8. I feel I have to say what I think is right, although others may know better than I do.

   1 2 3 4 5

9. I really want to do better than anyone else in my school work.

   1 2 3 4 5

366
10. I find that the best way to learn many subjects is to memorise them by heart.

1 2 3 4 5

11. In reading new material, I am reminded of things I already know, and see them in a new light.

1 2 3 4 5

12. I try to work solidly throughout the term and revise regularly when the exams are close.

1 2 3 4 5

13. Whether I like it or not, I can see that studying is for me a good way to get a well-paid or secure job.

1 2 3 4 5

14. I find that many subjects can become very interesting once you get into them.

1 2 3 4 5

15. I like the results of tests to be put up publicly so I can see by how much I beat some others in the class.

1 2 3 4 5

16. I prefer subjects requiring me to learn facts and details, to subjects requiring a lot of reading and understanding.

1 2 3 4 5

17. I like to do enough work on a topic to form my own point of view before I am satisfied.

1 2 3 4 5

18. I try to do all of my assignments as soon as they are given to me.

1 2 3 4 5
19. Even when I have studied hard for a test, I worry that I may not be able to do well on it.

1 2 3 4 5

20. I find that studying some topics can be really exciting.

1 2 3 4 5

21. I would rather be highly successful in school than be popular with my classmates.

1 2 3 4 5

22. In most subjects I try to do enough just to make sure I pass, and no more.

1 2 3 4 5

23. I try to relate what I learn in one subject to what I have learned in other subjects.

1 2 3 4 5

24. Soon after a class or lab, I re-read my notes to make sure I can read them and understand them.

1 2 3 4 5

25. I think that teachers should not expect A-level students to work on topics that are outside the set course.

1 2 3 4 5

26. I feel that one day I might be able to change things in the world that I see now to be wrong.

1 2 3 4 5

27. I will work for top marks in a subject whether or not I like that subject.

1 2 3 4 5
28. I find it better to learn just the facts and details about a topic rather than try to understand all about it.

1 2 3 4 5

29. I find most new topics interesting and spend extra time trying to find out more about them.

1 2 3 4 5

30. When a test is returned, I correct all the errors I made and try to understand why I made them.

1 2 3 4 5

31. I will continue my studies only for as long as necessary to get a good job.

1 2 3 4 5

32. My main aim in life is to find out what to believe in and then to act accordingly.

1 2 3 4 5

33. I see doing well in school as a competition, and I determine to win.

1 2 3 4 5

34. I don't spend time on learning things that I know won't be asked in the exams.

1 2 3 4 5

35. I spend much of my free time finding out more about interesting topics which have been discussed in different classes.

1 2 3 4 5

36. I try to read all the references and things my teacher says we should.

1 2 3 4 5

37. Our chemistry teacher gives us lots of notes to study from.

1 2 3 4 5
38. Our chemistry theory lessons consist of lectures or talks by the teacher.

39. In our chemistry lab work we are given instructions which tell us exactly what to do.

40. There are adequate opportunities for us to raise questions during chemistry lessons.

41. In class our chemistry teacher asks questions to test our recall of knowledge.

42. In class our chemistry teacher asks questions which make us think.

43. Our chemistry teacher sets us assignments or homework which require us to work cooperatively in pairs or small groups.

44. Our chemistry teacher sets us assignments or homework which require us to work independently or individually.

45. In our chemistry lab work we work individually.

46. In our chemistry lab work we work in pairs or small groups.

47. In our chemistry lab work we have to think a lot about the ideas involved.
48. In our chemistry lessons, lab work and theory are kept quite separate.

1  2  3  4  5

49. Discussing chemistry ideas with other students helps me in my learning of chemistry.

1  2  3  4  5

For question 50, the numbers stand for the following responses:

1 - less than once a week
2 - once a week
3 - twice a week
4 - once a fortnight
5 - more than twice a week

50. Further work in chemistry (eg homework, project work, summaries, further reading, preparing for tests) are set

1  2  3  4  5

Please indicate your gender by circling as appropriate:

FEMALE  MALE

371
APPENDIX L4

FINDINGS BASED ON THE LEARNING PROCESS QUESTIONNAIRE

Section L4.1 presents findings related to students' learning approaches, based on the analysis of the first 36 items of the LPQ.

Section L4.2 presents findings related to students' perceptions of their chemistry classes, based on the analysis of the last 14 items of the LPQ.

L4.1 STUDENTS' LEARNING APPROACHES

One way analysis of variance on each learning motive-strategy-approach subscale was carried out via the Minitab software, samples of which are at section L4.3.

Table L4.1 presents the mean scores on each of the learning motive-strategy-approach subscales by school with p values of significance.

<table>
<thead>
<tr>
<th>SCHOOL</th>
<th>SM</th>
<th>SS</th>
<th>SA</th>
<th>DM</th>
<th>DS</th>
<th>DA</th>
<th>AM</th>
<th>AS</th>
<th>AA</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>22</td>
<td>16</td>
<td>38</td>
<td>23</td>
<td>17</td>
<td>40</td>
<td>17</td>
<td>17</td>
<td>34</td>
</tr>
<tr>
<td>R</td>
<td>16</td>
<td>13</td>
<td>29</td>
<td>20</td>
<td>19</td>
<td>39</td>
<td>17</td>
<td>19</td>
<td>36</td>
</tr>
<tr>
<td>P</td>
<td>18</td>
<td>15</td>
<td>33</td>
<td>20</td>
<td>18</td>
<td>38</td>
<td>20</td>
<td>17</td>
<td>37</td>
</tr>
<tr>
<td>E</td>
<td>17</td>
<td>13</td>
<td>30</td>
<td>22</td>
<td>22</td>
<td>44</td>
<td>20</td>
<td>23</td>
<td>43</td>
</tr>
<tr>
<td>S</td>
<td>21</td>
<td>15</td>
<td>36</td>
<td>22</td>
<td>18</td>
<td>40</td>
<td>20</td>
<td>21</td>
<td>41</td>
</tr>
<tr>
<td>p</td>
<td>.025</td>
<td>.085</td>
<td>.008</td>
<td>.258</td>
<td>.123</td>
<td>.396</td>
<td>.383</td>
<td>.077</td>
<td>.144</td>
</tr>
</tbody>
</table>

Looking at data on the 3 main learning approach subscales (SA, DA and AA) there appeared to be significant difference (p≤0.05) between the schools on only the surface approach (SA) subscale; the difference was due mainly to the higher scores in school C and S compared with the relatively lower scores in schools R
and E.

L4.2 STUDENTS' PERCEPTIONS OF THEIR CHEMISTRY CLASSES

The following Table L.4.2 present mean scores on each item Q37 to Q50 by school, showing also p values of significance.

TABLE L.4.2
MEAN SCORES ON Q37-Q50 BY SCHOOL

<table>
<thead>
<tr>
<th>School</th>
<th>Q37</th>
<th>Q38</th>
<th>Q39</th>
<th>Q40</th>
<th>Q41</th>
<th>Q42</th>
<th>Q43</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (n=9)</td>
<td>4.0</td>
<td>4.4</td>
<td>3.6</td>
<td>4.1</td>
<td>3.1</td>
<td>3.2</td>
<td>1.4</td>
</tr>
<tr>
<td>R (n=6)</td>
<td>4.0</td>
<td>4.0</td>
<td>3.7</td>
<td>4.8</td>
<td>4.0</td>
<td>3.8</td>
<td>1.5</td>
</tr>
<tr>
<td>P (n=10)</td>
<td>4.2</td>
<td>2.7</td>
<td>4.4</td>
<td>3.8</td>
<td>2.9</td>
<td>3.4</td>
<td>1.2</td>
</tr>
<tr>
<td>E (n=10)</td>
<td>3.2</td>
<td>3.4</td>
<td>3.6</td>
<td>4.3</td>
<td>3.8</td>
<td>4.0</td>
<td>2.2</td>
</tr>
<tr>
<td>S (n=13)</td>
<td>4.0</td>
<td>2.5</td>
<td>4.3</td>
<td>4.5</td>
<td>4.0</td>
<td>3.8</td>
<td>1.8</td>
</tr>
<tr>
<td>p</td>
<td>.137</td>
<td>.010</td>
<td>.023</td>
<td>.385</td>
<td>.068</td>
<td>.662</td>
<td>.060</td>
</tr>
</tbody>
</table>

TABLE L.4.2 (CONT.)

<table>
<thead>
<tr>
<th>School</th>
<th>Q44</th>
<th>Q45</th>
<th>Q46</th>
<th>Q47</th>
<th>Q48</th>
<th>Q49</th>
<th>Q50</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>4.3</td>
<td>4.3</td>
<td>1.7</td>
<td>2.9</td>
<td>3.3</td>
<td>3.8</td>
<td>3.7</td>
</tr>
<tr>
<td>R</td>
<td>4.5</td>
<td>1.8</td>
<td>4.3</td>
<td>3.3</td>
<td>1.5</td>
<td>3.5</td>
<td>2.8</td>
</tr>
<tr>
<td>P</td>
<td>4.7</td>
<td>3.2</td>
<td>3.0</td>
<td>2.7</td>
<td>3.1</td>
<td>4.6</td>
<td>2.9</td>
</tr>
<tr>
<td>E</td>
<td>3.5</td>
<td>2.4</td>
<td>4.0</td>
<td>3.6</td>
<td>2.0</td>
<td>4.2</td>
<td>4.6</td>
</tr>
<tr>
<td>S</td>
<td>4.7</td>
<td>3.0</td>
<td>3.6</td>
<td>3.5</td>
<td>2.2</td>
<td>4.1</td>
<td>3.6</td>
</tr>
<tr>
<td>p</td>
<td>.019</td>
<td>.000</td>
<td>.000</td>
<td>.267</td>
<td>.007</td>
<td>.295</td>
<td>.018</td>
</tr>
</tbody>
</table>

From Table L.4.2 it appears that there are significant differences (p≤0.05) among the schools on seven items, i.e., Q38, Q39, Q44-46, Q48 and Q50; and on three other questions, Q37, Q41 and Q43 there are also some fairly significant differences.

373
However, the results are inconclusive because there appear to be no significant differences on any of the items between the good schools (i.e., R and P) on one hand and the weak schools (C and E) on the other hand.

**L4.2.1 INTERPRETATION OF SCORES ON ITEMS Q37-Q50**

On Q38, the frequency of teacher talk, on which there was significant difference between schools, school C had the highest score (4.4, which coincided with this researcher's observation) while schools P and S had the lowest scores (2.7 and 2.5 respectively).

Q39, on whether students were given exact instructions in lab work, all schools scored high (around 4); schools P and S had the highest scores (4.4 and 4.3 respectively) while the scores for the other three schools C, R and E were 3.6, 3.7 and 3.6 respectively.

On Q44 the scores were all high (between 4 and 5) indicating that in all five schools students were given homework or assignments which almost always or frequently involved individual work.

On Q45 the significant difference appears to be mainly between schools C and R, with scores in school C much higher than those in school R, which seems to indicate that students in school C perceived that they work individually more often than students in school R. The mean scores of the other three schools were sandwiched between those of schools C and R.

Students' responses on Q46, offer a good consistency check on the students' responses, since it is an item testing the converse of Q45, i.e., it is about doing work in pairs or small groups in the chem lab. The scores on Q46 seemed to be the converse of those in Q45 showing that students seemed to be rather consistent in the way they were responding to the items on the questionnaire. However, it is a pity that there is an oversight here on the part of this researcher in not placing Q45 and Q46 further apart on the LPQ, which might limit its usefulness as a parallel item for checking consistency. In other words, students in school R seemed to think they were doing work in pairs or small groups more often than those in school C.

On Q48, again the significant difference seemed to be between schools C and P as a higher group (i.e., the two all-girls schools) and the other three coed schools. It seems to indicate that students in schools C and P seemed to think that their chemistry lab work and theory are kept separate more often than students in the other three schools. In the case of schools R and E, it was not surprising that there appeared to be integration of lab work with theory lessons because of the structure
of the Nuffield A-level chemistry curricula. However, it was interesting to note that while following the same syllabus, students in school S seemed to think there was more integration of their lab and theory work than students in school P.

On Q50, there seemed to be significant difference in the students' perceptions about frequency of follow up work in chemistry. Students in schools R and P (the two schools which showed the most progression) seemed to think they were given follow up work twice a week, while those in school E seemed to think they were given work more than twice a week. Students in schools C and S seemed to think that they were given follow up work about once a fortnight.

On Q41 where there is again some school differences (p≤0.1) though not as significant as the first lot of 7 items, the difference seemed to be between two groups (school C and P, the two all-girls schools) and the other three schools which were coed schools. Students in the latter group of schools seemed to think that they were given questions to test their recall of knowledge more often than the students in the two all-girls schools.

On Q43 there is again some school difference (p≤0.1). Q43 is related to Q44, and concerns the students' perceptions of whether the teacher sets assignments or homework which require them to work cooperatively in pairs or in small groups. The mean scores on Q43 for all schools were fairly low, ranging between 1.2 and 2.2, compared to those for Q44, which ranged between 3.5 and 4.7, and which again provides some indication of the consistency in the students' responses. The overall picture given is that in practically all the schools, chemistry homework and assignments were pretty much individual work, with little paired or small-group work.

On Q37 (with a p value of about 0.1, indicating a small degree of significance between schools) mean scores of the four schools, C, R, P and S were each around 4, indicating that their students perceived that their chemistry frequently gave them lots of notes to study from. School E had a mean score of 3 indicating that its students seemed to think that their teacher gave them lots of notes only about half the time.

INFORMATION FROM THE REST OF THE ITEMS

Q40 the mean scores for all schools were high, between nearly 4 and nearly 5. School R has the highest mean score of 4.8 (followed very closely by school S), while the means for the other three schools were around 4, indicating that students in school R (and S to some extent) perceived that there were opportunities for them to raise questions during chemistry lessons more frequently than students in the other four (three) schools. Again the students' responses are in accordance with
this researcher's observation or perception that in schools R and S, (which are the only two sixth form colleges), the teachers seemed to adopt a less authoritative stance, and seemed "less stand-offish" or more "approachable" and "friendly" with the students; and also with this researcher.

On Q42 the mean scores for the three coed schools (R, E and S) were all around 4, while those for the two all-girls schools (C and P) were around 3, indicating that the students in coed schools seemed to perceive that they were given questions which make them think more often than the students in the all-girls schools.

On Q47, which is the parallel to Q42, except that it refers more specifically to lab work, again the mean scores for the two all-girls schools were lower than those in the other three schools, indicating that students in coed schools seemed to perceive that they were made to think a lot about the ideas involved in chemistry classes more frequently than students in the all-girls schools. Again the students responses to both Q42 and Q47 were in congruence, again pointing to the reliability of the students responses.

On Q49 the scores were all similarly high, between 4 to 5, indicating that the part played by discussing with friends is perceived as helpful in promoting chemistry learning in all 5 schools. The mean score of school P was the highest, 4.6 while that for school R was 3.5, one unit less. However, when mean scores were rounded off to the nearest integer, it appears that there were no difference between the other 4 schools, C, R, E and S, while that of school P was the highest. This seems to indicate that students in school P perceived that discussing chemistry ideas with other students help them in chemistry learning more than students in other schools. This finding is again in line with this researcher's observation that in school P there were not only an unusually small number of students (10 girls in the entire school) sitting for the impending A-level chemistry examinations, but that the classes and rooms were structured in such a way that these ten interviewees had opportunities to discuss (for example, these girls had their own study room to which they went during their free periods or in the interim periods between lessons.
APPENDIX L.5
ANALYSIS OF VARIANCE ON SURFACE APPROACH (SA), DEEP APPROACH (DA) AND ACHIEVING APPROACH (AA)

### ANALYSIS OF VARIANCE ON SA

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<thead>
<tr>
<th>Source</th>
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<th>MS</th>
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<td>107.3</td>
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<td>1174.1</td>
<td>27.3</td>
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<td>Total</td>
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LEVEL

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<td>37.667</td>
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<td>2</td>
<td>6</td>
<td>29.167</td>
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<td>3</td>
<td>10</td>
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<td>5</td>
<td>13</td>
<td>35.615</td>
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LED STDEV = 5.225

### ANALYSIS OF VARIANCE ON DA

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LEVEL

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<td>5</td>
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LED STDEV = 6.694

### ANALYSIS OF VARIANCE ON AA

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<td>Error</td>
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LEVEL

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<th>Mean</th>
<th>STDEV</th>
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</tr>
<tr>
<td>1</td>
<td>13</td>
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</table>

LED STDEV = 8.461

INDIVIDUAL 95 PCT CI'S FOR MEAN BASED ON POOLED STDEV

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<td>25.0</td>
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<td>40.0</td>
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<td>45.0</td>
<td>50.0</td>
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377
APPENDIX L.6

PROFILES OF STUDY SCHOOLS

L.6.1 PROFILE OF SCHOOL C

School C is a comprehensive, voluntary-aided, Roman Catholic School, all-girls, includes junior school till 6th form (aged 11-18 years); general ethos of the school seemed good/very good; the girls seemed disciplined and orderly.

The following information was extracted from The Times Educational Supplement 20 November 1992: Complete Guide to Public Examination Results 1992: "School C had 119 pupils aged 15, 76% scored 5 A-C passes in GCSE; 84 pupils aged 17, 93% taking A/AS level, average points per A/AS candidate is 12.5 pts."

Of the 9 interviewees, only one chemistry as a single science subject in GCSE, for which she scored a grade 'B'. The other 8 girls took coordinated science at GCSE for which grades scored are: 3As, 3Bs and 2Cs.

The following table shows the GCSE science subjects and grades scored; also the grades for A-level chemistry predicted by students themselves and by their teacher, Mr C.

<table>
<thead>
<tr>
<th>Student</th>
<th>GCSE subj.</th>
<th>GCSE grade</th>
<th>Self-predicted grade for A-level chemistry</th>
<th>Teacher predicted grade for A-level chemistry</th>
</tr>
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<td>C4</td>
<td>chem.</td>
<td>B</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>C6</td>
<td>coord sc</td>
<td>C</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>C8</td>
<td>coord sc</td>
<td>A</td>
<td>A</td>
<td>B</td>
</tr>
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<td>coord sc</td>
<td>B</td>
<td>B or C</td>
<td>C</td>
</tr>
<tr>
<td>C12</td>
<td>coord sc</td>
<td>C</td>
<td>B</td>
<td>B or C</td>
</tr>
<tr>
<td>C14</td>
<td>coord sc</td>
<td>A</td>
<td>A or B</td>
<td>A</td>
</tr>
<tr>
<td>C16</td>
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<td>B</td>
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<td>C18</td>
<td>coord sc</td>
<td>B</td>
<td>B or C</td>
<td>B or C</td>
</tr>
<tr>
<td>C20</td>
<td>coord sc</td>
<td>A</td>
<td>B or C</td>
<td>A</td>
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</table>
In the following year, according to 'The Sunday Times' 22 August 1993 issue this school was ranked as one of the best 253 in terms of A-level results in England, Wales and N. Ireland, with 30% of the A-level entries (i.e., about one-third) passing at grades either A or B, and 73% at grades A-E. This result was in improvement over the previous year's result, and compared favourably with the results in the top state school Colchester County High, which has 69% or about two-thirds of its entries scoring either grade A or B, and 95% at grades A-E.

This school was doing the Cambridge Syllabus, 9250, exactly the same one that is currently being used in Singapore. As an teacher from 1978 to 1984, I taught A-level chemistry students this syllabus; over that period, I also used essentially the same textbooks and reference books that were still being used here in school C and the other study schools here in the U.K., and included the main books used in school C such as Hill and Holman (1978); Atkins et al. (1990).

There was only one senior chemistry teacher, Mr C, who taught both L6 and U6, with about 30 students at each level, and he was the only teacher teaching at A-level chemistry. He told me that he was due to retire in the next year or so and had began to collect materials to write chemistry books during his retirement.

He gave me time to address students before the interview, to explain what my intentions were and so on. Practically all the girls were very friendly and helpful; only one out of the 10 was not interviewed in U6 - C2 who forgot her first appointment, and then was absent from school on the day of second appointed time.

During the first round of interviews which lasted a week, Mr C. was in a very foul mood. While waiting for students or during lull periods between interviews, I overheard him shouting over the phone at his lab assistant who had taken sick leave for some long period (she was off-work during the entire 6 days I was there). He told me 'take the girls, do what you want with them, but don't come and bother me'. I did not dare bother him but spent time browsing through the books and reference materials he had in his office which was also the chemical prep room. The place seemed so small and cluttered.

The L6 interviews were conducted in a not very conducive environment because they were done in the very small prep room where the phone occasionally rang and I had to stop my interviewing to take phone messages; sometimes we had to contend with someone speaking through the phone.

The U6 interviews were much better, thanks to the Mrs S., the lab assistant whom I did not meet during my L6 interviews. Mrs S. booked a small interview room for me, away from the chem lab and noise. Some advantages however of having
the interviews in the prep room were:

* I was able to listen to the chemistry lessons next door
* I was able to survey the teacher's books and references, materials etc lying about.

I enjoyed myself talking to the girls each of whom spent at least an hour with me. They seemed very earnest and honest and were genuinely engaged in thinking and verbalising; seemed not at all bothered whether my accent was different. This I suspect could be due to two reasons:

* there were Asians and foreign students in the school, hence the students were used to dealing with foreigners like me;
* some seemed all the more interested in talking to me because my accent was novel to them.

During the U6 round of interviews, Mr C. seemed more friendly and helpful and allowed me to ask him some questions about my interviewees and his teaching methods. From my informal conversation with him, and also from my informal 'observation' of his lessons, it appeared that Mr C. believed that the best way to learn was by good exposition (didactic teaching) on his part, complemented with regular assignments specially selected to cover key concepts, and regular lab work to train students in essential scientist's skills. He said he regularly 'hounded the girls to make sure they hand in their homework assignments'. He was a great believer in homework, and was proud of the fact that most of the exercises and homework he gave the students were his very own, i.e., not taken from textbooks or reference materials. He was extremely reluctant to provide me with samples of the worksheets he set the students because he said he was retiring soon and planned to write his own textbooks for chemistry. With the few samples he gave me, he strongly reminded me of his ownership of the copy rights.

The few sample worksheets he gave me revealed mainly questions on factual details being asked.

I conducted additional interviews with two U6 interviewees, C4 and C20 on the kinds and modes of feedback they had from their teacher on chemistry assignments, lab exercises, etc. Among other things, they confirmed that:

* most of their chemistry assignments and exercises were the teacher's own, i.e., not taken from commercial books or texts;

* all assignments were required by teacher to be regularly handed in; these were regularly marked and awarded grades A to E with brief comments by teacher.
LEARNING APPROACHES

Students from this school seemed to have significantly higher scores on surface approaches compared to students from the other four schools. On the deep and achieving approaches, there were no significant differences between schools.

Among the three basic learning approaches (SA, DA and AA), their scores for DA were the highest (40), followed by SA (38), then AA (34).

The higher scores on surface approaches of students in school C compared to those of students in the other four schools seemed to be correlated with the lower scores in terms of KEs at both U6 and L6 levels.

PERCEPTIONS OF CHEMISTRY LESSONS

From the completed questionnaires of the 9 interviewees from the school, overall their perceptions of the chemistry class was that they:

* were frequently given lots of notes;
* frequently had theory lessons comprising teacher talk;
* frequently had practicals in which exact instructions were given ie 'cookbook' type practicals;
* frequently opportunities to raise questions;
* about half the time given recall questions in class;
* about half the time given thinking questions in theory and lab lessons;
* frequently given individual assignments as well as individual lab work;
* had theory and lab work kept separate for half the time;
* frequently found that discussing chemistry ideas help them in learning chemistry;
* were given homework once a fortnight.

L6.2 PROFILE OF SCHOOL R

R is a sixth form college; in the 1993 A-level exams, the school had 768 candidates, and the average score per candidate was 13.4 points. I met 4 chemistry teachers, including head, Mr. P, and two chem lab staff Ms N. and Ms H. The teachers were generally friendly, helpful, were interested in, and supportive of, my research at the school. They seemed to know their students well, even at the L6 level. They seemed to provide a friendly and supportive learning environment for the students. I was impressed by the fact that the science department was able to provide a science tutorial period every day for students who needed extra help or
tuition in any of their science subjects.

The school followed the Nuffield A-level Chemistry Syllabus. I was given the scheme of work on my first visit to the school and brought round to see the science teaching resources which was very impressive. They had a lot of modern equipment (including a mass spectrometer) and a good stock of audio-visual materials and interactive independent learning programmes for learning various chemistry concepts. According to Mr P the chemistry teachers essentially tried to use a variety of teaching approaches to cater for the different learning preferences of students.

TABLE L.6.2

GCSE SUBJECTS AND GRADES; A-LEVEL CHEMISTRY GRADES PREDICTED BY STUDENTS THEMSELVES AND BY THEIR TEACHER: SCHOOL R

<table>
<thead>
<tr>
<th>Student</th>
<th>GCSE science subject</th>
<th>GCSE grade</th>
<th>Self-predicted grade for A-level chemistry</th>
<th>Teacher-predicted grade for A-level chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>coord sc</td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>R5</td>
<td>coord sc</td>
<td>A</td>
<td>A</td>
<td>A</td>
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<tr>
<td>R7</td>
<td>coord sc</td>
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<td>A</td>
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<tr>
<td>R2</td>
<td>coord sc</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>R4</td>
<td>coord sc</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>R6</td>
<td>coord sc</td>
<td>A</td>
<td>C</td>
<td>B or C</td>
</tr>
</tbody>
</table>

LEARNING APPROACHES

Students from school R like those from school E had the lowest scores on surface approaches among the five schools, indicating low surface approaches. Among the three basic learning approaches (SA, DA and AA), their scores for DA were the highest (39), followed by AA (36), then SA (29).

The relatively high scores on the deep approaches is correlated with their high total U6 KE scores as well as with their high progression scores.

PERCEPTIONS OF CHEMISTRY CLASSES

The students perceived that they:
* were frequently given lots of notes to study from;
frequently had theory lessons comprising teacher talk;
* frequently had practicals in which exact instructions were given;
* almost always had opportunities to raise questions in class;
* were frequently given recall questions in class;
* were frequently given thinking questions (questions other than recall, i.e., involving comprehension, application and so forth) during theory-lab lessons;
* were frequently given individual assignments as well as individual lab work;
* frequently had theory and lab work integrated;
* frequently found that discussing chemistry ideas help them in chemistry learning;
* were given homework twice a week.

The students perceptions of being frequently given questions which involved both recall and higher order thinking also coincided with this researcher's observation that there seemed a good amount of teacher-student interaction in chemistry classes.

The overview of students' perceptions together coincides with this researcher's observation that teachers and students seemed purposeful and committed to excellence in performance.

L6.3 PROFILE OF SCHOOL P

School P is an independent, fee paying, all girls school. Its junior department (aged 5-10) included reception, kindergarten, transition, comprised about 220 girls. Its senior department comprised about 600 girls (aged 11-18), including on average 150 in the sixth form. Entry is competitive at all levels.

In the GCSE exams 1992, the school was ranked first of 23 schools which were within the same London borough. It had 72 pupils aged 15, and had 92% of grades A to C GCSE passes. At the same time it had 72 students aged 17, 99% took the A/AS level exams, and the average score per candidate was 19.6 pts.

A-level chemistry was taught by 2 teachers, Mrs S. and Mrs O. There were five theory and three practical lessons a week, each period lasting 35-40 minutes. According to the teachers, students were taught that "chemistry is not just a collection of facts, but will also be exposed to the available theories" where they will find that "there are grey intermediate areas as well as the black and white ones that they are familiar with and are expected to adopt a questioning attitude throughout the course" and develop powers of independent thought. There was
only one chemistry lab staff, Mrs B. who was very helpful. In 1992/93 there were only 12 L6 students; in U6 two of them dropped A-level chemistry.

The syllabus taught was the "traditional" London Syllabus, 9080, (same as in School S) which is not very different from Nuffield Syllabus.

The assessment consists of three theory papers (80%) and an internal assessment of practical work (20%). Mrs O. said they had been using present syllabus for long time, about 10 years at least.

The teachers in the five study schools seemed to use more or less the same sort of reference books for theory as well as practical work.

The two teachers seemed unhappy about the change in the school whereby at GCSE no single science subjects were allowed to be taken. Instead, all students must take the Nuffield Coordinated Science course up to the 5th form, for which 9 periods a week were allocated. Previously only 1 science subject need be taken; the change means that coordinated science would take up 9 periods, which mean some students who like arts subjects would have less time on arts subjects.

I like all my 10 interviewees. All turned up on time, were very earnest, and serious, for both sessions. Their attitude seemed to reflect the general ethos of the school, everyone seemed to be serious, positive, very task-oriented, committed to work and to making schooling a success.
### TABLE L.6.3

GCSE SUBJECTS AND GRADES; A-LEVEL CHEMISTRY GRADES PREDICTED BY STUDENTS THEMSELVES AND BY THEIR TEACHER: SCHOOL P

<table>
<thead>
<tr>
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<th>self-predicted grade for A-level chemistry</th>
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<td>C</td>
<td>B</td>
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<td>A</td>
<td>A</td>
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<td>P20</td>
<td>chemistry</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
</tbody>
</table>

### LEARNING APPROACHES

Students from school P had almost similar scores on DA (39) and AA (37), and lower scores on SA (33).

The relatively high total KE and progression scores are understandable from the point of view that it was a selective school, with very good intake of students. As can be seen all these students took chemistry as a single science subject at GCSE and all scored either A or B. Thus, their high total U6 KE scores as well as high progression scores can probably be explained by their prior entry behaviour as well as their higher orientation to deep and achieving approaches vis-a-vis surface approaches.

### PERCEPTIONS OF CHEMISTRY CLASSES

* frequently given lots of notes
* frequently had theory lessons comprising teacher talk
* frequently had 'cookbook' type practicals
* frequently had opportunities to raise questions

385
about half the time given recall questions in class
* about half the time given thinking questions in theory and lab lessons
* almost always given individual assignments while lab work was done in pairs/small groups half the time, the other half was lab work done individually
* theory and lab work were integrated half the time, the other half theory and lab kept separate
* almost always true that discussing chemistry ideas with other students help chemistry learning
* given homework twice a week

L.6.4 PROFILE OF SCHOOL E

School E is a county comprehensive mixed school for pupils aged 11-18 years. The school was using the Nuffield A-level Chemistry Syllabus, same as School R. Teachers followed the textbooks very closely; and there were no separate schemes of work drawn up. There were two teachers teaching chemistry at the sixth form, Mr P. and Mrs K. Mr P., head chemistry, taught all of organic chemistry topics and Mrs K, head of science department, taught all the rest of the topics. The teaching method was essentially clear exposition by the teachers with lots of question-and-answer in lab-class periods. The two teachers were both very busy, rushing from the sixth form campus to lower school which was about 10 minutes drive away, all the time; in fact the two chemistry teachers seemed to come over to sixth form campus only for their lessons, and they then rushed back to lower school, where they had to teach students in the lower levels, and where all or most of the school's activities were. Mr R., the lab staff, was very helpful; he prepared the materials and apparatus which I needed and helped me tracked down some students who forgot appointments.

I was told that the students would be taught the option on Food Chemistry after the summer holidays in the L6. My interview-cum-waiting room was the chem prep room, just next to chem lab, where I was able to listen in to lessons. Both Mr P and Mrs K. seemed to adopt a very didactic teaching approach with a lot of teacher talk and then calling upon students now and then to check that they were following the teacher's exposition and explanations. Both teachers had clear powerful voices and seemed to command the respect of the students, who seemed engaged productively during lessons.

From discussion with teachers, I learnt that Assessment includes Hypothesis Formulation, Theorising, How to write proper language. I also learnt that Mock A level Exams would be taking place in early December.

The chemistry head, Mr P. seemed effective and influential in organic chemistry.
so that most interviewees seemed to be talking in terms of partial charges, nucleophilic reactions and the like, when they were referring to the mechanism of combustion reactions, which should be more appropriately conceived in terms of free radicals!

According to The Times Educational Supplement guide to public exams published on 20 November 1992, the school had 154 pupils aged 15; and had 34% scored 5 grade A to C passes in GCSE exams; it also had 76 pupils aged 17, and 93% taking the A/AS level exams, for which the average score was 12.9 points per candidate.

The following table 11.18 presents the GCSE science subjects and grades scored, plus the grades that the students predicted for themselves for chemistry in the coming exams. The teacher predicted grades were not available.

### TABLE L.6.4

**GCSE SUBJECTS AND GRADES; A-LEVEL CHEMISTRY GRADES PREDICTED BY STUDENTS THEMSELVES AND BY THEIR TEACHER: SCHOOL E**

<table>
<thead>
<tr>
<th>Student</th>
<th>GCSE science subject</th>
<th>GCSE grade</th>
<th>Self-predicted grade for A-level chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>coordinated science</td>
<td>B</td>
<td>B or C</td>
</tr>
<tr>
<td>E3</td>
<td>coordinated science</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>E5</td>
<td>coordinated science</td>
<td>B</td>
<td>D or E</td>
</tr>
<tr>
<td>E7</td>
<td>chemistry</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>E11</td>
<td>chemistry</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>E17</td>
<td>coordinated science</td>
<td>A</td>
<td>A or B</td>
</tr>
<tr>
<td>E19</td>
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</tr>
<tr>
<td>E6</td>
<td>coordinated science</td>
<td>A</td>
<td>C or D</td>
</tr>
<tr>
<td>E10</td>
<td>coordinated science</td>
<td>B</td>
<td>D</td>
</tr>
</tbody>
</table>

E1, E5 and E11 at the U6 level told me they wanted to drop chemistry as soon possible (i.e., after the A-level examinations) E1 and E5 wanted to do mathematics & computing while E11 wanted to pursue further education in physics, inspite of the fact that he liked organic chemistry. E1 and E5 did not like chemistry. They saw it as very difficult to understand. E1 told me I should have gone to interview them nearer their A-level exams because they he would be better able to handle my questions. I found it quite a challenge trying to be perservering and persistent.
in going through my interview schedule with these three students, in the face of their obvious lack of interest in chemistry.

I was particularly surprised and slightly taken back by E1's change in his attitude towards me and the whole U6 interview. At the L6 interview, I found him very easy and enjoyable to talk to. He seemed to have lost his interest and confidence in the subject over the period between the two interviews.

All the other students were very helpful and enjoyable to talk to, in particular E3, E7, E2, E6 and E10.

**LEARNING APPROACHES**

On surface approaches, students in school E had the lowest scores (30), together with those in school R (29). At the same time, school E scored higher than the other four schools on deep approach (44). On achieving approach, again school E scored higher than the other four schools (43).

**PERCEPTIONS OF CHEMISTRY CLASSES**

The following are a summary of the students' perceptions of their chemistry classes based on their responses on Q37-Q50. They perceived that they:

* were given lots of notes to study from about half the time;
* had theory lessons comprising teacher talk about half the time;
* had lab work and theory work separate for less than half the time, i.e., indicating that the lab work and theory work must be integrated for much of the time;
* frequently had 'cookbook' type practicals;
* frequently both in lab and theory work there were opportunities for them to develop thinking (not mere recall) skills;
* were frequently given questions which tested recall;
* were frequently given opportunities to raise questions in class;
* were frequently given lab and other class assignments which involved them in individual rather than paired or small-group work;
* frequently found that discussing chemistry ideas help them in chemistry learning;
* were given homework more than twice a week.

**L6.5 PROFILE OF SCHOOL S**

School S is a sixth form college (like school R), in the 1992 exams it had 296 students aged 17, 71% taking A/AS level, average score per candidate was 10.5
It is a Roman Catholic voluntary aided college, with open access policy, no tuition fees for students aged 16-18 years. All applicants were interviewed prior to admission. The level and type of course which a student chooses is the result of discussions involving the student, his/her parents, the 11-16 school and the College. Such provisional decisions are to a large degree dependent upon performance in the GCSE examinations.

In the 1993 exams 193 candidates, average score 12.6.

Entry requirements for A level Chemistry is a GCSE grade A-C in chemistry or double certificate in science, with a minimum of grade C. In addition, consideration may be given to other students under certain circumstances. The two-year chemistry course follows the University of London Syllabus 9080. According to the syllabus, "it follows in naturally for students who have successfully demonstrated their skills and abilities at GCSE level. At A-level, students will be expected to solve problems within a chemical context and to show awareness of the place of chemistry in society." The A-level chemistry course "emphasises the student's own role in the learning process and provides continual assessment of the student's progress throughout the course". The examination consists of three written papers (80%) and an assessment of practical work (20%).

I met 3 chemistry teachers: Mr G., Mr. B. Mr P.. The chem lab staff, Mr O. was very reluctant to help me get the chemicals and apparatus.

According to a the School's Newsletter, November 1993 Issue: "A record 90% of the sixth form college's 200 plus A-level students obtained pass grades in the 1993 exams. The percentage A-level pass-rate was 10% above the national average for schools and significantly above the national pass rate above the state sector alone. The number of students obtaining top grades A and B was also above national average at 26%. The corresponding national average was 24%."
### LEARNING APPROACHES

Students from school S had almost similar scores on DA (40) and AA (41), and slightly lower scores on SA (36).

The total KE and progression scores are intermediate between those of schools P and R on one hand, and those of schools C and E on the other hand.

### PERCEPTIONS OF CHEMISTRY CLASSES

The students perceived that they:
* were frequently given lots of notes;
* not frequently (or less than half the time) had theory lessons comprising

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**TABLE L.6.5**

GCSE SUBJECTS AND GRADES; A-LEVEL CHEMISTRY GRADES PREDICTED BY STUDENTS THEMSELVES AND BY THEIR TEACHER: SCHOOL S

<table>
<thead>
<tr>
<th>Student</th>
<th>GCSE science subject</th>
<th>GCSE grade</th>
<th>self-predicted grade for A-level chemistry</th>
<th>teacher predicted grade for A-level chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
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<td>C</td>
<td>A</td>
<td>A or B</td>
</tr>
<tr>
<td>S7</td>
<td>coord sc</td>
<td>C</td>
<td>D</td>
<td>C or D</td>
</tr>
<tr>
<td>S11</td>
<td>coord sc</td>
<td>A</td>
<td>B</td>
<td>A or D</td>
</tr>
<tr>
<td>S2</td>
<td>coord sc</td>
<td>B</td>
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<td>A</td>
</tr>
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<td>S4</td>
<td>chemistry</td>
<td>C</td>
<td>B or C</td>
<td>B or C</td>
</tr>
<tr>
<td>S6</td>
<td>chemistry</td>
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<td>B or C</td>
</tr>
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<td>S8</td>
<td>coord sc</td>
<td>C</td>
<td>C or D</td>
<td>C</td>
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<tr>
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<td>coord sc</td>
<td>A</td>
<td>C</td>
<td>C or D</td>
</tr>
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<td>coord sc</td>
<td>C</td>
<td>C or D</td>
<td>D</td>
</tr>
<tr>
<td>S14</td>
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<td>B</td>
</tr>
<tr>
<td>S20</td>
<td>coord sc</td>
<td>C</td>
<td>A</td>
<td>A or B</td>
</tr>
</tbody>
</table>

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390
teacher talk;
* frequently had 'cookbook' type practicals;
* almost always had opportunities to raise questions;
* frequently were given recall questions in class;
* frequently were given questions which require thinking in theory and lab lessons;
* almost always were given individual assignments while lab work was done in pairs/small groups half the time, the other half was lab work done individually;
* frequently had theory and lab work integrated;
* frequently found that discussing chemistry ideas with other students help them in chemistry learning;
* were given homework once a fortnight.
APPENDIX L.7

SUMMARY

Results in earlier chapters revealed that schools P and R seemed to promote learning more effectively than the other 3 schools.

While recognising that there are a multitude of variables which could affect student learning, this section examines some on learning approaches and students' perception of their chemistry lessons, from which it was hoped some clues could be found as to why some of the study schools (P and R) seemed to be more effective in promoting student learning.

The evidence from learning approaches and students' perceptions of their chemistry lessons is inconclusive.

From the field notes and observations made by this researcher (which is presented in the profiles of schools, the following speculatory explanations are offered (on which further research is needed):

Students in schools P and R seemed to have more supportive learning environment than students in schools C and E; which could, to some extent, account for the differential amounts of progression showed.
APPENDIX M

FURTHER CASE STUDIES

This appendix presents three further student case studies as follows:

Appendix M.1: Student E1 (Case II)
Appendix M.2: Student P4 (Case III)
Appendix M.3: Student C10 (Case IV)
APPENDIX M1

CASE II: STUDENT E1

(He scored 2B's in coordinated science at GCSE; self-predicted B or C for A-level chemistry; he hopes to drop chemistry and instead major on computer studies at university.)

(Drawings are at Appendix N2)

This student illustrates the case where total KE score at the L6 was among the highest; and where little progression in terms of KE scores was made between the U6 and L6. However, his case illustrates how the reduction in number of ACs revealed/ counted in itself could not necessarily be taken as an indication of progression. For in this case, it was all too evident to this interviewer that he had lost interest in chemistry; he was less forthcoming in his articulation, which meant that the fewer number of ACs revealed at U6 compared with the L6.

Among possible reasons for his non-progression are:

* His evident loss of interest in chemistry in the interim between the 2 interviews (which he made explicit at the end of the U6 interview);
* The persistence of some of the ACs he held (such as C1a, C3a, C3b, C3c);
* The use of non-formal or 'one factor only' type reasoning.

ASPECT A: PREDICTION ON TYPE OF CHANGE

At both U6 and L6 interviews, over the 5 events, E1 had predicted correctly the reactants and products.

At the L6, his responses on this aspect illustrated how KEs could be acquired in spite of existing ACs. For example, in event 1, while he predicted correctly that copper would oxidise to form copper oxide, like a number of other interviewees, he also said that copper could not burn (AC A1c). Then, in event 2 and he revealed the his view that only carbon containing compounds could burn, and that burning always produces carbon dioxide (AC A1a).

In event 2, when asked to predict the type of chemical reactions, he said: "...the flame reacts with oxygen. wax burns forms carbon dioxide and water", and in event 3, he said: "Yes, there's a chemical reaction because methane is turned into flame [Here flame appeared to be substantialised, AC A1a, and was conceived of both as a reactant and a product]. and carbon dioxide and water".

It also appeared that the presence of ACs as the substantialisation of heat, did not prevent him from knowing what reactants and products were involved in the 5 events discussed at the L6 level.
ACs A1a and AC A1c were not observed in his U6 responses, showing some progression.

At L6 level, when asked what he understood by the term 'burning', he said: "Combustion with air and so produce carbon dioxide and water."

This understanding of burning explained why he considered copper incapable of burning and seemed to reflect the everyday view, whereby only carbon containing substances/objects tended to be seen as capable of being burned. This view seemed to be persistent/further implicated in his U6 responses.

At the U6 level to the same question on his understanding of burning, he replied: "Give energy to a substance (he meant 'substance'; according to him, his English is "not good" and he "can't speak" properly") to make molecules vibrate faster and give out energy and you usually break bond."

His use of the term 'usually' is interesting and seemed to indicate further that he was still having ACs about the nature of burning, or that his view of burning is still at variance with the scientific view.

ASPECT B: PREDICTION ON OVERALL ENERGY CHANGE

On this aspect, from a chemist's perspective, E1 seemed inconsistent in both his L6 and U6 responses.

His L6 response on events 1 and 2 were very similar; and contained no KEs and 1 AC:

Eg in event 1: "Overall endothermic..because it absorbs heat from the bunsen flame".

Further probing revealed that he seemed to be using predominantly perceptual thinking like R7.1 and essentially held the same AC B1a that "a reaction must be overall endothermic if heat/heating is needed", which demonstrated the common misunderstanding of the role of applied heat and its relationship to overall energy change.

Eg in event 2: "An overall endothermic reaction..because you need to put in energy from the match."

(This response was extremely surprising when it seemed clear that the reaction must be overall exothermic. However, one possible reason for this surprising answer could be, that like some of the other interviewees, he really did not understand the nature of the flame (or even the nature of the question - a point which did not really occur to this interviewer at the time of the interview. Perhaps there was some confusion in his mind between activation energy and overall energy change.)

However in event 3, his response was: "Overall exothermic..give out heat..take in energy for breaking bond in methane and oxygen, then produce energy when make bond in carbon dioxide and water which is given out."

His L6 responses in events 4 and 5 were in fact similar to event 3 in that they incorporate the idea that the overall energy change is the resultant effect of bond breaking (which is
an endothermic process), and bond making (which is an exothermic process).

E.g. in event 4: "Overall exothermic... because give out heat from bond making between Mg & Cl. first absorb energy from surroundings to break H-Cl bond, for example, absorb 100J/mole but bond making energy greater than bond breaking energy so give out... product is less reactive, or more stable than reactants."

(2ACs associated with AC C3a are revealed in this response: that a bond was made between Mg and Cl in the aqueous state; and that the bond between H⁺ and Cl⁻ ions, broke only when Mg was added, which was an AC because in solution, there were only weak ion-pair attractions between H⁺ and Cl⁻ ions, there were no real bonds between them.)

Thus, it could be seen that he was conceptualising the 5 events very differently. In his scheme, there appeared to be more similarity between events 3, 4 and 5 than between events 1, 2 and 3.

His response in event 2 compared with event 3 is surprising, because with respect to aspect A, he had said that wax was reacting with oxygen producing carbon dioxide and water which was similar to what was happening to the methane in the bunsen flame reaction! Yet, he could predict an overall exothermic for the bunsen flame reaction, but an endothermic one for the candle flame reaction. Unlike the chemist, he did not seem to see them as similar events. Therefore, he used very different explanations for the energy changes involved.

Thus, he seemed to demonstrate partial understanding of the aspects of energetics involved in chemical reactions; but had not yet learned to see the generality across events.

At the U6 he did not show progression in terms of number of ACs held and consistency across events; in particular, he seemed not to recognise still the similarity in events 2 and 3. However, it did show some progression in event 1 by abandoning his old AC B1a, and by using conceptual using of perceptual thinking: "An overall exothermic reaction... because copper and oxygen form a lower energy compound... the heat is given off from bond making... they take in heat to break bonds and then they give out more energy during bond making... because copper-oxygen bond is a stronger bond."

Having abandoned his old AC, he picked up new ACs; as seen in his U6 response in event 2: "Overall endothermic... it absorbs more energy because one is gas, one is liquid (referring to the 2 products, carbon dioxide and water) but the reactant is solid."

When the interviewer echoed his response, "Overall endothermic?", he said: "Yes, because you form a gas and a liquid from solid... wax is a solid."

Two ACs were identified in this response:

a). the physical state of 'H₂O', one of the products, was misconceived as 'liquid' instead of 'gas';

b) kinetic stability was confused with thermodynamic stability. He seemed to have
inferred that the reaction is overall endothermic based on the thinking that a gas and a liquid are less stable than a solid, therefore, they must contain more energy than the solid, which means when the solid wax was converted to gaseous carbon dioxide and liquid water, energy must have been absorbed.

This is to be contrasted with his U6 response on event 3:
"Overall exothermic because heat come from the flame..at microscopic level heat come from vibration, bond making of carbon dioxide and water."

Thus again as in the L6, he was clearly conceiving the 2 flames differently; by predicting the overall direction of energy change in event 3 as different from event 2. He also introduced a new AC in misconceiving the heat released by the bunsen flame here as associated with vibration, which produced energy of much lower wavelengths.

His U6 response in event 4 (which was similar to that in event 5) was: "Overall exothermic..because heat is given out from making bond..ionic bond..between Mg$^{2+}$ and Cl. exothermic because MgCl$_2$ is more stable than HCl."

His overall U6 response showed that the 2 ACs revealed at the L6 level were still held by him. In addition, he revealed an AC which arises mainly due to the use of 'one factor only' type reasoning, in not considering the stability of both reactants and both products in his prediction on overall energy change. This type of thinking which lacked consideration of all factors involved was prevalent among a large number of interviewees and was discussed by researchers such as Rozier and Viennot (1991).

Overall on this aspect, El did not make much progression in terms of achieving greater consistency in the way he used KEs and in terms of the number of ACs. He abandoned only 1 AC (B1a) and picked up more ACs.

The tendency to acquire new ACs along the path of learning seemed to be common among the interviewees and is probably to be expected as a natural process in learning, as new knowledge are initially acquired in bits and pieces which are incomplete and unconnected, rather than as a coherent whole (Inhelder, Sinclair and Bovet, 1974; Di Sessa, 1988). This means that the likelihood of such knowledge being applied to the wrong context is very high.

From his statements associated with flames, he revealed, like many other interviewees, a lack of understanding of the nature of flames. Just as students like case IV, student C10, who saw no problem in conceptualising different kinds of bonds in magnesium and in copper, he was probably not seeing any problems in conceptualising the 2 flames in events 2 and 3 differently.

The fact that he was able to account for the energy changes involved in the combustion of methane could be explained by the fact that thermochemical calculations on heats of combustion, which specifically included that of methane, had been covered in class. The reason why he could predict the overall energy change for event 3 but not event 1 at the L6 level could probably be traced to, on one hand the dominance of perceptual thinking and on the other hand, that he did not conceptualise that event 1 was also a combustion reaction, which in turn could be due to the fact that the examples normally used to illustrate calculations on heats of combustion are those involving substances
conventionally thought of as fuels, and not metals.

**ASPECT C - HOW THE PROCESS IS IMAGINED**

On this aspect, there was no progression in terms of the number of KEs scored.

At both L6 and U6 in events 1 to 3, he was able to conceptualise the process appropriately in terms of particles (copper atoms, oxygen molecules and alkane molecules) and the bond breaking and bond making processes involved.

At both L6 and U6 his conceptualisation of the processes involved in events 4 and 5 were very similar, involving few KEs and the same ACs, which are:

a) The reaction between magnesium and dilute HCl involves bond formation between Mg and Cl, even if Cl is already in the ionic state.

b) This seemed to lead to the AC that the ionic bond between Mg$^{2+}$ and Cl$^{-}$ ions must still be existing in spite of there being no solid MgCl$_2$ formed (AC C3a).

c) And because he seemed to have learnt well that chemical reactions always involve bond breaking and bond making, he conceptualised the bond between H$^{+}$ and Cl$^{-}$, which he termed as 'ionic bond', as also existing in the dilute HCl solution before Mg is added (AC C3a).

The following extract from the L6 interview on aspect C, event 4 is illustrative:

E1.1: "...dilute HCl has H$^{+}$ and Cl$^{-}$ ionic bond between H$^{+}$ and Cl$^{-}$, ionic bond breaks when you add Mg ...[AC C3c] it absorbs heat energy from the surroundings to break bond. also absorb heat from surroundings to break metallic bond in Mg, then Mg$^{2+}$ and Cl$^{-}$ join together to form MgCl$_2$. after bond breaking, hydrogen is unstable in one compound, it have to exist in diatomic compound so 2... H from HCl quickly join another H atom to form H$_2$ gas."

I: "Mg is 2+..

E1.1: "Because got 2 outer shell electrons to form stable compound MgCl$_2$, need 2Cl to react with 1Mg. okay work backward... from equation we know Mg has 2 extra outer shell electrons, so need to lose 2 electrons to be stable; Cl need accept 1 electron to be stable full shell, so 1 Mg react with 2 Cl's to form stable compound, electron from Mg go to chlorine, chloride ion form a bond between them." [Note: these extracts are from verbatim transcripts, hence the occasional questionable use of the English language.]

I: "You said chlorine in dilute HCl is chloride ion Cl$^{-}$ has Cl$^{-}$ not got a full shell of 8 electrons..

E1.1: "Maybe 1 electron (ref to one of the 8 electrons in Cl-) get excited during reaction and promote to next higher level... orbital...this is ground state (drawing 3 sets of boxes, 1st set containing 2 sub-boxes, 2nd set another 2 sub-boxes and the 3rd set comprising
3 sub-boxes, each sub-box with 2 arrows, each pointing in a direction opposite to the other one - see f4.4, Appendix N2.1) this is ground state which means no reaction, and when heated, electron from outer shell take in more energy first, and some electron is promoted to next orbital so can accept more electron and form bond, forming another box (i.e., energy level or orbital) and this is reason why this electron has disappeared." [He seemed to be trying to justify his theory that Cl-, in spite of already having 8 electrons, could still accept another electron, by proposing that somehow a vacancy was created in the orbitals by the promotion of one of the existing electrons to higher orbitals in Cl-. This inference made was verified by much probing on the part of the interviewer.]

I: "Cl- take 1 more electron from magnesium means that it becomes Cl^{2-}?"

E1.1: "Point is afterwards it give out energy. become less stable. so it take in energy, get excited, go up to higher orbital but when bond making it give out energy so become less reactive, so by that time, electron would pair up because got less energy; different orbital got different energy level; need more energy to promote to another level but after losing energy, electron will go back to original level."

I: "If electron goes back to original level, that means there's no vacancy for magnesium's electron on Cl-?"

E1.1: "But during bond making all electrons still at higher energy level but after and during losing energy electron become less excited, and go back to original energy level and this is reason why it's not 2- because it becomes stable compound already by that time. bond making means they join together. then lose energy and go back to here (pointing to one of the sub-boxes which represented an orbital in f4.4, Appendix N.1A.

With respect to ACs, in addition to those already mentioned with reference to aspect B, such as AC C3a, C3b, his reference to electron from Cl- jumping to higher orbitals seemed to indicate that he had confused ideas that his teacher might have used to illustrate bond breaking and bond making in, perhaps a covalent carbon compound such as methane, with the nature of bond making in this redox reaction involving essentially magnesium atoms and H^+ ions.

It was a pity that at the U6 level, he was not as forthcoming as at the L6 interview which render comprehensive evaluation of his progression difficult. The fact that he was looking bored, uninterested and unwilling to spend time at the interview was made clear to the interviewer by his facial expressions, which resulted in the fact that his responses were not probed as deeply as this interviewer could have done.

The following extract is from the U6 interview:

E1.2: "...(writing equation.. Mg^{2+} + 2H^+Cl^- \rightarrow H_2(g) + Mg^2+Cl^-) because Mg got 2+ charge but H only got 1+ in aqueous solution so Mg is more likely to attract Cl^- than H^+ because there's a stronger electric attractional force between Mg & chlorine [AC C1a: He seemed to be confusing oxidation numbers with charges when he referred to Mg as having 2+ charge; his reference to H^+ was valid because he knew that the HCl acid exists as ions in solution.] and MgCl_2 is more stable compound than HCl."

I: "Dissolved MgCl_2 is more stable than HCl."
E1.2: "Yes, and hydrogen form H₂ because it need full shell. Hydrogen has to join together to become stable. No solid magnesium chloride is formed because it is soluble."

I: "Magnesium attracts Cl-.."

E1.2: "Yes, form ionic bond."

I: "Even when no solid magnesium chloride was seen?"

E1.2: "Yes, we’ve been told."

From his conception that there is an ionic bond existing between magnesium or Mg²⁺ and chlorine or Cl⁻ ions in the solution, it could be inferred that he probably thought of H⁺ and Cl⁻ ions from HCl just as existing as separate ions, but necessarily free ions.

On event 5, his responses at both L6 and U6 did not contain any of the key elements identified.

The ACs held could be inferred from his responses, which are given below:

L6: "First when you add the two together, chlorine (referring to the ‘Cl’ in the formula ‘NaCl’ in equation Na⁺Cl⁻ → NaNO₃ + PbCl₂ that he has written) becomes more delta minus [which is an AC here, showing a misconception that partial charges could have risen in aqueous NaCl, which is probably a lack of proper understanding about how electronegativity difference between two atoms in a covalent bond could lead to the formation of partial charges] and lead in lead nitrate (referring to Pb²⁺ in the formula Pb⁺NO₃⁻ has more positive charge so attracted here (drawing an arrow from Cl⁻ in NaCl to Pb²⁺ in Pb²⁺NO₃⁻) and this is nucleophilic reaction because a positive centre is being attracted. Attacked by the reagents [It seemed that he was confusing what he was then learning in his lessons in organic chemistry on reactions of covalent polar substances like halogenoalkanes with the precipitation reaction involving Pb⁺ and Cl⁻ ions. Similar kinds of confusion were also found in a number of the other interviewees]. Delta minus because chlorine is a very electronegative element, so it contains delta minus charge. High electron density got bigger share of electrons in chlorine than in sodium. Yes chlorine attack lead because plus and 2 plus here (referring to Na⁺ in formular of NaCl and Pb²⁺ in Pb²⁺NO₃⁻ respectively) minus attracted by 2+ (referring to Cl⁻ being attracted by Pb²⁺) and form lead chloride and then this one naturally one plus, one minus (referring to Na⁺ and NO₃⁻) they join together."

The following extract from the U6 interview illustrates his response, which was much less forthcoming than his L6 response:

E1.2: "There’s bond breaking and bond making."

I: "Which bonds are being broken?"

E1.2: "Because, what’s the meaning of the term ‘electronegativity please?’"

I: "What do you think it means?"
E1.2: "I should have did some revision last night..I think this one attracted this one because this one is more...no, I'm wrong..I'm just saying 2+ attracted to Cl and Na' attracted to nitrate..Point is I was thinking about electronegativity but it's wrong now."

I: "What's electronegativity?"

E1.2: "Attract more electron, say Cl and H joined together..Cl should be delta minus because it attracts electrons more..H delta plus because it attract less electron."

I: "Why does electronegativity not apply here?"

E1.2: "I just assume that..I think it's more for organic chemistry."

Comparing his L6 and U6 responses, it could be seen that at the U6 level, he was on the verge of repeating his L6 views, which were essentially confused ideas, when he checked himself. He seemed to realise that his L6 views about partial charges in chlorine of NaCl was incorrect, which led him to say that electronegativity applies to organic chemistry and not to the reaction being discussed.

It was quite surprising that E1, like a number of the other interviewees, seemed to make no progression in his understanding of this event, which is akin to the reaction between silver ions and chloride ions involved in qualitative analysis of chloride ions (which is included in the GCSE chemistry syllabuses as part of the practical chemistry exercises). The analogous reactions between silver ions and halide ions is also specifically included in virtually all the A-level chemistry syllabuses under the reactions of group VII elements. For E1, one main problem appears to be his inability to assimilate new knowledge properly into his existing framework, so that his explanations seemed to be coloured inappropriately by his new knowledge - e.g., viewing the precipitation reaction as involving a nucleophilic reaction.

ASPECT D - DRIVING FORCE

At L6 level his view that energy input was the driving force or active agent acting on passive substances causing the chemical change was consistently applied across all 5 events, even in the case of events 4 and 5 where there was no overt heat applied.

In this study, it appeared that the first 3 experiments reinforce this naive view (termed the "experiential gesalt of causation by Andersson, 1986b; Ogborn, 1990; Brosnan, 1992) and this was then used to explain the driving force of the subsequent events, 4 and 5. For example, E1 said of events 1 to 3, that "Driving force is heat from flame which is energy put into the reaction," and of event 4, "Driving force is energy absorbed from surroundings to break bonds..then bond making produce energy to break more bonds."

Here in his reference driving force as energy absorbed to break bonds, there is a hint that he seemed to be interpreting the interviewer's question in a way that was not intended. His interpretation seemed to be "What started the chemical reaction?", instead of "Why does this particular chemical reaction happen at all?" At the U6 level however, from his response, it could be inferred that he was clearly interpreting the question as intended by the interviewer.
At the L6 level, since his basic view of driving force is energy put into the reaction. At the U6 level, he made some progression on this aspect. He seemed to have grasped, at least partially, the idea that the reaction why a chemical reaction takes place is the tendency toward thermodynamic stability. This was seen in his responses on this aspect in events 1, 4 and 5, because in all 3 cases he mentioned that "Driving force was to form a more stable compound". Here again he seemed to show the 'one factor only' type incomprehensive reasoning, which was typical of many of the other interviewees' responses.

For event 2, he said: "Driving force? no idea...can't think of anything...carbon dioxide is less stable than wax molecule because it's a gas and wax is a solid...liquid water is less stable than wax."

He appeared confused and baffled because his view that driving force was to produce a more stable compound seemed inapplicable here. Several ACs can be postulated at this point:

a) that he had confused kinetic stability of physical states with thermodynamic stability of substances.

b) that he had disregarded the imperceptible reactant in the process, i.e., oxygen gas. Like many other students, he could be substantialising heat as oxygen which explained why he did not consider oxygen.

c) he had forgotten that the H2O would be formed as a gas instead of liquid.

For event 3, he had said that "the same principle as the candle applies" and therefore "I don't know."

**SUMMARY OF CASE II**

Thus, it can be seen that E1 is an example of a student who showed little progression in terms of acquiring new KEs and ACs. At the L6 level, he had included many KEs and also ACs. At the U6 the same KEs and ACs were still there, although he also acquired a few more ACs which appeared to be related to new knowledge learned.

His lack of progression was not easily accounted for, other than his own explicit statement that he wanted to drop chemistry as soon as A-level exams are over.
CASE III: STUDENT P4

(She scored 'A' for Chemistry, 'B' for Physics and 'B' for Biology. Self-predicted 'B or A' for A-level Chemistry; hopes to read Biochemistry at University.)

(Drawings presented at appendix N3)

This case was quite a contrast to case IV in that while her L6 KE score was not that much higher than that of C10 (13 vis-a-vis 9) she made a progression of 25KEs (vis-a-vis C10's progression of 1KE) over the 5 events and 4 aspects between the U6 and L6 interviews.

Among the reasons for this difference could be that she had fewer ACs at the L6 level compared to C10 (See chapter 9: At the L6 she revealed 8 ACs whereas C10 revealed 20 ACs), so that whereas C10 was hampered from further learning by her ACs, P4 was not. Hence at the U6, P4 showed a reduction of 2 ACs whereas C10 showed an increase of 2 ACs between the 2 interviews.

Aspect A - Reactants and Products

At the L6 she predicted correctly reactants and products in all events, except event 2, the burning candle.

In event 2, she did not think that the candle wax was chemically involved in any reaction; but was merely melting, and some of it vaporising and diffusing into the atmosphere. Instead, it was the wick which burned to form wick oxide with oxygen from the air.

At the U6 interview, she showed progression in predicting that the wax being an alkane would burn to give carbon dioxide and water; also that since it was a big alkane, it could also yield some smaller alkanes on burning.

Aspect B - Overall Energy Change

On this aspect, she made progression by shifting from macroscopic explanations to using microscopic explanations which included relevant particles and bond breaking and bond making processes. However, her explanations were still not completely adequate in that she had not included issues about relative strengths of the bonds broken and made.

At the L6 interview, like the previous 2 students in cases I and II, she used perceptually dominated thinking and predicted on overall endothermic reaction (AC B1a).

When asked what was the role of the heat from the bunsen flame in event 1, she responded thus: "Heat is needed because there's not enough copper oxide to do anything. you can't even see it..so heat is needed to make the copper oxide..heat actually causes the reaction..well, you need copper and oxygen, but the heat actually causes it to
She seemed to have exhibiting here what Andersson (1986b) termed EGC (experiential gestalt of causation) in her perception of the involvement of heat energy in the chemical change, i.e., to her heat input seemed to be the necessary and sufficient condition for chemical change. This AC was held by the vast majority of the students interviewed. This AC was revealed again in association with aspect D, when she was asked why she thought the reaction happen at all (See discussion on aspect D later).

It seemed to this interviewer that her AC or use of everyday reasoning that heat is the causal agent for chemical change, is so dominant in her thinking that it hindered her from reasoning more scientifically, in terms of particles and the microscopic processes (such as bond breaking) involved. This was further reflected in her responses in subsequent events.

For example, in event 2, the burning candle, when asked where the heat of the candle flame came from, she said: "From the burning of the wick." She could not elaborate on this, no matter how hard the interviewer tried to prompt her. Again in event 3, the bunsen flame, having said that the reaction between methane burning in oxygen was exothermic, she could not account for the reason why in terms of microscopic processes.

Asked to account for the heat being released, she said: "When those two (i.e., methane and oxygen) react together, it must be an exothermic reaction to have the heat produced...so when they join, heat's produced...there's like more energy than those two separately."

She seemed to be unwilling or unable to discuss the heat released in terms of particles and the microscopic processes involved. At the same time, she seemed to have exhibit two misconceptions here:

a) that the product had more energy than the two separate reactants;

b) the excess energy of the product was manifested in the form of heat of the bunsen flame. She seemed here to exhibit a problem that a number of the other interviewees had - that of the inability to distinguish between the reaction system and its surroundings. She seemed unable to differentiate between the products of the reaction (i.e., carbon dioxide and water vapour) from the surroundings (which include the flame).

Probed further as to what she thought was the part played by the match flame which was used to light the bunsen flame, she said: "It actually starts the reaction, ignites...just starts...then there's enough heat to carry on."

Asked where the heat that was 'enough to carry on' the reaction come from, she said: "From the flame which could come from there...the flame is the thing you actually see and feel heat from...if the flame's not there, you won't feel heat...that starts from there...flame is produced by those two burning...that is burning in oxygen."

Probed further on 'heat is produced by those two burning' she said, "If you have methane in a bottle, it won't combine with oxygen to produce a flame, you need to have the flame,
the heat to start the reaction, so heat from the flame start the reaction."

Asked for the part played by the heat from the flame, she said, "It actually starts this, so if it wasn't there, I don't think these two would react."

When asked to explain at the microscopic level how this heat starts the reaction, she said "Exciting the atoms, making more successful collisions."

Probed on "what determines whether collisions are successful", she said: "More energy, more active, more likely to crash into each other, more often than if they just hang around."

She seemed to be having the misconception that reactant particles do not crash into each other unless there is heat supplied to the system.

Again in event 4 having predicted an overall exothermic reaction, she seemed unable to account for it in terms of bond breaking and bond making. Instead, she said, "Heat released come from...energy which haven't been heat energy...been transformed into heat energy...could be energy from I don't know what potential energy stored but isn't as heat."

Asked where was the energy stored, she said: "In the product that has been made."

Probed further on how the energy could be stored in the product when it was not yet formed before the reaction has taken place, she said, "The energy is stored in either or one of those two... or both and it comes out as heat energy when they combine."

Thus, it became clear here that essentially she had the energy profile diagram in her mind when she referred to the heat evolved in this reaction as having been converted from potential energy of some sort which was stored in the reactants.

She predicted no overall energy change in event 5, precipitation reaction but was unable to give a reason for her answer.

Thus, through her L6 responses on aspect B, it could be seen that she had little concept of the energetics involved in the bond breaking and making processes of chemical reactions. Responses such as hers were prevalent among the interviewees.

However, at the U6 interview, her progression was obvious.

In event 1, having predicted an overall exothermic reaction, she went on to sketch and describe confidently the energy profile diagram for the reaction: "Because it needs activation energy which is heat (sketching the left or up side of a peak) and then it usually goes that way (sketching the right or down side of the peak and stopping at a level below the initial upward starting point resulting in an energy profile with the total energy content of reactants higher than that of product) to break oxygen bonds... and copper bonds, you must put in energy... but energy is given out when they join to make copper oxide... the energy made from that is greater than the amount of energy put in to split these two up."

Again in explaining the exothermicity of the methane-oxygen reaction in event 3, she said: "When heat is given, these (referring to the electrons in the C-H bonds in methane and
O=O bond in oxygen) get excited, the bond breaks and join...carbon with oxygen and hydrogen with oxygen...that's when heat is made and that starts the cycle again."

Note how her explanation for the exothermicity was given at a much greater depth at the U6 level. However, it was still not completely adequate in that there was no consideration of the relative strengths of the bonds made and broken which determine the direction of the overall energy change.

In event 4, the progression on her understanding of the issues involved in aspect B between the 2 interviews was also evident. Here in explaining why it was overall exothermic, she said: "You won't get much energy out of the formation of magnesium chloride 'cos they are in ions in the water...that means all the energy is from the formation of H₂ molecule...also attraction between the delta positive hydrogen atom of water molecules and Cl⁻, also between the delta negative oxygen of water molecules and the Mg²⁺ ion...that's making energy...but they are not that strong...they're attractions not bonds."

Like a number of other students, she seemed to have difficulty conceptualising the attractions between the solvent molecules and the particles of the solute as ion-solvent bonds.

In event 5, she predicted that it must be an overall exothermic reaction because "it's more stable...that means heat's been given out...obviously there's attraction between the chlorine (she meant the chloride ion from sodium chloride) and hydrogen (she meant the hydrogen end of the water molecule) and between the lead and the negative end (referring to H₂O molecule) and then these 2 are attracted to one another (referring to attraction between Na⁺ and Cl⁻ ions; and between Pb²⁺ and Cl⁻ ions)...the amount of energy given out from the combination of Pb²⁺ and Cl⁻ ions to form a solid is greater than the energy put in to break all these bonds."

From the above quotes from the interview transcript, it can be seen that she had made much progress in conceptualising the energy changes involved in the reactions discussed. However, consideration of relative bond strengths is still lacking.

Aspect C - How the process is imagined.

Over the 5 events, there was an improvement of 15KEs on this aspect, which was due mainly to the consideration of issues of bond breaking and bond/structure making in her responses, especially in event 2.

At the L6 level, while being able to predict that copper will lose electrons to oxygen resulting in the formation of oppositely charged ions which combine together, there was confusion between ionic and covalent bonding (AC C2a, section 6.3, chapter 6) because she thought that "there was more attraction to within one pair (referring to a unit of 'CuO') than outside the pair." Like many other students, she seemed to think that the attraction between the 'Cu' and 'O' within a unit of 'CuO' is stronger than that between 'Cu' and 'O' of different 'CuO' units, i.e., she appeared not to understand the concept of the ionic bond structure.

At the U6 level, such confusion was not evident.
For events 2 and 3, while at the L6 level, she had difficulty conceptualising the process of the reaction in microscopic terms, she showed progression at the U6 level in having no such difficulty at the U6 level. She was able to reason after a tortuous process, that the result of sufficient heat input was to split the O₂ molecule into 2 oxygen atoms, each with 6 outer shell electrons and also to split the alkane into carbon atoms with 4 outer shell electrons and hydrogen with a single electron which then share electrons to form covalent molecules of carbon dioxide and water.

Like many U6 interviewees, she initially thought that in the combustion of alkane, the bond within the O₂ molecule undergoes "heterolytic fission" resulting in the formation of "O²⁻ and O²⁺ ions (i.e., oxygen atom with 2 excess electrons and one with 2 electrons short respectively) O²⁻ ions join with the H⁺ which was produced together with the C⁺ ions, from the splitting up of the alkane molecule to form water and the O²⁺ which has only 4 electrons join with the C⁺ to form carbon dioxide." It was only on further probing by the interviewer that she finally realised that atoms or free radicals were more likely to be formed during the bond breaking process, rather than charged species such as C⁺, H⁺, O²⁻ and O²⁺.

The fact that this alternative mechanism for the combustion of methane, involving the production of charged particles instead of free radicals, is so prevalent among the interviewees, lead one to speculate and find some reasons. Among possible reasons are:

* the confusion of the concept of oxidation numbers with electrical charges (AC C1a) - because students had been taught that C in CH₄ has a oxidation number of 4- and H has a oxidation number of 1+, they thought that when the C-H bonds break, C ends up with a 4- charge and H end up with a 1+ charge;

* the confusion of combustion reactions with nucleophilic and electrophilic reactions in organic chemistry (i.e., those involving electrical charges, either full or partial charges such as halogenoalkanes which contain positively charged C centres and alkenes which involved negatively charged C centres).

For events 4 and 5, her progression was most evident in the way she was able to conceptualise the particles and the bonds which were broken and made. For example, at the L6 level, she was uncertain of the effect of water on the solute particles. She had in fact postulated that particles of solutes such as sodium chloride exists as units of 'NaCl' with the bond between the Na⁺ and the Cl⁻ practically intact; and the effect of dissolving was to break the weaker bonds between the 'NaCl' units but not within the 'NaCl' units, which was a reflection of the confusion of ionic and covalent bonding.

At the U6 level, the confusion between ionic and covalent bonding seemed to have cleared. She had clearer conceptions of the solvation effect of water and the attractions between the free ions of the solute and the water molecules. Thus, for event 4, she was able to conceptualise the dilute HCl as comprising free H⁺ and Cl⁻ ions.

However, at the U6 level, she still suffered from the misconception which was common among the interviewees: that in the magnesium-dilute HCl reaction, the Cl⁻ ions "must let go" (or give back) of the one electron which it has taken from the hydrogen atom (AC C3c) in the formation of the chloride ion, so it becomes just chlorine atom, then Mg gives these 2 outer shell electrons to 2 of these Cl⁻ ions so you get Mg²⁺ and 2Cl⁻ ions and
At the U6 level, as at the L6 level, she thought that in the absence of water, the magnesium-dilute HCl reaction would be "faster" - a view which was shared by a large number of the interviewees. From the scientists' perspective, she (and the large number of interviewees like her) seemed inconsistent in not considering the solvation effect of water, which resulted in the dissociation of HCl into its free ions. However, at another level, from her (their) own perspective, she (they) might not be inconsistent since in her (their) framework, the reaction process involves the transfer of electrons from magnesium atom to chlorine atoms. In other words, since she (they) did not have the scientific view that the reaction process involves the transfer of electrons from magnesium atoms to hydrogen ions, she (they) infer that the reaction could be faster in the absence of water.

It was a pity that time constraints did not allow this interviewer to pursue her reasons for saying the non-aqueous reaction is faster. However, it was likely that she (they) was associating the increased reaction rate with the increase in the concentration of HCl.

Aspect D - Driving Force

Over the 5 events, there was no increase in the number of KEs counted in her responses on the driving force or why she thought the reaction took place; at both U6 and L6 interviews, she did not include a single KE of a scientific explanation in her responses. Again her responses on this aspect were typical of the study sample.

At both U6 and L6 levels, she consistently (see section 10.2, chapter 10) conceived of heat energy input was the driving force in each of the 5 reactions discussed.

At both interviews, for events 1 to 3, she was very certain that heat supplied was the driving force. With respect to events 4 and 5, she was perplexed because there was no obvious heat input. However, from her responses, it could be seen that she held the view that heat or energy input of some kind is the driving force of reactions. Her view was of course, at variance with the scientific view that it was the release of energy or increase in total entropy of the universe which drives the reaction.

For example, her L6 response in event 4 was "...in this experiment, you didn't heat it, you just put them together and there was heat being produced but the other ones (referring to preceding events) we had to start it off, heat being produced. don't know...strange...".

Her U6 response in the same event was: "Driving force...reactants being together and being in an environment where they can take energy from the atmosphere or the surroundings."

Again on the driving force in event 5 her responses at both U6 and L6 levels were more or less the same. For example, at the U6 level, she said: "Driving force...just their presence together...and they might have taken heat from the surroundings."

Thus, throughout both U6 and L6 interviews, and over the 5 events, she seemed to have the same misconception that it was energy input of some sort, rather than the decrease of energy content or the increase in entropy of the universe, which was the driving force or
the reason why chemical reactions took place.

It is likely that P4 and perhaps a large number of the other interviewees, were interpreting this researcher-interviewer's question in a way differently to what was intended, inspite of the emphasis that the question associated with this aspect D was, "Why do you think this chemical reaction happen at all?" and not, "What do you think causes this reaction to be started off?" or "What do you think initiate this reaction?"

This was interesting that while other students from the same school (eg student P10 and P18) referred to entropy in their explanations on driving force, P4 did not. In this researcher's opinion, the main reason why students like P4 seemed to choose to disregard the intended meaning of the question was because they had not thought about or grasped the issue of driving force. That they had not grasped the concept of driving force could probably be linked to either the lack of emphasis given to this concept by the teacher, or that it is just too abstract for these students to grasp.

SUMMARY OF CASE III

This case illustrates the progression over the one year period between the two interviews, showing the increase in richness and details of the student's explanation, and hence the increased number of key elements (KEs) in a scientific explanation contained in it. It illustrates her shift from the use of perceptually dominated thinking at the L6 with respect to event 2 when she said the wax was not involved in burning, to the use of conceptually based thinking at the U6, when she seemed to acquire a chemist's view of the chemical change associated with a burning candle.

It also illustrate how ACs (including major ones such as the Mg-dilute HCl reaction involves the transfer of electrons from Mg atoms to Cl atoms) could persist and coexist with newly gained scientific concepts. It was interesting to note that she made no mention of the terms 'entropy' or 'enthalpy' at both L6 and U6 interviews; this was a contrast to students P18, P10 (from the same school) who both mentioned these terms even at the L6 level. This, in the present researcher's view could be due to at least two reasons:

* where there is a strongly held preconception, like the conception of heat input as causal agent of chemical change (Andersson's "experiential gestalt of causation, 1986b; Ogborn, 1990); this could hinder the acceptance of other views (Viennot, 1979; Gilbert, Osborne and Fensham, 1982).

* where students do not understand or grasp a concept, they try to shut them out of their minds and refuse to talk about them.

This case also illustrates how students could be consistent in the use of their alternative ideas - here P4 consistently conceived of heat as the causal agent for the chemical change in all 5 events.
APPENDIX M.3

CASE D: STUDENT C10

C10 (Her drawings are at Appendix N4.1 and N4.2) scored 2B's for Coordinated Science in GCSE; predicted 'B' grade for A-level chemistry, her teacher predicted a 'C' grade for her A-level chemistry, hopes to study medicine at University.)

This case is an example of a student who had low KE scores at the L6 level; and did not seem to make much progression at the U6 level.

She seemed to have acquired bits and fragments of scientific ideas which gave the resemblance of having learnt; however, when probed further, then many deep-rooted ACs were revealed, and it seemed that these ACs were unaffected by the extra year of formal chemistry instruction in the period between the two interviews.

Her case also provides an excellent illustration of how unsatisfactory written test and close questions could leave undiscovered many ACs which could continue to hindered her further learning.

Event 1 - L6

Her prediction of what would happen to the copper when placed in the very hot bunsen flame was scientifically acceptable: "Copper will burn. oxidised and form copper oxide" and would be considered as good as those given by other high achievers.

So was her next response on how she conceived the process: "Copper oxidised lose 2 electrons."

At which point, she was asked to say more about the process. She then said: ". Copper gain an oxygen, or copper get certain amount of valence electrons and oxygen joins them and there'll be lots...or could it be the other way round, oxygen lose the electrons..not sure.".

Asked how she pictured copper (and later, oxygen in air) she said: "positive ions surrounded by negative electrons..oxygen is covalent bonding, 2 oxygen atoms sharing their electron system." Again such responses would be rated as scientifically acceptable.

Asked whether any other products were produced besides copper oxide, her response was surprising: "Could get hydrogen gas given off as a waste (writing the equation 'Cu + O2 \rightarrow CuO + H') you could test for hydrogen by a lighted splint, you would go 'pop'..or maybe carbon dioxide might be given off..yes so instead of hydrogen it could be carbon dioxide given off (writing a second equation, Cu + O2 \rightarrow CuO +CO2) because I don't think the copper and the oxygen combine perfectly so there will be something emitted."

I: "You don't think the copper and oxygen combine perfectly."

C10.1: "Yeah, I don't think they do, not perfectly, so something does get given off..CO2"
Here was an interesting case of student talking herself into ideas of transmutation, predicting that there would be some further by-product (possibly, in her imagination, hydrogen, or, more likely, she thought, carbon dioxide). A number of students appeared to find it quite easy to talk themselves into this AC and the reasoning appears to be connected with a general naive conception that burning involves carbon in some way (to produce carbon dioxide) and that incomplete combustion of the carbon results in soot!

Another possible interpretation of her response could be that like a number of other students, her distinction between what constitute the reaction system and what its surroundings are different to those of the interviewer. This means she could be referring to a reaction system which is different to that of the interviewer. In other words, instead focusing her thinking on the copper-oxygen system, she could be uncertain which reaction system to focus on, and was probably referring to the bunsen flame reaction (the methane-oxygen reaction system) as well. Whichever of these interpretations was the case, the root of the problem seemed to be the lack of understanding of the driving force of chemical reactions which lead to her 'anything goes' thinking about reactants and products.

C10 was also confused about the term electronegativity which led to the idea that oxygen could lose electrons to copper; this is indicative of another common underlying confusion between covalent and ionic bonding.

Asked to predict the overall energy change, she said, "Overall... takes in heat... taking in heat energy to make bonds (AC B3a)."

Here C10 also showed two common mis-conceptions:

i. that a reaction would be overall endothermic if the application of heat is needed; this kind of reasoning was found in a number of the other interviewees - the use of naive perceptually dominated reasoning or 'one factor only type' reasoning;

ii. that energy is taken in to make bonds - this probably is the result of naive reasoning too; the fact that in the macroscopic world, energy is needed to make things, so in the microscopic world, energy is needed to make things, including bonds.

Her response was also indicative of a general level of confusion between activation energy and overall energy change; this was exemplified in her next statements.

Asked to say a bit more about the role of heat, she said: "Heat speed it up, make everything faster and then make them join... bond together."

Asked what the driving force was, she said: "The heat you put in, that's the driving force".

Event 1 - U6

At U6, as in the L6, she had no problems in predicting the reactants and products involved.

Asked how the process was conceived, she said: "Heat cause them to move, they share electrons, they try to get to the lowest energy they can... copper and oxygen form covalent
bond. copper and oxygen share electron system. copper give one, oxygen take one." [She seemed to have confused ionic with covalent bonding in referring to copper and oxygen sharing electron system and yet copper giving one electron and oxygen accepting one electron.]

Her confusion was even more obvious when after a while, she said: ""No, oxygen must give to copper because oxygen has more electrons than copper. I don't think copper has enough electrons with only one outer shell electron. Need 2 more electrons to make bonds between the two, need 3 electrons, so I think oxygen gives copper 2 electrons" (drawing 3 diagrams, the first showing the symbol 'Cu' with 1 'cross' representing the 1 outer shell electron; the second showing the symbol 'O' with 6 'crosses' representing the 6 valence electrons; and a third diagram showing 'Cu' and 'O' side by side, with 3 'crosses' between them).

Thus, she seemed to make no progression on either her KEs on aspect C or her overall conception of the process of chemical reaction, showing the same confusion between ionic and covalent bond (AC C2a) at both the L6 and U6 interviews.

Asked to predict the overall energy change, she said: "Overall exothermic. giving out energy. bonds give out energy when broken, when they're formed again, they take in energy. (This response which includes AC B3a, was placed in category ii in section 10.2, chapter 10)."

To which the interviewer asked: "What are the bonds which are broken?"

She then replied: "Is it Van der Waals bonds inside the copper, and the oxygen (AC C2b, section 6.3, chapter 6). When these bonds break, energy is given out and when bonds are formed between copper and oxygen they take in energy.".

During the L6 interview C10 had demonstrated a lack of understanding of the concepts of electronegativity and electrovalency; at the U6 interview this was still persistent and seemed further compounded by additional confused ideas which included Van der Waals forces, which thought were the bonds in oxygen and in metallic copper which were broken during the reaction.

In fact, it seemed to this interviewer that she had regressed in a way. The reason is: at the L6, she appeared to have the scientific view that the bond within the oxygen molecule is a covalent one, with "2 oxygen atoms sharing their electron system" and that copper comprised "positive ions surrounded by negative electrons", and there was no mention at all of Van der Waals bonds. In contrast, at the U6 level, she seemed to think that it was Van der Waals bonds inside the copper and the oxygen which break and which release energy.

This syndrome of regression in conceptions showed by her here, was quite prevalent among the interviewees, even among those who made a lot of progression (see section 12.1, case 1). Perhaps this is the natural consequence of learning - of acquiring knowledge in unconnected bits and pieces in the early stage of learning (di Sessa, 1982) or of undergoing disequilibrium before achieving accomodation and equilibrium again (Furth, 1981). Or perhaps some cases, it is the result of selective inattention - the fact that the interviewee has chosen to ignore old knowledge and to construct explanations based on
new knowledge learned.

Whereas she did not mention bond breaking at the L6 level, at U6 she did, but only with the AC that it involves the release of energy. In other words, the AC uncovered at the L6 level that bond making requires heat input, instead of being abandoned, was further supported at the U6 level, by the twin view that bond breaking releases energy.

On driving force, she said: "Heat from the burner is the driving force (AC D1a)."

Here, as in the L6 interview, she revealed a AC held by the vast majority of the interviewees there is an active causal agent behind chemical change; and more specifically, in reactions like event 1 where heat is the necessary and causal agent for chemical change.

Event 2

Again C10 seemed most unusual in 2 senses; firstly in her most unusual ACs about what is going on when the candle is burning and secondly, in showing no progression at all on her ideas in this event. The extracts given here are more lengthy to illustrate the surprising views that C10 held with respect to the burning candle.

Event 2 - L6

Asked if there were chemical reactions going on when the candle is burning, C10.1 said: "There must be chemical changes in the atmosphere...the oxygen must have burned."

I: "What do you understand by the term 'burning'?"

C10.1: "Burning is between some kind of fuel and a material...so it would be burning between oxygen and the candle...it gives out carbon dioxide...or maybe no, I think it just burn up the oxygen...then if there is not enough oxygen it would burn up the carbon dioxide and turn that to carbon monoxide which will be poisonous."

I: "It will burn up the oxygen...and then if there is not enough oxygen, it would burn up the carbon dioxide...what do you mean by the 'it'?"

C10.1: "The candle...the flame...and when the flame burns up the oxygen, if there is none left, it would burn up the carbon dioxide."

[The flame appeared to be seen here as an active agent or reactant, AC A1a.]

I: "Please write down what you think is the chemical equation for the reaction you are referring to."

C10.1: "Oxygen plus some heat...and it will give off...No, it doesn't...I'm not sure what it does at this stage but...I think when you got carbon dioxide in the air (writing equation 2.1 'O₂ + heat → CO₂') and it burns it...and you have the heat...it will give you carbon monoxide but I'm not sure how it works (writing equation 2.2 'CO₂ + heat → CO'). it's CO₂.
plus the heat gives carbon monoxide...I know carbon monoxide is very dangerous so when you burn a candle you got to have plenty of oxygen."

I: (referring to the equations she had written): "Where does the 'C' in CO₂ come from?"
C10.1: "It comes from the atmosphere."

I: "What do you think is the part played by the wax?"

C10.1: "Oh."

I: "Is the wax involved in this chemical change?"

C10.1: "No, I don't think so...it's just to hold the wick, the string, it won't catch fire, but it will melt."

I: "Why do we need the wick then?"

C10.1: "Because you can't...if you just have a match, it would probably do the same thing but it'd burn your fingers very quickly so I think it just holds the flame for a long time until the wax melted, but I think the same reaction will take place if you held the match in a cigarette lighter."

Asked how she imagined the process at the microscopic level, she said: "Oxygen is being almost destroyed while made very very hot, then it changes into something else...once you burn something it won't be the same, it would be a different chemical...yes, because when you burn petrol, it turns into all sorts of things and then the exhaust of the car...so I think the same here. Oxygen changes into maybe carbon dioxide."

The ideas of transmutation (AC A4a, section 4.3, chapter 4) revealed in event 1 surfaced here again in event 2.

I: "How do you picture carbon dioxide at the microscopic level?"

C10.1: "It will be a carbon and oxygen molecule there...another oxygen molecule there" (drawing 3 circles, arranged at the 3 apices of a triangle, with 'C' written on the middle circle, which has 2 lines, one on each side, extending out from it to the other 2 circles with 'O' written at their centre; i.e., in effect she had drawn what could be interpreted as a V-shaped molecule, comprising one C atom singly bonded to 2 O atoms, one on each side).

I: "Oxygen molecule."

C10.1: "No, oxygen atom...these lines are bonds, I think they are hydrogen bonds or...but it's the bonding between...oh, they are covalent bonds but is a type...I'm not sure which bond but is a type of bonding between molecules."

During this interview, the fact that she had her views of reactions and types of bonds so confused (e.g., for her to even think that the bonds in carbon dioxide are hydrogen bonds seemed incredulous to this researcher, for whom, this is the first experience in eliciting
students' ideas) caused the interviewer to be rather 'unsettled' and to refrain from asking the question on aspect B, i.e., asking her to predict the overall energy change.

This interviewer was caught by surprise at her poor grasp of what was going on and then that the prediction question might be too difficult for her. For the same reason, the standard question on driving force was not presented to her. Instead what was perceived as an easier question by the interviewer, on the role of heat was presented to her.

I: "What do you think is the part played by heat here?"

C10.1: "It must be to do with the energy because this is giving out energy whereas...or rather taking in but I'm not too sure. No, it gives out."

She seemed to have misheard or misinterpreted the interviewer's question, which again this interviewer did not pursue further, having decided on the spot that since her grasp of chemistry seemed rather weak, persistent pursuit of the same point might unsettle her. On hindsight now, this researcher might have been over-cautious or have underestimated her ability to withstand more in-depth probing.

Event 2 - U6

It was rather surprising that C10 did not seem to have any clearer conceptions of the reactions in the candle flame when she was interviewed one year later, when she was in the U6 form, as could be seen from the following extract:

I: "Reactants are..."

C10.2: "Oxygen and carbon dioxide."

I: "Anything else..."

C10.2: "I suppose anything else that's in the air...but I think oxygen and carbon dioxide are the main reactants."

I: "And what are the products?"

C10.2: "Once, the candle burn all the oxygen, it will perhaps burn the carbon dioxide and that will give carbon monoxide...so I don't know whether it will burn carbon dioxide to start with. I think it does (AC A.3a, section 4.3, chapter 4)."

I: "What do you mean by the term 'burn'...or 'burning'?"

C10.2: "Where energy is used to...it's usually between a fuel or a material and it gives out energy again."

(Note the lack of understanding of the concept of burning here - there is no mention of the role of oxygen.)
I: "Is wax involved in burning?"

C10.2: "No, the wax just holds the wick."

I: "Is the wick involved in any chemical reactions?"

C10.2: "No, it's just like the bunsen burner. has a flame but doesn't involve in the reaction."

I: So nothing..none of the material in this candle is involved in any chemical reactions in the flame?"

C10.2: "No, none at all."

I: "You said oxygen and carbon dioxide are involved, please write down what are possible products."

C10.2: (writing equation 2.1 'O₂ + CO₂ → 2CO'). "I think carbon monoxide will be formed when it burned but I think something else will be formed as well. maybe water so maybe if it burns hydrogen it will give out water as well."

I: "Where does hydrogen come from?"

C10.2: "There are small amounts of hydrogen in the air anyway, and it could burn with that, so maybe it's. (writing equation 2.2 'O₂ + H₂ + CO₂ → CO + H₂O')"

The above extracts illustrate in a way, perhaps a slight progression for C10 who in spite of still not having improved in her conceptualisations of the chemical reactions going on in the candle flame, had at least appeared to move from having a kind of transmutationist view at the L6 level, where oxygen atoms are transmuted into carbon atoms to a conservationist view of chemical reactions at the U6 level, where there was an awareness that the atoms which appear on the product side of the equation are same as those on the reactant side, only differently combined.

In this interview, the interviewer having been more prepared for her unusual answers, did not become 'unsettled' as a result of her responses and was able to continue with the standard question on prediction of overall energy change (aspect B) to which she responded: "I think it will give out. or maybe take in energy because more energy is needed to break bonds so it means it could take in energy."

At this point, the interviewer reminded her that in event 1, she seemed to have heard her saying a different thing:

I: "Now you're saying energy is needed, taken in to break bonds.. Did I hear you saying that energy is needed to form bonds in the copper reaction?"

(It is likely that she, like a number of other interviewees, had incorporated the scientific view that energy is needed to break bonds into her AC B3a that energy is needed to form bonds and that bonds when broken release energy. The way these 2 seemingly opposing views had been modified or adapted to fit her conceptual framework seemed to be by
thinking of energy needed to start the bond breaking process, and once that started energy is released by the bonds which are breaking up."

C10.2: "Yes.. so I think it's when bonds are broken, energy's given off and energy's taken in to form bonds... yes you can get enough energy from the breaking of the bonds (referring to reactants on left hand side of equation 'O₂+H₂+CO₂') to form the new bonds (referring to products on right hand side of the same equation, i.e., 'CO+H₂O')."

I: "Could you expand on the bonds which are broken...what kinds are they?"

C10.2: "Those are molecules which always occur in pairs so will be internal bonds."

I: "Just now you said in copper and oxygen are Van Der Waals bonds."

C10.2: "Yes inside of them will be."

I: "What about inside of O₂, H₂, CO₂..."

C10.2: "Yes, inside these are weak bonds but I'm not sure whether Van der Waals bonds are present in all molecules." [Here the same AC C2b uncovered earlier with respect to event 1 surfaced again, showing that she conceptualised Van der Waals bonds as INTRA-molecular bonds rather than inter-molecular bonds.]

C10 seemed quite confused about bonding. At the L6 level, she seemed at least to know that oxygen in air comprised 'O₂' molecules each with 2 atoms "sharing their electron system... joined by covalent bond". At the U6 level, she seemed to have regressed (but only to some extent - since as discussed earlier, at the L6 level she did show that she had no clear understanding of ionic bonding, since she was not even sure of the direction of the electron transfer between oxygen and copper) to saying that inside oxygen (and copper metal) are Van der Waals bonds. However, she was not the only student who seemed to have such confusion about bonds. There were a number of students in this study who like her, seemed confused about the various types of chemical bonds - covalent, ionic, hydrogen bonds, Van der Waals bonds and so forth. This highlights, among other things, one problem in chemistry learning (which is probably similar to learning in other scientific discipline as well) - that because concepts are so closely intertwined, and finely differentiated from each other, confusion in any one area will almost inevitably lead to confusion in other areas.

This case of C10 illustrates how confusion about ionic or covalent bonding at the L6 level seriously hindered further understanding about bonding and chemical bonds, including the nature of inter- and intra-molecular bonds, which was reflected in a similarly confused response in the U6 interview.

Event 3 - L6

C10.1: "Gas combines with... oh, the splint as you light it on the match it burns the gas that comes out of the gas tap and I think it's burning methane."
I: "What happens to the methane...first, show how you picture methane before it burns."

C10.1: "'CH₄'...under microscope it will be like that (f3.2, Appendix N4.1A, showing a 3-dimensional tetrahedral molecule, with 'C' at the centre) and I think that is 109° in between the angles... with the oxygen, methane will burn and change into... it'll have heat energy... it will burn the oxygen from the atmosphere... you'll get... something. I'm not sure what at all."

I: "You think oxygen is involved here..."

C10.1: "Yes... or maybe could be just the methane."

I: "Could be just methane burning..."

C10.1: "Yes, but I think with the oxygen surrounding it as it comes out of the tap... oh no, there is no oxygen in the tubing, so no, I think it's just the methane burning."

(′She seemed to think that oxygen is not necessary for burning, AC Alb; however, she changed her mind soon, in the process of writing the chemical equation."

I: "What are products..."

C10.1: "Maybe hydrogen or oh no, carbon dioxide again (writing equation 3.1 'CH₄ + O₂ → )... I think there's going to be CO₂ and maybe water vapour... some kind of water or H... maybe H will be given off... I think the oxygen must appear when you burn it [Here, like a small number of other interviewees, she seemed to interpret the involvement of oxygen in burning as it being produced as a product. It seemed to this interviewer that because these students were able to recall that oxygen is involved in burning but did not really understand its role in burning, the result was that they thought that in burning, oxygen could either be involved as product or a reactant... when you're burning methane... I'm not sure so oxygen and methane must be reactants and products are water, maybe carbon monoxide or hydrogen or carbon dioxide given off. (completing equation 3.1 so that it became 'CH₄ + heat → CO₂ + H₂ + H₂O')."

It was not easy trying to count the number of KEs in her conceptualisation of the change involved. Her ideas seemed very fluid and uncertain, which were quite typical of the students interviewed. For example, she, seemed to think that it is possible for methane to burn without oxygen being present (the majority of the other interviewees while not necessarily all having the scientific view of the reaction involved, at least knew that oxygen must somehow be involved), then she seemed to recall that oxygen must somehow be involved in burning, at which point she suggested that "oxygen must appear when you burn it". Then she seemed to shift her view to saying that "oxygen and methane must be reactants".

However, she seemed to have either shifted from this view of the involvement of oxygen as reactant when the equation she wrote has 'heat' as reactant rather than oxygen. Here it is highly likely that in her conception, oxygen and heat meant the same thing - i.e., heat was substantialised as oxygen - a AC found in a number of other cases in this study.

There was inconsistency between her spoken words and the equation she wrote, not only
in terms of what reactants are involved but also in terms of the products - she mentioned carbon monoxide as a product but this was not shown in the equation, whereas the other three products she mentioned (water, hydrogen and carbon dioxide) were reflected in the equation.

On how the process was conceived, aspect C, she responded: "Methane gets very hot.then it splits up.forms separate carbon and hydrogen atoms. some carbon combines with oxygen forms carbon dioxide..some hydrogen also combines with some other oxygen..gives water..some hydrogen just go off as H2."

On driving force, she said, "The heat given..without the heat, nothing will happen (AC D1a)."

Again, this is a manifestation of the naive view that heat is the causal agent of change (Andersson, 1986b) or it could be that she was interpreting the question in a way different to what the interviewer intended. The interviewer had asked her to explain why the reaction takes place at all; whereas she could be interpreting it as: What causes the reaction to start or to be activated? Perhaps, it could even be the manifestation of the 'one factor only' type thinking, or perceptually dominated way of thinking (Driver, 1985) - heat is perceived as needed to set off the reaction, hence it must be the causal agent.

Event 3 - U6

At the U6 her response in aspect A is similar to that at L6.

C10.2: "Yes, there's chemical reaction..methane is being burned in oxygen, to form water and maybe carbon monoxide or hydrogen or maybe carbon dioxide (writing equation 'CH₄ + O₂ → H₂O + CO; then cancelling off 'CO' and replacing it with 'H')."

(Her use of 'H' instead of 'H₂' to represent the product hydrogen appeared to be another indication of AC C1a, confusion between atoms and molecules.)

On how the process was conceived: "Again methane will get very hot, the carbon and hydrogen atoms will split up.become separate.. and they recombine with the oxygen.to form the products..not sure what kind of bonding is involved here."

While showing that hydrogen was formed as a product in her equation, her response on how the process was conceived seemed to indicate that she thought both hydrogen and carbon would separately combine with oxygen.

As pointed out earlier, this inconsistency which seemed to be the result of the fluidity and uncertainty of her ideas is perhaps inevitable since she seemed to hold many confused ideas.

On overall energy change, she predicted: "Heat's given off, from heat stored in methane (AC B2a, section 5.3, chapter 5) and then as it burns it'll give out heat and water and other products." 

I: "Heat is stored in methane..?"
C10.2: "No, the energy and then the heat will come from burning... the heat will come when methane is lit in the bunsen burner and the energy will come from breaking the bonds... the C-H bonds and the oxygen bonds possibly... will be break and give out energy which is used to form new bonds... I think there'll be more energy from breaking of bonds than will be needed to form bonds here (AC B3a; this response is placed in category ii in section 10.1, chapter 10)."

Asked on driving force, she said: "The heat from the bunsen again... yes, it's the catalyst."

Here she seemed to think of the term 'catalyst' as meaning something to initiate or start a reaction rather than something which merely speed up a reaction. However, since this interviewer did not probe on her meaning of the term 'catalyst' no definite conclusion could be made here.

It can be seen that her ideas on all 4 aspects did not change much at all between the 2 interviews.

Event 4 - L6

She predicted, "Hydrogen gas and magnesium chloride solution will be formed."

Like many of the other interviewees, she was able to predict the outcome of this reaction.

On how the process was conceived, she said, "Mg displaces... the hydrogen gets given off so the Mg combines with chlorine to form the MgCl₂ which is dissolved into it."

Here, it seemed that what she, like many other students, misconceive of Mg forming a bond with Cl whereas Cl plays no part in this reaction.

On prediction of overall energy change, she said, "Gives off heat... from the breaking of bonds."

Here she again revealed the AC that bond breaking is exothermic; and seemed to use the 'one factor only' type reasoning by not considering bond making.

On driving force, she said, "Maybe the hydrogen from HCl acid cause the reaction between the magnesium and the chloride... oh maybe HCl acid altogether cause the reaction which make the hydrogen gas be given off... because if it were by itself nothing would happen but it's when the HCl acid is poured on to Mg that it changed, so HCl acid must have done something to Mg."

Her view on driving force reflected what researchers such as Brosnan (1992) termed as one of the characteristics of common-sense explanations of change—that changes are seen as caused by an active agent acting on a passive object. This is a contrast to the chemist’s view that chemical change is the result of interaction of equal partners rather than in the causal power of one participant. Again such a view of chemical change was prevalent among the L6 interviewees; and at the U6 level some students abandoned this view and seemed to make progression towards the chemist view of interaction of equal partners.
On how she pictures dilute HCl, she said: "It would be a hydrogen and chloride atoms together... but I don't know the difference between hydrochloric and hydrogen chloride so I assume it'd be the same but... it's a liquid whereas Mg is a solid so the Mg atoms are all packed tightly together but the hydrochloric one will be separate and quite far apart. I assume the acid can break up Mg so... must be able to break the bonds between the Mg atoms. I'm not sure what it does.”

It was surprising that at A-level, she did not know the difference between hydrochloric and hydrogen chloride, and yet was able to predict correctly the outcome of the reaction.

On bonds in the Magnesium, she said, "There must be something between the Mg. If you got positives and negatives then there must be something holding these together... they must be electrostatic because positive and negative attract each other... and the hydrochloric acid must be able to break them up and so the... chloride will attract the magnesium because they are opposite charges so attract each other."

Her reference to the something electrostatic within Mg and so forth was not contrary to the scientific view and the reference to acid breaking it up is also not incorrect from the macroscopic or the layman's view. However, the fact that she seemed unable to conceptualise the dilute acid as comprising H+ and Cl- ions (which was surprising since this concept had been covered at the GCSE level), and that it was the electron transfer between Mg and H+ with the resulting energy changes and so forth which brought about the breaking of bonds in Mg meant that no KEs were scored on her response.

On how she pictured MgCl₂: "There'll be Cl-Mg-Cl (drawing f4.1 showing essentially a V-shaped 'molecule' with 'Mg' at the centre and joined to a 'Cl' on each side of it with a single line)... these lines represent some kind of bonding... maybe hydrogen bonding... I'm not sure... maybe a type of hydrogen bonding or... no... it could be covalent because I think covalent takes place between... in the same molecule... it's bonding between more than 1... or more atoms in a molecule and they must share their electrons in some way... can't remember... there is an electron diagram... with the valence electrons and they will be situated around it... Cl has 17e, Mg has 12e so its Mg got 12e so got 2 valence electrons... I'm not sure where the chloride molecule comes... the chloride molecule would join on... one here maybe and one here... and when they join on you get the magnesium chloride molecule but I'm not sure... they share their electrons somehow (f4.2)

Note her utter confusion about particles (AC C1a), and bonding. Again there seemed to be no understanding about the electropositive nature of metals like Mg, which would lead one to infer its tendency to lose its valence electrons and so forth.

Event 4 - U6

At the U6 level, again she was able to predict the outcome in terms of reactants and products without difficulty.

On how the process was conceived, her response was: "Because these are positively
charged (referring to Mg) it'll combine with Cl which are negatively charged and become
attracted and it will then have to give off the H."

On the overall energy change, she predicted, "Overall exothermic because it's giving
out.. it'll give out.. well the energy is here, breaking these sort of bonds will be less
than the energy needed to form magnesium chloride so there'll be net giving out of energy."

I: "You're saying 'energy needed to form'?"

C10.2: "Energy given out is more than the energy needed so there'll be energy left."

I: "You're saying there are bonds being broken in magnesium metal?"

C10.2: "No.. there'll be internal bonds, but not any bonds split between Mg atoms since
Mg is by itself."

Like a number of other students, here she seemed to think that there are no inter-atomic
bonds in Mg which needs to be broken in the reaction. This seemed to be a kind of
regression given that at the L6 level she referred to electrostatic bonds in Mg which were
broken by the acid.

Also by saying now that there are no bonds to be broken she seemed to contradict her
earlier point about there being Van der Waal bonds in copper which needs breaking (event
1). This seemed to show that she was not thinking scientifically - she seemed unable to
generalise that copper and magnesium are both metals and therefore they should have
similar sort of bonding; that she said of copper should apply to magnesium. She seemed
to be referring to each event and substance in isolation; and there seemed no concern on
her part about maintaining a consistent view of event or concept (e.g., metal).

I: "Internal bonds of magnesium?"

C10.2: "These are inside the atoms as opposed to between the atoms which will.. which
may break and here between the H and Cl in HCl there'll be bonds breaking actually
between the 2 molecules [She seemed to be using the wrong term again here. What she
probably meant was the 2 atoms i.e. H and Cl in HCl. Here again, it seemed that her
confusion about the various particles surfaced again.]."

Here by referring to internal bonds of Mg she seemed to be referring to intra-atomic
bonds, the nature of which this interviewer did not probe, because this had not been the
focus of the interview and also because of the need to cover other aspects in the interview
schedule.

I: "You're saying when these bonds, the internal bonds in Mg and bond between H and
Cl in HCl break, energy is given off?"

C10.2: "Yes..oh, they may have to take in energy to break bonds.. it depends how much
energy is within the molecule anyway and to actually break the bonds to maintain a
certain amount of energy it may have to take in more."

I: "In the copper experiment you said there're bonds being broken in copper and oxygen
and as these bonds are broken they give off energy."

C10.2: "I think so, not sure anymore..in the first stage of reaction they'll break bond. when bonds are broken, they'll give out energy; and then they'll take in energy when bonds are formed but if you..let's go back to copper oxide..if these were to recombine, I think it will take in energy to break those bonds..so the first reaction (meaning bond breaking) will be exothermic whereas the subsequent reaction (meaning bond forming) will be endothermic."

I: "How about here..(referring to event 4)"

C10.2: "Same will apply..so when internal bonds of magnesium break, energy is given off and when bond in HCl is broken energy is given off.. then when magnesium chloride is formed, energy is taken in."

I: "How do you picture the bond existing between hydrogen and chlorine in dilute HCl?"

C10.2: "Sort of H bonded to Cl (drawing f4.1, 'H-Cl') but the electrons will be attracted to either the H or Cl depending on which is most electric.. electrically charged.. sort of negative and sort of positive..[Here she revealed that she had not grasped the concept of electronegativity.]. I think electrons will be drawn towards the Cl because the electrons will be sort of down here so I don't think it'll be an equal bond so it won't lie straight between them (adding a '-' to the Cl & a '+' to H in H-Cl) yah, electrons to one side."

But she seemed to have acquired some idea of the polarity of the H-Cl bond.

I: "What causes this bond to break?"

C10.2: "Cl will be attracted by the Mg so the bond will be broken by Cl going over to Mg."

Her view that the H-Cl bond is broken as a result of Cl going over to Mg was prevalent among the interviewees; sometimes even among those who remembered having learned that aqueous acids like HCl produces hydrogen ions. In some of these cases, the ionic bond was thought to exists between the H+ and Cl- ions; which was then broken by Cl- going over to Mg.

I: "What is it about magnesium that attracts chlorine?"

C10.2: "Magnesium is positively charged."

I: "This piece of Mg metal is positively charged?"

C10.2: "Yes."

I: "But the way you've written..doesn't look so..'Mg' (referring to equation 4.1)"

C10.2: "Positive so if I put Mg** instead of Mg..this is Cl- so need 2Cl's for every Mg .."

I: "What is the bond between Mg & Cl?"
C10.2: "Ionic...no, yes, it's salt so ionic bond."

She seemed to think of the metal as existing as 'Mg\(^{2+}\)'. Again she was not unique in having this view. There are at least two possible sources/reasons for having such an AC:

* there could have been confusion between an element and its compounds;
* there was confusion between oxidation number and charges - she could have learned that group II metals like Mg has an oxidation number of 2+ and wrongly applied it here to the metal in its uncombined state.

This view of hers which involved no concept of electron transfer in this reaction nor an awareness that dilute HCl contains mainly free H\(^+\) and Cl\(^-\) ions are quite common among the interviewees.

On driving force, "It's heat again and unless... I don't think there's any kind of catalyst. but once the bonds break it'll be attracted but I don't know what causes the bond to break to start with. I think it's the attraction between Mg and Cl once they combine."

Here, her lack of understanding about bonds and energy change involved in bond breaking was again evident when she referred to heat (input) as driving force and yet said that she did not know what cause the bond to break to start with.

**Event 5 - L6 and U6**

(Time seemed to run out for this event at both interviews; so that her responses were hardly probed but were taken at face value.)

At both L6 and U6, she was able to predict the formation of sodium nitrate and lead chloride, and at the same time, she misconceived both products being formed as solutions.

Here, like many of the other interviewees, she seemed to have learned fairly well the rule about swapping partners. That to say, given 2 reactants 'AB' and 'CD', the products formed are just recombinations of the original partners, i.e., 'AD' and 'CB'.

On how the process was imagined, again both her L6 and U6 responses were quite similar.

At the L6 level, to help her visualise the process of the reaction, she was asked how she pictured the process of dissolving of NaCl salt in water. To which, she responded: "Water breaks up the electrostatic bond between sodium ions and chloride ions but the ionic bond is still there... the electrostatic bond stops them attracting."

Here, like many of the other interviewees, she seemed to think that the process of dissolving leaves the ionic bond intact but breaks some other weaker bond (which in most of the other interviewees' conception is a Van der Waals bond, whereas in her case, she did not think of it as Van der Waals bonds, but some "electrostatic bond" within the
sodium chloride structure. Again her confusion/lack of understanding about ionic bond was revealed when she seemed to differentiate it here from "the electrostatic bond". Here, it seemed that she did not think that the ionic bond is electrostatic in nature.

On how the reaction took place, "Positive sodium and negative nitrate they attract.. so also positive lead and negative chloride and form the products."

Again her explanation was rather superficial (inspite of having been prompted to imagine that she was looking at the reaction as it was occurring through a special machine which would allow her 'to see the tiniest of particles'), and perhaps similar to one that a student from a lower grade would give.

On overall energy change: "Maybe no energy change..maybe bond breaking energy is equal to bond forming energy."

Here, like a vast number of the other interviewees, she held the AC that the reaction process as involving the breaking of the ionic bonds within the two reactants.

On driving force: "The attraction due to opposite charges."

Here, her response is superficially inconsistent with those she gave for the earlier events: for event 1 and 3 it was heat input (she was not asked about event 2) and for event 4 it was the acid. However, on a broader level and from her own perspective, she seemed quite consistent in maintaining the view there is a cause behind chemical change - in events 1 to 3, it is heat, in event 4 it is the acid and in event 5, it is the attraction due to opposite charges.

At the U6 on how the process was imagined: "Na cannot combine with Pb because it's 1 positive charge, and Pb's 2 +ve charge.. so they'll repel each other, so will Cl and the NO3..so that's the only way they could combine"

This response was very similar to her L6 response, showing no progression in understanding at all.

On overall energy change: "Overall exothermic.. because energy needed to break these ionic bonds will be greater than the energy to form these."

On seeking clarification of her view that energy is needed to break the ionic bonds: "Oh yes..no, the energy from breaking..the energy needed..it probably has the energy within itself to break the bonds, but the energy from breaking those bonds will be greater than the energy needed to form these new bonds."

Here again she appeared to be thinking that energy is needed both to break and make bonds; and that once the bonds begin to break, they release energy.

C10's reference to energy being needed to break bonds was probably part of the fragments of new knowledge she picked up from A-level topics in organic chemistry as well as from thermochemical calculations involving bond enthalpies and so forth, which had been superimposed on her existing AC B3a, that bonds release energy when broken.
On driving force: "Not sure..what actually cause it to combine..maybe it's the attraction between Na and the nitrate and..the Cl and Pb..because Na is positively charged and Cl is negatively charged."

This response was almost identical with her L6 response on the same event but seemed inconsistent with her U6 response on the previous events including on event 4, where she said of driving force "it's heat again."

Again it seemed rather incredible that across events she did not seem to make progression on aspects B, C and D, the process aspects of chemical change, while having fairly good ideas of what reactants and products are involved in the events except for the burning candle. She seemed to be just as confused about the nature of bonds and the energy changes involved in bond breaking and bond making at the U6 as at the L6.

SUMMARY OF CASE IV

This case illustrates how a student could score a grade 2Bs for coordinated science at GCSE level and aspired to do medicine at university and yet seemed utterly confused about some of the most fundamental ideas in chemistry.

It illustrates various kinds of naive ideas such as those related to burning and substantialisation of heat, and transmutation ideas which were found in younger pupils (e.g., Andersson, 1986a; 1990).

It also illustrates how confusion about bonds and bonding if not sorted out at the L6 level could seriously hamper further learning at U6 level and result in further (even more) confusions. Whereas students like El seemed not to make much progression because of apparent loss of interest in the subject, C10 seemed not able to make progression because her deep-rooted mis-understandings were not sorted out.

It also illustrates perceptually dominated thinking and the lack of scientific reasoning - the ability to use underlying concepts and principles to apply across events. She seemed to treat each task and each substance independently without recognising the relevant commonalities in question; giving rise to inconsistencies in her views and explanations. The limited 'one factor only' type reasoning was also obvious.

It also shows the fluidity and fragility of ideas in situ - the inconsistency between what she said at one point and what she wrote at the next point in time.
APPENDIX N

STUDENTS' DRAWINGS
APPENDIX N.1.1

L6 DRAWINGS OF CASE I, STUDENT R7
\[ C_2H_4 + \text{O}_2 \rightarrow \text{ZHO} \]

\[ \text{H-H} \rightarrow \text{CO}_2 + \text{CO} \]

\[ \text{C-C-C-} \rightarrow \text{CO}_2 + \text{CO} \]

**Fig 1**

**Fig 2**

At first look HCl reacts as a molecule in acid:

\[ \text{H-Cl} \]

\[ [\text{H}]^+ + [\text{Cl}]^- \]

**Fig 4**
\[ \text{fig 6} \]

\[ \text{NaCl} \text{ (aq)} + \text{Pb(NO}_3\text{)}_2 \text{ (aq)} \rightarrow \text{PbCl}_2 + \text{NaNO}_3 \]

Don’t make the rules too simple.

\[ \text{fig 7} \]

Nano scale chloride solid is covalent.
\[ \text{Mg(s)} + 2\text{HCl(aq)} \rightarrow \text{MgCl}_2(aq) + \frac{1}{2}\text{H}_2 \]

\[ \text{H}^+ + \text{Cl}^- \rightarrow \text{H}_3\text{O}^+ + \text{Cl}^- \]
\[ \text{Mg}(s) + \text{HCl} \rightarrow \text{MgCl}_2 \rightarrow \text{MgO} \]
\[
\text{NaCl (aq)} + \text{Pb(NO}_3\text{)}_2 (aq) \rightarrow \text{CuSO}_4 (aq)
\]

\[
\rightarrow \text{NaNO}_3 (aq) \quad \text{PbCl}_2 (s)
\]
APPENDIX N.2.1

L6 DRAWINGS OF STUDENT CASE II, STUDENT E1
Mg → CO₂ + H₂O

Part of CO₂ in ocean, corals, corals, corals; & limestone.

See section 1.3

C₅H₅N
\[ C_xH_y + O_2 \rightarrow CO_2 + H_2O \]

\[ H_4 + O_2 \rightarrow CO_2 + H_2O \]

\[ 3 + HCl \rightarrow MgCl_2 + \text{H}_2\text{O} \]
\[
\text{Mg}(s) + \text{HCl}(aq) \rightarrow \text{MgCl}_2(aq) + \text{H}_2(g)
\]

\[
\text{Mg}^{2+} + 2\text{Cl}^{-} \rightarrow \text{MgCl}_2
\]

\[
\text{H}_2 + \text{H}_2 \rightarrow \text{H}_2
\]

\[
\text{H}_2\text{O} + \text{H}^+ + \text{Cl}^- \rightarrow \text{H}_3\text{O}^+ + \text{Cl}^-
\]

\[
\text{Mg}^{2+} + \text{H}^+ + \text{Cl}^{-}
\]
Each shell is an orbital.
\[ \text{[NO] }^+ + \text{[Cl]}^{-} \cdot \text{BaCl}_2 \]

\[ \text{[Pb] }^2+ + \text{[NO}_3\text{]}^{-} \]

\[ \text{Na}^+ + \text{Cl}^{-} + \text{Pb}^2+ + \text{NO}_3\text{ }^{-} \rightarrow \text{NaNO}_3 + \text{Pb}\text{Cl}_2 \]

\[ \text{Na}^+ + \text{Cl}^{-} \cdot \text{PbCl}_2 + \text{NaNO}_3 \]

\[ \text{Na}^+ + \text{Cl}^{-} \cdot \text{CuSO}_4 \text{ } 2\text{H}_2\text{O} \rightarrow \text{NaNO}_3 + \text{Pb}\text{Cl}_2 \]

\[ \text{Hg}^2+ \text{AgNO}_3 \rightarrow \text{HgNO}_3 \text{AgCl} \]

\[ \text{Ca}^{2+} \text{ } \text{CO}_3\text{ } \]

\[ \text{p. 442} \]

\[ \text{El.1 (s)} \]
$N_f$  $12n$  $N_f$  $12n$

$11n$

$\text{f} \ 4.5$

of $Cl^-$ in HCl under excitation jump to higher levels.

$e^-$ from Mg pair up in + levels then become stable.

\[ \text{Cu}^{2-} \]

P. 443  \[ \text{a} \, \text{a} \]
NaCl + Br₂ =

2NaCl + Br₂ = 2NaBr + Cl₂

F⁻ > Cl⁻ > Br⁻ > I⁻ > more reactive

Mg²⁺ + (O₂)⁰ → MgO

2O₂ + 4Mg → 2MgO

[Ca]²⁺ + 2[O]⁰ → [Ca₂O₂]⁻
APPENDIX N.2.2

U6 DRAWINGS OF STUDENT CASE II, STUDENT E1
\( \text{Ionic bd with cov. character} \)

\[ \text{Cl}^+ \text{Na}^+ \text{Cl}^- \text{Na}^+ \rightarrow \text{H}^- \text{O}^+ \text{H}^+ \text{O}^- \text{H}^- \text{O}^+ \text{H}^+ \text{O}^- \]

\[ \text{H}^- \text{O}^+ \text{H}^+ \text{O}^- \text{H}^- \text{O}^+ \text{H}^+ \text{O}^- \]

\[ \text{H}^- \text{O}^+ \text{H}^+ \text{O}^- \text{H}^- \text{O}^+ \text{H}^+ \text{O}^- \]

\[ \text{H}^- \text{O}^+ \text{H}^+ \text{O}^- \text{H}^- \text{O}^+ \text{H}^+ \text{O}^- \]

\[ \text{H}^- \text{O}^+ \text{H}^+ \text{O}^- \text{H}^- \text{O}^+ \text{H}^+ \text{O}^- \]

\[ \text{H}^- \text{O}^+ \text{H}^+ \text{O}^- \text{H}^- \text{O}^+ \text{H}^+ \text{O}^- \]

\[ \text{H}^- \text{O}^+ \text{H}^+ \text{O}^- \text{H}^- \text{O}^+ \text{H}^+ \text{O}^- \]
APPENDIX N.3.1

L6 DRAWINGS OF CASE III, STUDENT P4
\[ f_{1.2} \]

\[ f_{1.1} \]

\[ \text{eqn 1} \]

\[ \text{eqn 2} \]
\begin{align*}
2 \cdot \text{H}_{2}(g) + \text{O}_{2}(g) & \rightarrow 2 \cdot \text{H}_{2}\text{O}(l) \quad \text{eqn 2} \\
\text{P} \leq \frac{1}{\sqrt{10}} \\
\text{P} \geq \frac{1}{\sqrt{501a}} \\
\text{P} \geq \frac{1}{\sqrt{501b}} \\
\text{P} \geq \frac{1}{\sqrt{5.3a}} \\
\text{P} \geq \frac{1}{\sqrt{5.3b}} \\
\text{P} \geq \frac{1}{\sqrt{5.4a}} \\
\text{P} \geq \frac{1}{\sqrt{5.4b}} \quad \text{eqn 4}
\end{align*}
\[ 1 \text{Ag} + 2 \text{HCl(aq)} \rightarrow \text{AgCl(s)} + \text{H}_2(\text{g}) \]

\[ \text{Mg}_2^+ + 2\text{OH}^- \rightarrow \text{Mg} \text{(OH)}_2 \text{ precipitate} \]

\[ 2 \text{Na}^+ (\text{aq}) + \text{Pb}^{2+} (\text{NO}_3^-)_2 (\text{aq}) \rightarrow \]

\[ [\text{Na}]^+ / [\text{Cl}]^- / [\text{Pb}]^{2+} / [\text{NO}_3^-] \]

[green] + \text{PbCl}_2 \text{ precipitate} [green]
\[ {\text{As.4}} = \frac{1}{2} \exp \left( -\frac{\gamma}{\gamma_b} \right) \]

\[ \left[ \text{Pb} \right]^{24} \cdot 2 \times \left[ \text{C} \right]^{-} \]

\[ \text{Pb} \]

\[ \text{C} \]

\[ \text{As.2} \]

\[ \text{Pb} \]

\[ \text{C} \]

\[ \text{C} \]

\[ \text{Pb} \]

\[ \text{C} \]
APPENDIX N.4.1
L6 DRAWINGS OF CASE IV, STUDENT C10
\[ \text{Cu} + 2e^- \rightarrow \text{Cu}^{+} \]

\[ 2\text{Cu} + \text{O}_2 \rightarrow 2\text{CuO} \]

\[ 2\text{Cu} + \text{O}_2 \rightarrow 2\text{CuO} + \text{CO}_2 \]
5.1

Sodium + Chloride

5.2

Magnesium + Hydronium → MgCl₂ + H₃O⁺

5.3

Lead Nitrate + Sodium Chloride → Lead Chloride + Sodium Nitrate + Hydrogen
\( \text{O}_2 \text{ + heat} \rightarrow \text{CO}_2 \)  
\( \text{O}_2 + \text{CO} \rightarrow 2 \text{CO}_2 \)  
\( \text{CO}_2 + \text{H}_2 \rightarrow \text{CO} + \text{H}_2 \text{O} \)  

= 2 \text{CO}_2 \)  
\( \text{CO}_2 + \text{H}_2 \rightarrow \text{CO} + \text{H}_2 \text{O} \)  

\( \text{CH}_4 \)  

\( \text{C} \)  

\( \text{f}_{2.1} = \text{f}_{3.2} \)  

\( \text{CH}_4 \rightarrow \text{CO}_2 + \text{H}_2 + \text{H}_2 \text{O} \)  

\( \text{CH}_4 + \text{H}_2 \text{O} \rightarrow \text{CO}_2 + \text{H}_2 \text{O} + \text{H}_2 \text{O} \)  

\( \text{CS} (\alpha) \)
$C_n(4, \ldots, 4)$

$4.2$

$\text{Mg CL}$
\[ \text{Cu} + \text{O}_2 \rightarrow 2\text{CuO} \]

\[ \text{O}_2 + 2\text{CO}_2 \rightarrow 2\text{CO}_2 \]

\[ \text{O}_2 + \text{H}_2 + \text{CO}_2 \rightarrow \text{CO} + \text{H}_2\text{O} \]

\[ \text{CH}_4 + \text{O}_2 \rightarrow \text{H}_2\text{O} + \text{CO}_2 \]

\[ f 3,1 \]

\[ c_{10.2} \text{Ph} \]
\[
\text{Mg}^{++} + \text{HCl} \rightarrow \text{MgCl}_2 + \text{H}
\]

\[
\text{H}^+ + \text{Cl}^- \rightarrow \text{Mg}^{++}
\]

\[f 4.1\]

\[
\text{NaCl}^+ \quad + \quad \text{Pb(NO}_3\text{)}_2^2^- \rightarrow \text{PbCl} + \text{Na(NO}_3\text{)}
\]

\[f 4.2\]

\[\text{form as soln.}\]

\[\text{BB in NaCl} \quad \& \quad \text{Pb(NO}_3\text{)}_2\]

\[\text{Lucy Cook}\]

\[\text{unaltered water}\]

\[\text{Some pellets} + \text{number C1 \& C2}\]
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APPENDIX O

Reliability check on coding of transcripts

Appendix C sets out in detail the criteria used in analysing the transcripts to determine the numbers of Key Elements. A check was made on the reliability of the application of these criteria. Some transcripts were read by two subject experts and comparisons were made between the results of these two and this researcher's results. The comparisons were made at the level of aggregation as set out in Appendix G, tables G1 to G4. For each data item, i.e. the total count of key elements across the five events for one of the Aspects A, B, C, or D, the discrepancy in this number was expressed as a percentage of the total possible count. Nine such pairwise sets were compared, each involving the four events so giving thirty six comparisons in all. The mean discrepancy over these thirty six was 5%, with the largest single discrepancy being 20%. This gives a rather optimistic view because many of the counts are zero: in some such cases, but not all, the zero arises because the issue was not addressed in the interview, often because of the subject's failing on prior items. It is hardly possible to disagree when there is nothing there. If all the zero discrepancies are omitted, then the mean discrepancy was just under 9%. This gives a pessimistic view, because some of the zeros do represent judgements that relevant material that is in the transcript fails to meet the criteria.
The p-values in Tables 4.1 and similar tables were generated from the F-values by carrying out one-way analysis of variance, using the MINITAB programme. It is a measure which allows one to see to what extent differences in the mean values can be attributed to chance, by taking into account the spread of values. If the spread is narrow and the differences are large, then the latter are less likely to occur by chance.