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THE APPLICATION OF REPERTORY GRID ANALYSIS IN ELICITING CONCEPTUAL FRAMEWORKS AND CLASSIFICATORY KNOWLEDGE OF BIOLOGICAL NATURAL KINDS CONCEPTS

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Thomas John Johnston McCloughlin

May 2008

Thesis
8642

Chiron, an unusual equid, instructs Achilles in the sciences and arts. C'a d'or, Venice

A thesis submitted in accordance

of the requirements of the University of Dublin

for the degree of

Philosophiae Doctor

by

Thomas John Johnston McCloughlin

under the supervision of

Dr. Philip Matthews

Declaration

I declare that the work described in this thesis is my own work and has not been submitted as an exercise for a degree at this or any other university

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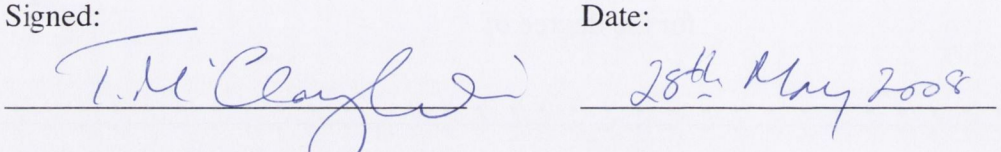

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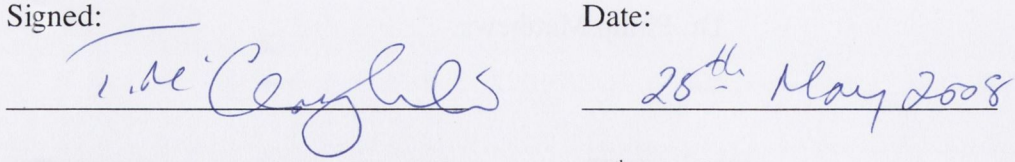

Thomas John Johnston McCloughlin 28th May 2008

Dedication

This work is dedicated to

Aoife, Sophia & Muire who have lived with it all their lives,

To my father, Joshua who did not live to see its completion,

But especially to Sinéad, who has enriched my life

more than any number of words can say.

May it be a fitting tribute to you all.

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Figures and tables

Figures

Figure 1.1 Concept map of Chapter 1 2

Figure 1.2 A scanned image of page 14 from the early herbarium of voucher specimens. I a species of crucifer; II bluebell; III ribwort plantain 4

Figure 1.3 George Kelly, 1905 – 1967 5

Figure 4.1 Graphic interpretation of the Mehzirich 'map' 39

Figure 4.2 The fundamental unit of a concept map 40

Figure 4.3 A generalized concept map demonstrating hierarchical arrangement 43

Figure 4.4 A spoke or radial concept map shape 44

Figure 4.5 A chain or linear concept map shape 44

Figure 4.6 A net or web concept map of this chapter 45

Figure 4.7 Lists of linked concepts represented as integers and the associated daisy graph 46

Figure 4.8 An example of a concept circle 47

Figure 4.9 A cluster map of a 6th class student's record of a lesson on 'worms' 48

Figure 5.1 A concept map of Chapter 5 done by CMap Tools™ 59

Figure 5.2 The structure of Kelly's psychological space 68

Figure 5.3 An empty grid 71

Figure 5.4 Plot of the first and second principal axes loadings (components) as a scatter-graph of ACSLG5 111

Figure 5.5 Plot of the first and second principal axes loadings (components) as a scatter-graph of ACSTK5 113

Figure 5.6 Plot of the first and second principal axes loadings (components) as a scatter-graph of ACSAF5 114

Figure 5.7 Plot of the first and second principal axes loadings (components) as a scatter-graph of ACSLS5 114

Figure 5.8 Plot of the first and second principal axes loadings (components) as a scatter-graph of ACSAN5 115

Figure 5.9 Plot of the first and second principal axes loadings

(components) as a scatter-graph of ACSON5 115
Figure 5.10 Bar-chart of three city-block distance comparisons for six students 117
Figure 6.1 A concept map of Chapter 6 done by CMap Tools 125
Figure 6.2 Instructions given to the students and an English translation 131
Figure 6.3 Visual stimuli used in the study on mammals 132
Figure 6.3 Visual stimuli used in the study on mammals 133
Figure 6.4. Unrotated Plot of 1st and 2nd principal components for 13 year olds 155
Figure 6.5. Unrotated Plot of 1st and 2nd principal components for 14 year olds 157
Figure 6.6. Unrotated Plot of 1st and 2nd principal components for 15 year olds 159
Figure 6.7. Unrotated Plot of 1st and 2nd principal components for 14/15 year olds 161
Figure 7.1 A concept map of Chapter 7 as drawn in CMap Tools 170
Figure 7.2 The core graphic from which the stimulus pictures were derived 175
Figure 7.3 The first set of equids 176
Figure 7.4 The second set of equids 176
Figure 7.5 Parameters of DISPLAY 180
Figure 7.6 Output of DISPLAY FOR PK111 181
Figure 7.7 A representative grid from first year 182
Figure 7.8 A representative grid from second year 183
Figure 7.9 A representative grid from third year 184
Figure 7.10 A representative grid from fourth year 184
Figure 7.11 A representative grid from fifth year 185
Figure 7.12 A grid from one expert 185
Figure 7.13 A grid from a second expert 186
Figure 7.14 A representative grid from first year 187
Figure 7.15 A representative grid from second year 188
Figure 7.16 A representative grid from third year 189
Figure 7.17 A representative grid from fourth year 189
Figure 7.18 A representative grid from fifth year 190
Figure 7.19 A grid from one expert 190
Figure 7.20 A grid from another expert 191

Figure 7.21 Parameters of FOCUS 192
Figure 7.22 Part of the output of FOCUS possessing a dendrogram for the elements 198
Figure 7.23 Output of FOCUS for PK111 199
Figure 7.24 Dendrogram for the constructs of AN111 200
Figure 7.25 Dendrogram for the constructs of ABr211 200
Figure 7.26 Dendrogram for the constructs of LL311 201
Figure 7.27 Dendrogram for the constructs of KM411 201
Figure 7.28 Dendrogram for the constructs of JM511 201
Figure 7.29 Dendrogram for the constructs of one expert 202
Figure 7.30 Dendrogram for the constructs of another expert 203
Figure 7.31 Dendrogram for the constructs of JH122 204
Figure 7.32 Dendrogram for the constructs of KN222 204
Figure 7.33 Dendrogram for the constructs of DL321 204
Figure 7.34 Dendrogram for the constructs of CF422 205
Figure 7.35 Dendrogram for the constructs of SH521 205
Figure 7.36 Dendrogram for the constructs of one expert 205
Figure 7.37 Dendrogram for the constructs of another expert 206
Figure 7.38 Plot of first and second principal components for elements marked with an 'x' and constructs (polar vectors) 207
Figure 7.39 Plot of first and second principal components for AN111, the representative first year 208
Figure 7.40 Plot of first and second principal components for ABr211, the representative second year 209
Figure 7.41 Plot of first and second principal components for LL311, the representative third year 210
Figure 7.42 Plot of first and second principal components for KM411, the representative fourth year 211
Figure 7.43 Plot of first and second principal components for JM511, the representative fifth year 211
Figure 7.44 Plot of first and second principal components for one expert 212

Figure 7.45 Plot of first and second principal components for another expert 213
Figure 7.46 Plot of first and second principal components for CF122, the representative first year 214
Figure 7.47 Plot of first and second principal components for AB222, the representative second year 215
Figure 7.48 Plot of first and second principal components for CF321, the representative second year 216
Figure 7.49 Plot of first and second principal components for AT422, the representative forth year 217
Figure 7.50 Plot of first and second principal components for JM521, the representative fifth year 218
Figure 7.51 Plot of first and second principal components for one expert 219
Figure 7.52 Plot of first and second principal components for another expert 220
Figure 7.53 Parameters of SOCIO 224
Figure 7.54 Socionets for the first years: first set 228
Figure 7.55 Socionets produced by the first years: second set 229
Figure 7.56 Socionets produced by the second years: first set 230
Figure 7.57 Socionets produced by the second years: second set 231
Figure 7.58 Socionets produced by the third years: first set 232
Figure 7.59 Socionets produced by the third years: second set 233
Figure 7.60 Socionets produced by the fourth years: first set 234
Figure 7.61 Socionets produced by the fourth years: second set 235
Figure 7.62 Socionets produced by the fifth years: first set 236
Figure 7.63 Socionets produced by the fifth years: second set 237
Figure 8.1 Concept map of the main features of this chapter 242
Figure 8.2 Two disparate plant parts that share a superficial perceptual quality 247
Figure 8.3 *Senecio squalidus*: "Another bloody yellow composite" 247
Figure 8.4 An example of one drawing no. 318 252
Figure 8.5 Combined Diagram, glossary 255
Figure 8.6 Results for AMPRSL6 (N. Ireland) & VASC138 (Valencia) 263
Figure 8.7 Constrained choice student, Northern Ireland 263

Figure 8.8 More open choice student, Northern Ireland 266
Figure 8.9 Constrained choice student, Valencia 267
Figure 8.10 More open choice student, Valencia 268
Figure 8.11 Concept Map of Chemist/Microbiologist 269
Figure 8.12 Concept Map of Expert Botanist 270
Figure 8.13 Sociogrids for the N. Ireland Group 272
Figure 8.14 Sociogrids for the Valencia Group 272
Figure 8.15 A socionet for the Valencia group at 80% over 80.0 273
Figure 8.16 Sociogrid for the Valencia Group (Figure 8.14, LHS, enlarged)
Arrows indicate the biologists and MUSC1315 and VASC136 274
Figure 8.17 Sociogrid of the two experts and three notable students 275
Figure 8.19 Percentage of students who correctly assigned family
names to groups of plant scale drawings 277
Figure 9.1 Induction of rules between concepts 290
Figure 9.2 Simple Bayes net of an array of biological natural kinds concepts 291
Figure 9.3 Output of the INDUCT program 293
Figure 9.4 DISPLAY of seven chemistry concepts 294
Figure 9.5 FOCUS of seven chemistry concepts 295
Figure 9.6 PRINCOM of seven chemistry concepts 295

Tables

Table 1.1 Outline of the chapters in this thesis 8

Table 1.2 Four studies carried out using RGA to elicit mental structures of learner's classifications of BNKCs. 13

Table 2.1 Questions and sub-questions raised by the existence of BNKCs 14

Table 2.2 Aristotle of Stagira's contributions to biology 17

Table 2.3 Nominal, natural and artefact kinds 19

Table 2.4 Evidence in support of psychological essentialism 24

Table 3.1 Differentiation of classification, categorization, and category 29

Table 3.2 Calculation of similarity between zebra and horse, where '+' denotes the presence of the feature, and '-' denotes the absence. 32

Table 5.1 An example of a completed grid 70

Table 5.2 Means of deriving the concepts and features used in a RGA study 77

Table 5.3 Information given to each student on a 'crib' sheet to enter into the Bannister-Fransella program 79

Table 5.4 The grids produced by ACSBF5 80

Table 5.5 Difference matrix for ACSBF5 81

Table 5.6 Sums of the differences 81

Table 5.7 The grids and difference matrix produced by ACSSG5 83

Table 5.8 The grids and difference matrix produced by ACSON5 84

Table 5.9 The grids and difference matrix produced by ACSAS5 85

Table 5.10 The grids and difference matrix produced by ACSFO5 86

Table 5.11 The grids and difference matrix produced by ACSSS5 87

Table 5.12 The grids and difference matrix produced by ACSTK5 88

Table 5.13 The grids and difference matrix produced by ACSAF5 89

Table 5.14 The grids and difference matrix produced by ACSLS5 90

Table 5.15 The grids and difference matrix produced by ACSCL5 91

Table 5.16 The grids and difference matrix produced by ACSLG5 92

Table 5.17 A table of the ρs and ranks for both attempts of the procedure for ACSON5 as produced by Circumgrids III 95

Table 5.18 Intensity and consistency scores for the subjects produced by

Circumgrids III 96
Table 5.19 Microsoft Excel output of paired two-tail Student's t-test 97
Table 5.20 Two grids of the average of the eleven subjects' grids 98
Table 5.21 Two averaged grids rounded to one significant figure 99
Table 5.22 Information given to each student on a 'crib' sheet to enter into the coordinate grid program 101
Table 5.23 An example of a grid produced by ACSLG5 with column sums appended *ad posterior* 102
Table 5.24 Grid of implicit ranks produced by ACSLG5 103
Table 5.25 Logical inconsistencies per rank produced by ACSLG5 103
Table 5.26 Inconsistency sums per row and column 105
Table 5.27 Integrative complexity per ranks 106
Table 5.28 Total integrative complexity per construct 107
Table 5.29 Table summarizing the key features of four multivariate protocols 108
Table 5.30 Correlation matrix 109
Table 5.31 Eigenvalues, percent values of the eigenvalues, and eigenvectors 110
Table 5.32 1st, 2nd and 3rd Principal Axes Loadings 110
Table 5.33 Grid resulting from ranking elements (column headings) against constructs (row headings) 120
Table 5.34 Row Correlations (R) 121
Table 5.35 Eigenvalues, percent value of the eigenvalues and eigenvectors 121
Table 6.1 Examples of Scott Atran's Folkbiological levels (Atran, 1999) 126
Table 6.2 Details of the visual stimuli used in the study on mammals 134
Table 6.3 ANOVA source table for between-grid comparison for 13 year old students: constructs 139
Table 6.4 ANOVA source table for between-grid comparison for 13 year olds: elements 139
Table 6.5 ANOVA source table for between-grid comparison for 14 year olds: constructs 140
Table 6.6 ANOVA source table for between-grid comparison for 14 year olds: elements 140

Table 6.7 ANOVA Source Table for Between-Grid Comparison for 15 year olds: constructs 141
Table 6.8 ANOVA source table for between-grid comparison for 15 year olds: elements 141
Table 6.9 Correlations between grid angles 142
Table 6.10 Averaged grid for 13 year old students 144
Table 6.11 Averaged grid for 14 year old students 145
Table 6.12 Averaged grid for 15 year old students 146
Table 6.13 General degree of correlation between average grid and each 13 year old student 149
Table 6.14 General degree of correlation between average grid and each 14 year old student 149
Table 6.15 General degree of correlation between average grid and each 15 year old student 149
Table 6.17 The correlation matrix for 13 year old students 150
Table 6.18 The correlation matrix for 13 year old students continued 150
Table 6.19 The correlation matrix for 14 year old students 151
Table 6.20 The correlation matrix for 14 year old students continued 151
Table 6.21 The correlation matrix for 15 year old students 151
Table 6.22 The correlation matrix for 15 year olds continued 152
Table 6.23 The eigenvalues for unrotated components for the 13 year old students 153
Table 6.24 The eigenvalues for unrotated components for the 14 year old students 153
Table 6.25 The eigenvalues for unrotated components for the 15 year old students 153
Table 6.26 The eigenvalues for unrotated components for the 14 and 15 year old students 153
Table 6.26 The eigenvalues for unrotated components for the Biologist 153
Table 6.29 Difference Grid (Average Grid for 13 year olds - Biologist) 166

Table 6.30 Details of the information gained from RGA on the visual stimuli used in the study on mammals 168
Table 7.1 Descriptions of the images in the equid study 173
Table 7.2 The items given to all the students 174
Table 7.3 List of features for the students to choose from 177
Table 7.4 A matrix of element matching scores for PK111 197
Table 7.5 Socio Element Analysis of 2 grids in the first year cohort: element correspondence 225
Table 7.6 Table comparing the number of links of the experts with other Individuals 238
Table 7.7 Details of the information gained from RGA on the visual stimuli used on the study on equids 241
Table 8.1 Some adaptive questions concerning plants 235
Table 8.2 The five families and the Latin binomial for the five specimens used in each family 251
Table 8.3 An extract from the worksheet 253
Table 8.4 The Glossary given to the students in Northern Ireland 254
Table 8.5 The family descriptions given to the subjects, English version 256
Table 8.6 The family descriptions given to the subjects, Spanish version 257
Table 8.7 Example of output of the FOCUS calculation 262
Table 8.8 Example of output of the PRINCOM calculation 264

Abstract

Concepts give structure and order to the world around us. However, many learners are impeded by the perceived difficulty of concepts presented to them, and as a result of the mode of presentation. Students' conceptual structures have been studied at length in science education in the hope of remediating impediments to learning. Despite much research in conceptual development, and prior conceptions in particular, relatively little has focused on the structures of biological concepts and less again on biological concepts that are natural kinds. This work describes four empirical studies concerning biological natural kind concepts that involve using repertory grid analysis (RGA) as a tool for investigating the structures of representations of these concepts and how students classify them. RGA possesses a powerful set of tools, which a researcher may utilise in order to examine the structures of conceptual frameworks, as concept mapping also claims to do. Modern RGA is computer-based tool and models of conceptual structures can be represented in graphical form. Protocols were used to compare the conceptual frameworks of a group of individuals, and conceptual change can be monitored in a rigorous way that is not possible with customary concept mapping techniques. Convenience samples of senior primary and post-primary students were used in the Republic of Ireland, Northern Ireland and Valencia; two qualified biologists were retained to provide a base-line comparison. The studies consisted of tasks whereby students were presented with sets of stimuli (the first study which used words, and the others used graphics): (i) one set of five equids and the concept 'goat'; (ii) two sets of six equids (consisting of examples drawn from the following three categories: extant, extinct and imaginary); (iii) a large set of mammals; and (iv) five sets of dicotyledonous plant families. Grids of rankings were elicited from the students' interaction with the stimuli and these were subjected to mathematical procedures such as principal components analysis and cluster analysis. In the first introductory study it was found that RGA could be used to represent the conceptual structures of science learners. Perceptually similar concepts were clustered together and outlying concepts formed separate groups. In-between concepts such as hybrids were dealt with in an idiosyncratic way, *i.e.,* the students constructed their own understanding of how these 'fitted-in' and where to make the appropriate 'cuts' in the array of living things before them. The elicited grids in the case of the mammals were be 'averaged' and compared (either between individuals or between groups which could include the qualified biologists or not); whereas in the studies on equids and dicotyledons visual networks were produced, called 'socionets'. Those produced for the students in the equid and dicotyledonous family studies demonstrated a commonality in the way these concepts were represented at a given limit but differences were noted over the time frame investigated (five year groups in the case of equids) and differences between the N. Ireland and Valencia groups were noted in the case of the dicotyledons study. Some students could be denoted as 'consensual' *i.e.,* they had the greatest number of links whereas others shared very little with their peers or the experts in terms of their ability to represent the concepts provided, *i.e.,* they were 'isolated' in their conceptual structures. Those socionets produced for in the mammals study displayed cultural or folkbiological understanding of the mammals rather than using their formal biological understanding. These findings point to the rich reality of the students' understanding of the living world and therefore how practitioners can investigate such understanding using RGA.

Contents

Main Title i

Frontispiece iii

Authorship/supervision v

Declaration vi

Permission to copy/borrow vi

Dedication vii

Acknowledgements viii

Figures and Tables ix

Figures ix

Tables xiv

Abstract xviii

Contents xix

Chapter 1. Background, aims and objectives 1

1.1 Biographical origins of this thesis 1

1.2 Aims of the research presented in this thesis 5

1.3 Method and technique 9

1.3.1 Investigating the nature of biological natural kinds concepts 9

1.3.2 Investigating learners' classifications 10

1.4 Further dividends of the study 11

1.4.1 Folkbiology 11

1.5 Summary 12

Chapter 2. Concepts 14

2.1 Introduction to concepts 14

2.2 The role of concepts in mental life 14

2.3 Types of concepts 18

2.4 Natural kinds 19

2.4.1 The distinctiveness of biological kinds 21

2.5 Intuition and essence 22

2.6 Conclusion 26

Chapter 3. Classification and Categorization 27

3.1 Introduction to classification 27

3.2 Computational models of similarity 29

3.3 Prototypes 33

3.4 The exemplar approach 34

3.5 Revisiting the classical view of concepts 34

3.6 Fuzzy set theory 35

3.7 Conclusion 37

Chapter 4. Conceptual frameworks in science 38

4.1 Introduction to conceptual frameworks 38

4.2 An analysis of Novakian concept mapping 39

4.3 Classifying concept maps 42

4.4 Types of concept mapping representations 45

4.4.1 Daisy diagrams 45

4.4.2 Concept circle diagrams 46

4.4.3 Cluster maps or webs 47

4.4.4 Fill-in-the-map or 'skeleton' maps 48

4.4.5 Construct-a-map 49

4.5 Scoring concept maps and concerns regarding validity 49

4.6 Uses and usefulness of concept mapping 54

4.7 Conclusion 56

Chapter 5. Repertory grid analysis: principles, methods and applications to biological natural kinds concepts 58

5.1 The work of George Alexander Kelly 60

5.1.1 Biography 60

5.1.2 The origins of Kelly's theory 61

5.1.3 Man as scientist 61

5.1.4 The importance of prior knowledge 63

5.1.5 The role of sensing and responding 64

5.1.6 Constructs and elements 65

5.1.7 The geometry of psychological space 66

5.1.8 Grids 69

5.1.9 Kelly's repertory grid method 71

5.2 Slater's repertory grid method 73

5.3 Distinguishing non-equids from equids 74

5.3.1 Elicitation of constructs 74

5.3.2 Bannister-Fransella analysis 77

5.3.3 Discussion of the grids 93

5.4 Comparing grids 93

5.4.1 Intensity and consistency 94

5.4.2 Averaging grids 97

5.4.3 Conclusion to Bannister-Fransella analysis 100

5.5 Coordinate grid analysis (CGA) 101

5.5.1 Calculation of logical consistencies 102

5.5.2 Principal components analysis (PCA) 107

5.5.3 Comparing in CGA 115

5.6 Bieri analysis 118

5.6.1 Methodology 118

5.6.2 Principal components analysis (PCA) 120

5.6.3 The relationship between the Bieri and Bannister-Fransella analyses 122

Chapter 6. Explorations with natural kinds and repertory grids: *mammalia* 123

6.1 The study of mammals 123

6.2 The purpose of studying perceptions of mammals 125

6.3 Methodology 130

6.3.1 Production of visual stimuli 130

6.3.2 Elicitation of the grids 131

6.3.3 The role of language 135

6.4 The Slater analysis of multiple grids 135

6.4.1 Analysis of variance 136

6.4.2 Correlation between grid angles 141

6.4.3 Final note on ANOVA 142

6.4.4 Averaging grids 143

6.4.5 The general degree of correlation 147

6.4.6 Principal components analysis of the average grids derived through Slater analysis 149

6.4.7 Interpreting the Cartesian plots of the loadings 153

6.4.8 Comparison of two grids: the students versus the experts 164

6.4.9 Distillation of the results 167

6.4.10 Conclusion 167

Chapter 7. Explorations with natural kinds and repertory grids: *Equidae* 169

7.1 Distinguishing equids 172

7.1.1 Computer elicitation 178

7.1.2 Data entry – elements 178

7.1.3 Data entry – constructs 179

7.1.4 Rating / tanking the elements to the constructs 179

7.2 Results from the studies on equids 179

7.2.1 Displaying a grid 180

7.2.2 Grids of the first set of equid images 182

7.2.3 Grids of the second set of equid images 187

7.2.4 FOCUS and cluster analysis 191

7.2.5 Calculating distance 193

7.2.6 Calculating clusters 195

7.2.7 Dendrograms for the second set of equids 203

7.2.8 Principal Components Analysis (PrinCom) 206

7.2.9 Principal components plots of the second set of equids 214

7.3 SOCIO 222

7.3.1 Socionets 226

7.3.2 First years 226

7.3.3 Second years 230

7.3.4 Third years 232

7.3.5 Fourth years 234

7.3.6 Fifth years 236

7.3.7 Distillation of the results 238

Chapter 8. Explorations with natural kinds and repertory grids: *Dicotyledonidae* 242

8.1 Introduction to chapter 8 242

8.2 Introduction to the study of plants from a cognitive perspective 244

8.2.1 Educational implications of studying plants 245

8.3 The elicitation of repertory grids of student's conceptions of plants 250

8.4 The analyses of the repertory grids: DISPLAY, FOCUS,

PRINCOM, and SOCIO 259

8.4.1 The results of FOCUS 260

8.4.2 The results of PRINCOM 267

8.4.3 The results of SOCIO 270

8.4.4 Which families were easier for the students to work with? 275

8.4.5 Distillation of the results 278

Chapter 9. Final discussion and conclusion 279

9.1Recapitulation of the preceding chapters 279

9.1.1 Recap of chapter 1 280

9.1.2 Recap of chapter 2 280

9.1.3 Recap of chapter 3 281

9.1.4 Recap of chapter 4 282

9.1.5 Recap of chapter 5 282

9.1.6 Recap of chapter 6 284

9.1.7 Recap of chapter 7 285

9.1.8 Recap of chapter 8 286

9.2 How well were the aims of the thesis addressed 287

9.3 Other directions 288

9.5 Other domains 293

9.6 Ending biographical note 296

Bibliography 297

Appendices (on CD)

There is no appendix for Chapters 1 to 4 and 9

Appendix 5.1 Kelly's manual elicitation of a grid

5.1.1 Methodology

5.1.2 Calculation of 'factors'

5.1.3 Reflection

5.1.4 Further factors and factor rotation

Appendix 5.2 Manual calculation of trial vectors

Appendix 6.1 Further notes on using Idiogrid

Appendix 6.2 Structure coefficients & component score coefficients (unrotated & varimax)

Appendix 6.3 Plots of rotated principal components

Appendix 7.1 Information given to students during the questionnaire administration and examples of one student's responses

Appendix 7.2 (Folder) The stimuli for the *Equidae* study

Appendix 7.3 (Folder) The grids of the *Equidae* study

Appendix 8.1 (Folder) The stimuli for the *Dicotyledonidae* study

Appendix 8.2 (Folder) The grids of the *Dicotyledonidae* study

8.2.1 Grids

8.2.2 Focus

8.2.3 PrinCom

8.2.4 Socio

Chapter 1 Background, aims and objectives.

> *"Ask the gardener, why he thinks yonder cherry-tree exists in the garden, and he shall tell you, because he sees and feels it; in a word, because he perceives it by his senses."*
>
> George Berkeley (1713)

This thesis is concerned with investigating the nature of post-primary students' concepts of living things, in particular how post-primary learners internalise visual representations of living things such as mammals and flowering plants. This first chapter (Figure 1.1) will outline the structure, main themes and the aims and objectives of the thesis; the main detail will be provided in separate chapters.

1.1 Biographical origins of this thesis

Human intellectual activity has attended to the diversity and forms of living things at least since humanity began to make more than temporary records of their thoughts; further, the ancient authorities, *e.g.*, Aristotle, Theophrastus and Pliny devote a great deal of their time and energy to writing about living things (French, 1994)[1]. The author, as a seven-year old boy, began to become interested in the diversity of living things through informal education firstly by his mother who taught him how to press and preserve leaves in a scrapbook of the trees in the immediate area.

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[1]Aristotle wrote a large opus entitled *History of Animals*; the smaller accompanying work *Parts of Animals*; *On Plants*; plus other single volumes: *Movement of Animals*; *Progression of Animals*; *Generation of Animals*; the *Dissections* are lost. Theophrastus, Aristotle's successor at the Lyceum, wrote *History of Plants* and *Causes of Plants*; Pliny, rewriting much earlier *historiae* from Greek and other traditions, produced the *Natural History*.

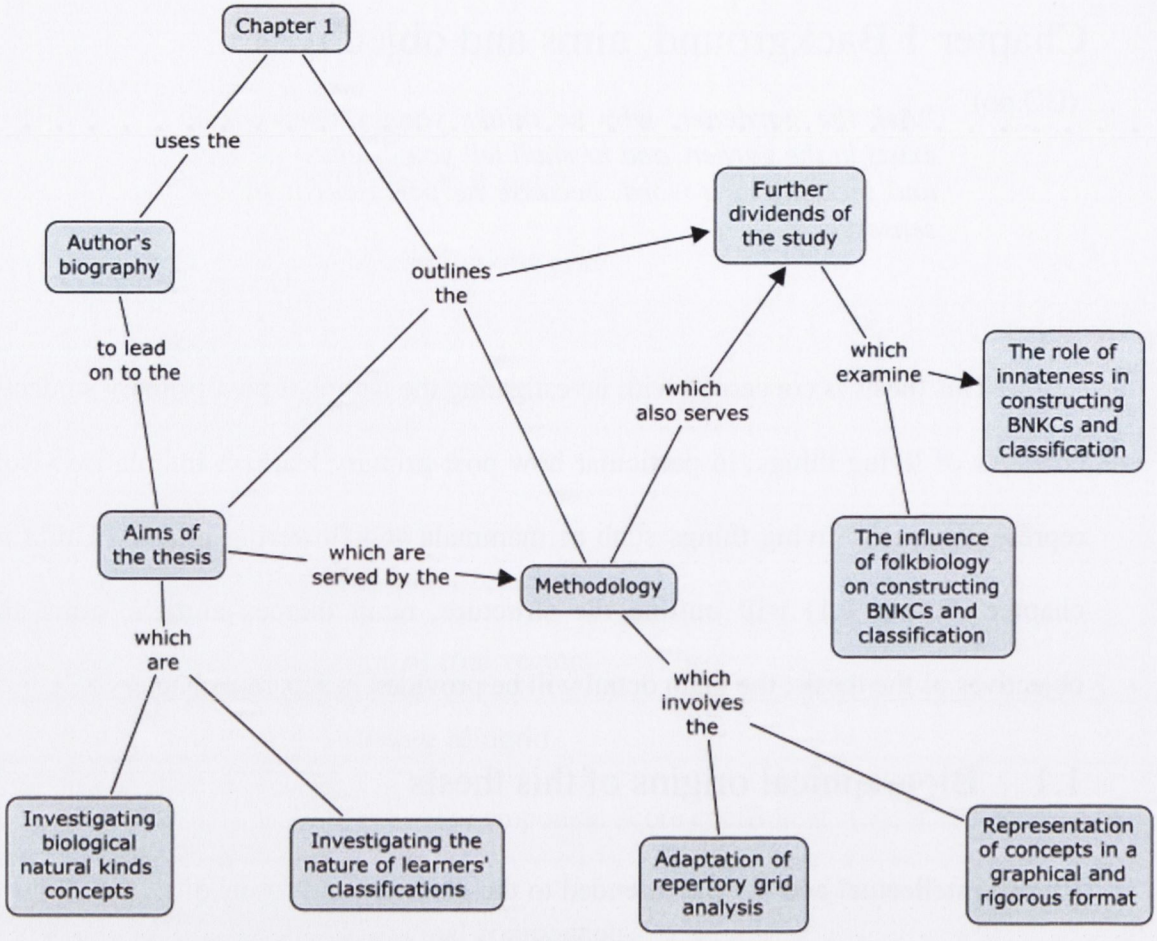

Figure 1.1 Concept map of Chapter 1

This informal education was expanded by his grandfather who taught him how to interact with cattle and other animals, gather wild honey, source wild fruit and herbs, prepare fare from game; by which time having continued to collect, press and preserve wild flowers, a herbarium was forming (Figure 1.2). This forced the author to think about the order of living things. Simple theories were developed as problems were encountered in the identification of difficult species. In Figure 1.2, there are three voucher specimens of a crucifer, bluebell and ribwort plantain. The crucifers were difficult to identify, particularly as both wild and cultivated forms are found in nature and that there is great variation depending on the time of year. At this point, the author attempted to remember each flower encountered as is, but because of this

variation a theory is necessary. It is the case that the origin of the word 'crucifer' is 'cross-forming', *i.e.*, describing the arrangement of the four petals, therefore a generalization was made that flowers with this four-petal cross-like arrangement would be a crucifer too. Thus a simple theory was used to help identification, a theory which, as it happened is how botanists identify members of family *Cruciferae*, now called *Brassicaceae*, though unbeknown to the author at the time. Formal education in grammar school brought about an intellectual development through biology but also through art. However biology being the main academic preference became the focus in undergraduate courses where formal and extensive training in classification took place.

Privately, the herbarium developed further with advice from staff at the Ulster Museum in Belfast, and interest in the history of biology coupled with attempts to systematize the herbarium required the study of systematics.

Published research in biology (Irwin *et al.*, 1991; McCloughlin & Irwin, 1991) was focussed on anatomical and epidemiological studies of parasites; and study for a higher diploma in education at Trinity College introduced the author to educational and cognitive psychology, a masters degree in education developed this further. Study in theology, also at Trinity College, introduced the author to the language and philosophy of the ancient authorities such as Aristotle and Plato, which complemented the first studies in the philosophy and history of education. This thesis is the next step in the author's development and draws on all these facets, which may at first seem disparate; thus there is a need to begin with a clear aim for the enterprise, now following.

Figure 1.2 A scanned image of page 14 from the early herbarium of voucher specimens. I a species of crucifer; II bluebell; III ribwort plantain

1.2 Aims of the research presented in this thesis

This work aims to present:

(a) a novel adaptation of a Repertory Grid Analysis used for eliciting role constructs in clinical psychology, to that part of science education that deals with the ways that learners structure certain concepts and

(b) how these concepts and structures can be described in a rigorous and graphical form. Thus, the outcome of this thesis will be a new methodology for researching science concepts that can be used to enhance the quality of teaching and learning.

The methodology employed throughout this work uses George Kelly's repertory grid technique or analysis (RGA) in different forms (see Figure 1.3). RGA can be categorized as a technique to determine the structure of representations of concepts. Chapter 3 will examine a range of techniques providing a background for RGA.

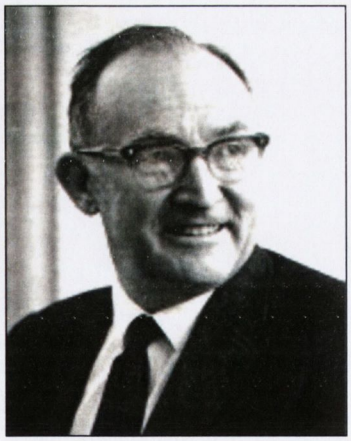

Figure 1.3 George Kelly, 1905 – 1967[2]

[2]Image taken from http://www.ship.edu/~cgboree/kelly.html last accessed 22nd January 2006.

RGA can be used to determine the structure of learners' scientific concepts in a quantitative manner so that changes in the structure of those concepts can be objectively detected. More rigorous comparisons can be made between class sets of structural representations, or frameworks, of biological concepts possessed by students. These frameworks can be compared on an individual basis, compared to identify changes at several time points, or grouped to give an overview of an entire class group. They may also be used to compare an educators framework with those of her/his students. When the word framework is used it denotes a generic term that includes many common methods of elucidating a learner's conception of an entity, prior or otherwise and representing this conception in a graphical, *i.e.*, diagrammatic, format. Typically, these frameworks are called 'concept maps' or 'mind maps'; these are reviewed in Chapter 2.

Biological concepts can be ordered in a systematic hierarchy of:

- atoms and molecules
- cells,
- tissues,
- organs,
- systems,
- organisms,
- populations,
- habitats, and
- biospheres.

Some or all of these can be represented in charts, diagrammatic representations, photographs, electronmicrographs, computer graphics, models

whether they are scaled, iconic or symbolic and constructed in plastic, wood, metal, clay or some other material. It is an ongoing theme in biological education research that researchers have been engaged in testing the efficacy of all these representations as teaching aids, learning devices, in effect, a directed play entity or 'toy', and as evidence of learning *i.e.*, conceptual formation or change. Diagrams, typically line diagrams rather than 'sketches', continue to be employed in teaching, learning and assessing (TLA) biology serving as a pictorial short-hand of biological concepts. In recent years the pioneering work of Joseph Novak (Novak, 1990; Novak & Gowin, 1984; Novak *et al.*, 1983) in concept mapping has promised a new methodology in TLA biology that would be transformative, but this has not been taken up on a large scale. Novak's work and that of his co-workers and colleagues will be reviewed critically in Chapter 3. A major outcome of this thesis is the claim that RGA provides a rigorous conceptual representational method that lacks many of the shortcomings of Novakian concept mapping and other related types of knowledge representation.

Chapter 4 examines in detail the ways that scientists approach classification. Two such ways are focussed on the methods that formal biologists use to show phylogenetic[3] relationships which are grounded in theories of evolution and how cognitive scientists apply mathematical models to classification and categorization. In the course of the thesis the way RGA fits into either approach will be illustrated. It

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[3]Phylogenetics, also known as phylogenetic systematics, is the study of evolutionary relatedness among various groups of organisms, *e.g.*, species, populations, and it treats a species as a group of lineage-connected individuals over time, it derives from the *phylon* = tribe, race and *genetikos* = relative to birth. Phylogenetic taxonomy (Traverse, 1996) which is an offshoot of phylogenetic systematics, is a means of classifying groups of organisms according to degree of evolutionary relatedness.

will be later claimed that RGA provides an approach that relates both to the methods used by formal biologists and cognitive scientists.

The second half of this thesis describes the methodology and empirical results in detail beginning in Chapter 5 with the background to RGA, its principles, methods and applications. The succeeding four chapters then present the method and results for four separate studies in which students' conceptual frameworks are investigated. They are studies of natural kinds using repertory grids:

(i) Five equids and *goat*, Chapter 5;
(ii) *Mammalia*, Chapter 6;
(iii) *Equidae*, Chapter 7;
(iv) *Dicotyledonidae*, Chapter 8.

The chapter outlines are summarized below in Table 1.1 . Finally, Chapter 9 concludes the thesis with evaluations of the studies in the light of the original aims.

Table 1.1 *Outline of the chapters in this thesis*

Chapter number	Chapter outline
1	Aims, objectives and background
2	Concepts: natural and nominal kinds
3	Classification, categorization, phylogeny, cladistics
4	Examining structures, conceptual frameworks or maps
5	Repertory grid analysis: principles, methods and applications to biological natural kinds concepts. Early studies in RGA relating to biological natural kind concepts
6	Studies of natural kinds using repertory grids: *Mammalia*
7	Studies of natural kinds using repertory grids: *Equidae*
8	Studies of natural kinds using repertory grids: *Dicotyledonidae*
9	Conclusion: evaluation of the studies in the light of the original aims

1.3 Method and technique

1.3.1 Investigating the nature of biological natural kinds concepts

The set of concepts that have been singled out for special investigation are biological natural kinds concepts, henceforth denoted as 'BNKCs'. BNKCs is a term that will require clarification, which is provided in some detail, in Chapter 2. "Natural kind" is a technical philosophical term covering things that do not show *necessary* and jointly *sufficient* features (Schwartz, 1977) and BNKCs are typically contrasted against artefacts (Keil, 1996). Each level of biological organization is itself a concept, and within each are several levels of concepts. Keil (1996) suggests that there is a broad developmental pattern in which emerging concepts are nested; Keil's (1996) view contrasts with the formal biological view that living kinds can be organized in a hierarchy and that this reflects a 'natural' order and produces a natural classification, *i.e.*, living kinds are classified in a way that reflects reality. Many, if not all, biological concepts are natural kinds. Natural kinds concepts are a special class of concepts, which are themselves difficult to define.

This study is also an attempt to contribute to the improvement of the quality of teaching and learning in biology education within the scope of science education research. Thus we are concerned with specifically biological natural kinds such as animals, the Class *Mammalia*, and plants, flowering, *i.e.*, the Class *Dicotyledonidae*. The focus on biological concepts is consistent with the biographical note above. Other BNKCs such as the bacteria, fungi, and viruses are not considered at all within this study, nor are humans discussed specifically.

1.3.2 Investigating learners' classifications

During the course of the thesis, the structure of students' classifications will be investigated. It is hypothesized that students in post-primary school often fail to overcome any preexisting schemata of classification, formed in early childhood, called naïve classifications or folk-taxonomies. Such an alleged deficit in performance indicates two possible sources of the problem:

(1) that the instruction in biology they receive is ineffective, and/or that

(2) something is preventing the change in thinking taking place, i.e., there are resilient structures in place in the mind to begin with.

In fact these two things are linked — the instruction could be unreliable because it is trying to overcome a resilient structure that has not been accounted for. It is more likely however that current instruction methodologies and students' learning stages exclude novel ideas or methods which do not take into account the existence of mental structures resilient to change. Children possess innate qualities, such as constraints to learning localized in specific domains, that they bring to the classroom or laboratory, and these are often in conflict with the content of the syllabus. The result of this conflict may be reduced attainment. The neuronal structure of the human brain may be so constructed that it recognizes, or imposes, order on sensory stimuli. So, for example the ability to classify may be considered innate. This ability appears to be ubiquitous and an important part of human cognition. Indeed, Jean Piaget proposed that one of his schemata of thinking would be 'classification'. However, the idea that humans classify is sometimes taken to be a 'just so' and something only to be considered briefly with young children and then ignored in relation to learning. As we shall see, classification is in fact, the crux of human cognition.

A secondary aim of this study is to add to the knowledge of innate abilities in regard to biological natural kind concepts. As shall be seen in Chapter 2, little work on investigating BNKCs has been done in education. Students can organize inferences using a taxonomy that resembles scientific classification. In one of the studies following, a comparison of learners' classifications is compared with that of two professional scientists. Classification of natural kinds is a special kind of object recognition. Furthermore, classification is a higher order thinking skill or schema. These and other sorts of inferences *e.g.*, causality, are solutions to adaptive problems. It is believed that current instructional methods are inadequate either to utilise this faculty or overcome its preformed structures. This study uses repertory grid technique to establish the structure of representations of BNKCs in an effort to determine the constraints in students' conceptual structures and it suggests ways of adapting this technique to other areas of science education.

1.4 Further aspects of the study

1.4.1 Folkbiology

In the last twenty years, the idea that biological cognition is an innate process has grown in importance. The essence of this idea is that there exists a domain in the mind that deals with biological kinds, and as such has profound implications for the teaching and learning of biology. Works in folkbiology (*e.g.*, Medin & Atran, 1999) contribute to the innate thesis by pointing out the universality of taxonomies, in which people construct folk classifications across cultures, and noticing that such classifications often serve to 'carve up nature': to impose an order on it that reflects how nature is perceived to be structured.

1.5 Summary

The main aims of this research are about adapting Repertory Grid Analysis from the clinical context to studying biological natural kinds concepts in order to form graphical representations of learners' "semantic space". The secondary aims concern gaining further insights into the ways students conceptualise animals and plants, the traditional central concepts in biology, and how they order them systematically, *i.e.*, their classifications. The four studies undertaken to realize these aims are summarized herewith with more precise objectives (Table 1.2).

Table 1.2 *Four studies carried out using RGA to elicit mental structures of learner's classifications of BNKCs.*

Chapter number	Concepts employed and the form of stimuli used.	Objectives
5	Pony, horse, zebra, mule, donkey, goat This study used words	To determine whether RGA can be used to represent BNKCs To investigate possible uses of RGA as a means of representing classifications of BNKCs To determine the protocol for comparing conceptual structures of a small number of individuals using Spearman's ρ
6	Zebra, variants of zebra: existing, extinct, imaginery, fossil forms of equids, breeds of horses, various equids with partial stripes This study used grayscale graphics.	To determine the efficacy of a larger scale study using RGA To examine the possibility of a pre/post-test methodology within a RGA study To examine the attention given to images of fossil, ecologically rare, and imaginary variants of equids To compare the conceptual structures of biological experts with those of novices To determine the protocol for comparing conceptual structures of large class groups of individuals using conceptual networks
7	A set of 30 line drawings of flowering plants found in nature in the British Isles.	To perform a complex sorting task placing members of families in groups, using a short descriptive key to name the family coupled with RGA To determine how learners approach and internalize BNKCs associated with plants
8	A set of 21 laminated cards of mammals in full colour with a graphic of a child walking to provide an idea of scale. This study used colour graphics.	To examine cultural or prior knowledge-based constraints on BNKCs associated with mammals To examine the possibility of using large grids To determine the protocol for comparing conceptual structures of large class groups of individuals using averaging

Chapter 2 Concepts

> *"If we lived on a planet where nothing ever changed, there would be little to do. There would be nothing to figure out.* [...] *And if we lived in an unpredictable world, where things changed in random or very complex ways, we would not be able to figure things out.* [...] *But we live in an in-between universe, where things change, but according to patterns.* [...] *We were able to hunt game or build fires only because we had figured something out."*
>
> Sagan (1991, p. 59)

2.1 Introduction to concepts

In Chapter 1, it was stated that the foci of this study were:

(i) biological natural kinds concepts (BNKCs) and

(ii) classifications constructed with such concepts.

In this chapter, the nature of BNKCs are discussed. Some key aspects are indicated in Table 2.1 and are addressed in the following chapters and sections.

Table 2.1 *Questions and sub-questions raised by the existence of BNKCs*

Features of BNKCs	Main issues raised	Related issues
Concepts	The nature of concepts (p18ff)	How concepts are perceived / processed in the human mind (Chapter 3)
Natural kinds	The nature of natural kinds (p19ff)	Are natural kinds essentialistic (p22ff)?
Biological	The sort of biological concepts this thesis is concerned with (Chapters 5 – 8)	The 'special-ness' of biological concepts (p21).

2.2 The role of concepts in mental life

Smith & Medin (1981, p. 1) famously stated that "*without concepts, mental life would be chaotic*"; and Murphy (2002, p. 1) asserts that "*concepts are the glue that hold our*

mental world together". If we did not 'represent' perceptions of real things then each time we encountered an object we would have to perceive it anew as if we had never come across it before. Humans would have no referring ability, nor the ability to identify anything. There would be no basis for making simple predictions (simple or complex) nor providing explanations for observations (Smith and Medin, 1981; Murphy 2002). However, Murphy (2002, p. 3) believes that communication between humans in everyday life would be seriously impaired; yet at the same time, we are warned not to '*get carried away on the "everything is concepts" bandwagon*'. It is an easy temptation to fall into though.

Concepts are thought to be building blocks in terms of which knowledge is represented. Peacocke (1999) provides a broad overview of concepts from a philosophical, *i.e.*, logico-analytical, perspective and describes the concepts with which this thesis is concerned as perceptual concepts. Other philosophers might denote these concepts as 'percepts'. Use of the terms 'perceptual concepts' or 'percepts' underscores the idea that BNKCs are anchored in the processes associated with perception. This raises an important question: what is perception? Perception is an English word that in the vernacular context the user can appeal to a common knowledge as to its meaning, but beyond that, an actual definition may not be forthcoming. There is a sense of receiving something, and a sense of knowing, whether cognition or recognition. Questions arise as to what is actually represented in our mental life, be it the entities themselves or merely our perceptions of them, and what 'represents' mean. And then there is the question of what is actually happening in our mental life, in other words, what we are doing with these concepts. Such questions are addressed by Peacocke (1999, p. 61). Keil (1996) adopts a view of

concepts similar to Neisser (1987) that concepts are relational entities and hence they can be categorized, classified and arranged in taxonomies and given nomenclatures.

Furthermore, Keil (1996) believes that the ways concepts relate to each other and the world are non-arbitrary, and hence concepts have an explanatory role. In short, concepts help humans understand how the world works. However, in order to do this, concepts must embody some sort of theory, whether 'naïve', 'folk', or 'formal', of the 'folk' that perceive them. Keil (1996) suggests that such beliefs 'may be largely causal in nature' and that they are embedded in intuitive theories. Carey (1985), Murphy and Medin (1985), Johnson-Laird (1983), Medin and Wattenmaker (1987), Gentner (1983) have also examined how concepts may be embedded in theories or mental models.

In this project concerning the use of repertory grids analysis, concepts are *not* taken to be how the so-called 'classical view' describes concepts: *i.e.*, by definitions. The general rejection of the 'classical view' of concepts is described in Murphy (2002, pp. 12-40) and Keil (1996, p. 267). Keil (1996, p. 267) and Murphy (2002, p. 13) state that the terms: *necessary* and *sufficient* are sticking points in whether a 'classical' or 'non-classical' view of concepts holds true. *Necessity* in respect of definitions is whether an entity has the parts of a definition to be considered a member of a category. *Sufficiency* in respect of definitions is whether an entity has *all* the parts of a definition. Children may adopt a semi-classical stand-point as an *ad interim* theory in learning about living kinds. Thus some children in their developmental journey, may appear to act in an Aristotelian manner. However, Atran (1999, pp. 83-87) believes the criticisms by Mann (1940), Russell (1945), and particularly Popper (1950) of the 'classical view' to be the result of misunderstanding the nature of

Aristotle's philosophical project: "*they did not understand the logic of Aristotelian definition very clearly*", (Hull, 1965). Moreover, Atran (1990, p. 86) states that Aristotle's contribution to biology is more than serving as a benign precursor, but rather, Aristotle's work is a "*monumental movement in human thought*" (see Table 2.2). The divisions of the Aristotelian living world are made in roughly the same places that younger children place them: *e.g.*, humans are in a category of their own. Further work is needed to determine to what extent and when, children become Aristotelian and how this naïve theory serves as an intermediary in the development of biological thought. Children wish to make sense of the world, and such a sense needs to be commonsense. Aristotelian science was an attempt to determine the essential nature of commonsense ontology (Atran, 1999, p. 85), thus it is not surprising that children might at least appear to be Aristotelian in their scientific learning.

Table 2.2 Aristotle of Stagira's contributions to biology (after Atran, 1990)

Features
The elaboration of the distinction between the biological species and genus
The advent of the family concept
The ascendancy of the notion of the phylum
The shift from common-sense understanding of local everyday experience, to ever more reflective attempts to cope with novelty
The whole of the living world, including humanity, as an object of study and insight

2.3 Types of Concepts

Locke (1690/1964); Quine (1960, 1977); Putnam (1975); Schwartz (1980) and Keil (1996, p. 25ff) *inter alia* have given much attention to the three main types of concepts; namely:

(i) natural kinds,

(ii) nominal kinds and

(iii) artefacts or artificial kinds.

This three-fold division of concepts is outlined in Table 2.3. There is an important distinction between the words used to denote concepts and the concepts themselves and yet both entities are represented differently. That they are represented differently is evidenced by children who have not acquired the words of the things they are attending to, such is a parent's plight to understand their child's indication when she or he does not yet possess the word. Furthermore, adults may have temporary loss of memory of words or terms but not of the entity itself except in cases of brain impairment. Semantic brain impairment may induce permanent loss of terms for specific categories.

Table 2.3 *Nominal, natural and artefact kinds*

Author	Nominal Kinds	Natural Kinds	Artefacts
Locke (1690/1964)	We have access to nominal essences They have defining features		
Putnam (1975)	"one-criterion" concepts Nominal kinds have essences	The referents of natural kind terms possess underlying real essences	Artefacts have essences
Quine (1960, 1977)		Similarity is the key to understanding what natural kinds are and how we come to know them	
Schwartz (1980)	Nominal kinds have no real essence Only a nominal essence only the product of human convention	Only terms of natural kinds can be "indexical"	Terms of artefacts are a type of nominal kind

2.4 Natural kinds

The term "natural kind" has its origin in philosophy where it is a technical term developed by philosophers to answer certain questions about projectability of predicates and the nature of scientific investigation (Keil, 1996). One such philosopher was John Locke (Locke, 1690/1964) who held, in effect, that a natural kind classification results from the desire *"to copy things as they really do exist, and to represent to ourselves that constitution on which all their properties depend"*.

Cosmides & Tooby (1994, p. 100) describe natural kinds as having invisible, defining "essences" that cause their perceptual attributes. Gelman & Markman (1986, 1987), and Markman (1989) found that natural kind membership is a powerful organizer of inferences in young children. In general, being a member of a natural kind carries more inferential weight than being perceptually similar. In addition, children give more weight to natural-kind membership when reasoning about traits that actually are more likely to vary as a function of membership in a natural kind, such as breathing, than when reasoning about traits that are more likely to vary as a function of perceptual similarity, such as weight or visibility at night.

Schwartz (1978, p. 311) calls any term, *i.e.*, noun, that functions by means of an underlying trait only, a "strict natural kind term". Any term that gathers its extension not by an underlying trait but by a list of semantically associated descriptive properties a "nominal kind term". Schwartz posits himself as a *via media* between adherents of the intension / extension theory[4] in which all general nouns are nominal kind terms and the polar hypothesis where virtually all general nouns are strict natural kind terms. Schwartz finds both of these positions implausible as there are many nominal kind terms such as terms for artefacts, distinctions of rank, relations, legal terms, ceremonial terms and much more. Schwartz points out that many singular terms do not fit the intension / extension view and importantly those intensions of biological kinds are not semantically associated with the terms. Therefore Schwartz believes the most plausible hypothesis is that there are both strict natural kind terms

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[4]The 'intension/extension theory' is the theory that concepts must satisfy the requirements of having both an intension and an extension. The intension of a concept consists of its properties or propositions or definitions whereas the extension of a concept consists of individuals that are consistent with the properties *etc.*

and nominal kind terms, that both kinds of terms are plentiful in "natural" language, and that many, but not all, natural kind terms lack a meaning dimension. This raises the question of why they exist, or how can they exist? The absence of a meaning dimension for a kind suggests an objective existence removed from human experience and as such a problem for radical constructivism. Furthermore, there may be a utilitarian reason. Schwartz suggests that natural kind terms occur where the same "stuff or thing" takes many different forms. This would certainly apply to biological kinds on a number of levels.

2.4.1 The distinctiveness of biological kinds

Biological kinds are distinctive because they are almost all natural kinds. Plants are often named for reasons of utility, *i.e.*, what they can be used for in terms of manufacture, medicine or mythology, *e.g.*, soapwort[5], woundwort, nipplewort, masterwort, wolfsbane; but also as pure descriptives, *e.g.*, rose-bay-willow-herb or primrose; and to ensure lack of confusion, *e.g.*, false oats, pseudo-acacia, mock orange blossom, false castor-oil plant; but all the aforementioned examples can have alternative local, vernacular and of course Latin binomials. Generalistic natural kind concepts such as cow and sheep used to vary according to locality in recent history *e.g.*, breeds restricted to a region such as herdwicke sheep to the north of England; or/and *moilie* cattle to the north of Ireland. Explorers and travellers would see organisms both analogous, koala as to European bear, and homologous, tapir as to equine. Cycad palms are often mistaken for pineapple fruit owing to their superficial

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[5]the suffix '-wort' in English plant names derives from the Anglo-Saxon *wyrt* meaning 'root' or that which has roots. [6] The Cambridge A Level syllabus at the time examined 13 animal phyla and the Irish Leaving Certificate Syllabus examined 7; both syllabi examined 6 plant divisions.

similarity (see Chapter 8, p228ff). Carey (1994) believes that taxonomic organisation is a property of the conceptual-linguistic system in general, particularly the nominal system.

2.5 Intuition and essence

Two words which have a bad press in academic circles are 'intuition' and 'essence' because they imply a subjectivity to some or metaphysicalism to others about how the world works. However, it is the case that we sometimes know things having little or no firm basis for that knowledge, *i.e.*, we possess intuition. We can have an appreciation of a living thing and how it fits into a theory or classification without being able to clearly define what it is we 'recognise', *i.e.*, its indefinable "essence". As Gelman and Medin (1993) put it, essences are predictive of, but distinct from, more observable features.

Whenever the word intuition is used it is more correctly couched in the phrase "intuitive theory". Intuitive theory is defined by Wellman (1990) and Carey (1985) as a cognitive structure that embodies a person's "*ontological commitments*", *i.e.*, those which specify the basic kinds of things that there are in the world, and provide modes of explanation for the phenomena in its domain. Intuitive theories are involved in the processing, in a limited way, of "*privileged input*", constraining the data received through the sensory system.

Medin (1989, p. 1476) described how essences influence theorising about the world since they constrain or generate properties that may vary in their centrality. This is important because one of the things theories do is to embody or provide causal linkages from deeper properties (*e.g.*, zebra are herbivores and predated upon) to

more superficial or surface properties (*e.g.*, zebra have stripes as a pattern disruption among long grass in groups).

Gelman *et al.*, (1996) describe this type of essentialism as *psychological essentialism* and believe it to be when people have an implicit assumption about the structure of the world and how it is represented in categories. Gelman *et al.* (1996) also believe that psychological essentialism is one step away from the 'causal determinism' of Brown (1990) and Bullock *et al.*, (1982) who provide six points of evidence in support of psychological essentialism; see Table 2.4.

Table 2.4 *Evidence in support of psychological essentialism*

1	The explicit articulation of an essentialist philosophy
2	People appeal to invisible causal mechanisms
3	The assumption of innate dispositions or potential
4	Unalterability or maintenance of identity over superficial transformations (Keil, 1996)
5	Inductive potential
6	Consensus of taxonomies across cultures

Locke (1690/1964) also ascribed to the notion of "essences" of objects and defined them as follows: "*essence may be taken for the very being of anything, whereby it is what it is. And thus the real internal, but generally, in substances, unknown constitution of things, whereon their discoverable qualities depend may be called their essence*"

The status of the essence of an object has been a philosophical question since the ancient Greeks, and was particularly important in the work of Aristotle of Stagira. To Locke, natural kinds have real essences but they are undiscoverable, since we cannot perceive them. We only have access to their "nominal" essence that is a conventionally fixed definition. Gelman and Wellman (1991) state that essences are generally never observed, may remain unknown, and may be unspecifiable terms which partly describe intuition (*i.e.*, the means of detecting essences). Medin and Ortony (1989, p. 186) suggest that in spite of these difficulties adults treat concepts as having essences, and even when the essence is claimed to have been described it is not strictly a definition (Pinker, 1997 p. 324). Indeed it is a problem of some

notoriety to find definitions for natural kind concepts, as we have seen. Kripke (1972a, b) also doubts that lists of necessary and sufficient features can easily describe natural kind terms *i.e.*, those that lack *a priori* definitions. Definitions of natural kinds usually employ other natural kind terms. This difficulty of finding definitions is an important point in biology education when species are described by a list of features and students are taught to look for and form these lists as a valid bioscientific method. Putnam (1975, p. 141) shows why a concept cannot be defined by conjoining a set of necessary and sufficient properties. Atypical or abnormal members, a situation common in the biological domain, seem to show that no one feature-category relation can be analytically true.

However, Kripke and Putnam were certainly not the first to point out the problems with traditional or classical accounts of meanings as simple feature lists. Wittgenstein (1953) is perhaps best known to psychologists and philosophers as arguing for the *family resemblance* view of concepts wherein no one feature of a concept is necessary to its meaning. Rosch (1975) in particular, has traced aspects of her views back to Wittgenstein. Notwithstanding, it is Putnam and Kripke who have made perhaps the most concerted attack on traditional views of meaning by arguing that there may be no simple property or properties that language users always rely on to pick out the referents of a term. Keil (1996 p. 27) acknowledges that such necessary and sufficient features might in fact exist, but they are, according to the Putnam-Kripke thesis rarely, if ever, part of an analytic meaning that is known to most users of the term in question, and they are not the criteria used to pick out the extension.

2.6 Conclusion

The brief review of concepts and especially natural kinds has shown that there are definite structural entities in relation to concepts that can be described. It has been seen that there are types of concepts, natural kinds are a recognised category and that they have a particular structure. The empirical work that is the focus of this thesis provides some insights into the nature of school students' understandings of, or intuitions about, natural kinds. It will be seen that there is evidence of their thinking in terms of hidden essences. The methodology was developed from the assumption that if something is hidden from the conscious mind of the student, then merely asking them to overtly classify natural kinds will reveal little of value. Repertory grid analysis has been shown in its original domain of psychiatry to be particularly valuable at eliciting hidden ideas, thoughts, perceptions and the connections between them.

Chapter 3 Classification and Categorisation

> "*I will not dwell at length on the importance of classification and categorization in the cognitive domain; how difficult our lives would be if we did not have classification skills; how many kinds of activities have classification at their heart. Suffice it to say that classification is basic to all our intellectual activities.*"
>
> Estes (1996, p. 4)

3.1 Introduction to classification

When one first considers the term 'classification' in the context of learning it may well be that an image of struggling to come to terms with a large number of Graeco-Roman names, definitional lists of features of classes and other taxa to be learned by heart, and most likely a range of diagrams with varying degrees of intricacy. This would have been the author's personal experience of studying for the 1986 Cambridge A Level biology examination and teaching the Irish Leaving Certificate Biology Syllabus for eight years. In these syllabi a number of *phyla*[6] are examined and themes chosen in a number such as the 'alternation of generations' in the *pteridophytes*. However, the reason learners find this part of the two syllabi difficult and tedious is because very often the learner and/or the teacher has a poor understanding of the theory that underlies the study of classification: *viz*. Darwinian evolution. Indeed, anecdotal evidence suggests that even when they do possess a theory some teachers hold a version of evolution that is more akin to that of Lamarck, or hold an ambiguous version of evolution and do not relate it to the part of the course on classification. An anonymous reviewer (Anon., *pers com.*) labelled the study of classification as 'passé' and not a 'real contribution to science'; so, to some researchers, the research concerning classification is finished and all that there is to know about 'it' has been elucidated. Notwithstanding such views by learners, teachers, and researchers, an

examination of the literature on classification reveals that most research involving classification as a cognitive process has been focussed on inanimate objects, and specifically geometric shapes (Bruner *et al.*, 1956; Inhelder & Piaget, 1964; Kofsky, 1966 and Denney, 1972), and thus the need to examine classification of living things is timely. It is worth noting that classification in the "pure" scientific sense is still on-going, but that it has evolved itself to include methodologies such as phylogenetics and biometrics and that classification is a large part of the field called 'systematics'.

However, recently, a re-examination of the Piagetian model of child development, coupled with that of Vygotsky has focussed on education researchers' attention being more on the schema of classification, *e.g.*, the Cognitive Acceleration through Science Education project (Shayer and Adey, 1999, 2003; and Adey and Shayer, 2002). Classification of living things was addressed in activities in the 11-14 years CASE project in tasks where cards displaying pictures of animals had to be sorted with justification by the learner as to how (s)he arrived at the sorting. The learner articulating their own view of how they arrived at the groups they produced is a key feature of the CASE methodology.

Scientists represent concepts of living things in diagrams that are akin to concept maps; therefore one way to learn and assess the learning of, the so-called 'correct' system of ordering living things would be through such diagrams. Such diagrams would allow the educator to find out if the categories formed are formal-biological or folk-biological or somewhere in-between. However, the learner or novice is likely to be in possession of a system of categories that is both (i) extensive and (ii) resilient to change – having been hard-won through personal experience.

However the extent of both these features as applied to living things has to be as yet fully investigated.

Before proceeding to examining the processes involved in classification it is incumbent upon the author to mention that there is a tendency to confuse the terminology in this area. Thus the main terms used in connection with classification are outlined in Table 3.1. However, as Estes (1996) points out, the terms *concept* and *category* are used interchangeably, *e.g.*, in Smith & Medin (1981) as are *categorisation* and *classification*.

Table 3.1 *Differentiation of classification, categorization, and category (Estes, 1996)*

Term	Description
Classification	Classification implies only that a collection of objects is partitioned into groups (note, that this description of classification differs from a systenatists)
Categorization	Categorisation implies that a collection of objects is partitioned into groups and that knowledge of the category tells us something about the properties of its members
Concept	Many concepts are not categories
Category	A group of objects whereby by being members of that group implies some knowledge of the group, and the properties of its members

3.2 Computational models of similarity

"*Similarity is at the very heart of a theory of cognition and memory*" (Estes, 1996)

Thorndike (1913) assumed that the similarity between any two situations or things is measurable in terms of the proportion of common elements and that similarity is the basis for generalization, or transfer of learning, between tasks. Ratcliff (1978) Estes (1996) in turn assumed that a perceived stimulus pattern resonates with stored patterns

activating vectors in the memory array in direct relation to similarity of the perceived to the stored patterns. This appears to be an early form of prototype theory outlined in the following section and thus it is important to note the close link between the two phenomena. Estes' (1996) way of conceptualizing and ensuring similarity derives from the work of Medin (1975) and Medin & Schaffer (1978).

Why is it that some concepts group together in a certain way whilst others do not? Or, in other words why are some concepts more 'coherent'? Similarity may well be a way for explaining interesting generalizations about a set of concepts. Hahn & Chater (1997) propose that:

> *"Similarity is at the very center of a theory of concept and the theory of similarity would explain* [...] *why people have the concepts that they do"*

A key question is: "*what is it that makes two objects similar*?" An obvious answer is that they have features in common, features that are perceptible and are concepts in themselves. A second research question is: "*what is the relationship between concepts and similarity*?" Hahn & Chater (1997) note that there is little research directly integrating the two terms. Similarity, although it may be frequently employed as an explanatory notion in the concepts literature is seldom given closer scrutiny. Likewise, models of similarity typically assume given properties and thus concepts as a starting point. If we emphasize that very close connection between concepts and similarity, it follows that categorizing an object will involve judging the similarity between that object and some other.

However, the classifying of living things according to perceptual, *i.e.* visual, similarity cannot be the complete picture because adults sometimes refrain from

classifying together things that seem superficially the same but differ in theory-relevant properties. The problem in investigating the process and skill of classification is that there may be a battery of processes that enable the human mind to deal with the large number of objects it encounters.

One of the many ways of calculating similarity is by the 'product rule' shown in Equation 3.1, which works well in the case of binary-valued attributes, *i.e.*, whether or not they are present. This rule was based on the multiplicative combination of cue and context and developed into a model of animal discrimination learning by Medin (1975) and then extended to the first effective formalization of the concept of instance-based categorization learning (Medin & Schaffer, 1978).

$$Sim(i,j) = s^{N-k} \qquad \textit{Equation 3.1}$$

where N is the number of features; i,j are the patterns; k is the number of matches; Sim, is the pattern similarity. s is a parameter that is typically between 0 and 1 and can have its value assigned. An example is illustrated in Table 3.2 where a set of features of *zebra* and *horse* are compared. Where features apply equally, the value of s is set to 1; where they differ, the value is designated s_1 and s_2.

Table 3.2 *Calculation of pattern similarity between zebra and horse; where '+' denotes the presence of the feature, and '-' denotes the absence; following the system of Estes (1996).*

	Single-toed animal and associated bone structure	Typical equine dentition and diet	Stripes continuing to maturity	Coarse hair forming a mane and at the end of the tail	Pronounced 'chestnuts', *i.e.*, vestigial hooves	Typical neighing call
Horse	+	+	-	+	+	+
Zebra	+	+	+	+	-	+
Feature Simularity	1	1	s_1	1	s_2	1

Pattern Similarity in the first case = $1 \times 1 \times s_1 \times 1 \times s_2 \times 1 = s_1 s_2$

Estes (1996) states that the product rule is widespread in models of classification due to its simple and useful properties such as the role of 'relational information' without the need for a special mechanism for the storage of such 'information'. This advantage of the product rule advances the theory that recognition has less to do with storage of the information concerning a living kind, such as images of whole or complete objects or iconic / symbolic entities, and more with computation. Posited against this is David Marr's (1982) theory of vision. Marr's (1982) classic theory conjectured that humans decompose living things into iconic / symbolic entities which are stored in the memory. In order to recognise a horse, several of the iconic / symbolic entities must be re-called and composed together to create as near an approximation of horse as possible. According to Estes (1996) features or attribute values are stored in the memory. The work of taking account of relations among features is accomplished by application of the product rule at the time the memory is probed. Estes' (1996) model has interesting features in that

any two or more objects can be compared, and the implicit bipolarity of taking into account matches and mismatches. These are all relevant to the way the RGA will be used to elicit ideas concerning living kinds discussed at length later. A key question concerning the process of classification and how learners represent living kinds is how much of the information about a living kind is stored in the human mind. Further to answering this question is the theory that humans store full or partial images of the living kinds called prototypes.

3.3 Prototypes

The term prototype has been used to mean a representation of the best example for a given concept (Medin & Schaffer, 1978; Mervis & Rosch, 1981). The prototype view assumes that each category is associated with a prototype, that is the stored representation of the properties that typify members of the category (Hahn & Chater, 1997 p. 45). A prototype is a stored representation of the usual properties associated with the concept's instances such as in a schema or frame theory (Minsky & Papert, 1969; Rumelhart & Ortony, 1977). The classification of the new object, for example *roundworm*, will depend on how similar that object is to the *worm* prototype and also to the prototypes of other categories, *e.g.*, *flatworm*. The simplest view of a prototype is that it is a stored mental representation of the same nature as a mental representation of the specific objects (Hahn & Chater, 1997, p. 46). Therefore, judging the similarity between a specific object and a prototype in classification is the same process as judging the similarity between two objects.

By contrast, some prototype views assume that prototypes are not represented in quite the same way as specific objects but are specified in somewhat more abstract terms. In its simplest form, abstract specification could simply list certain properties

which previously appeared in instances of the category while other features might be ignored entirely thus making the representation abstract. However, it is not clear how such a list would be constructed and referred to. The various listed properties might also have weights or scores reflecting varying degrees of relevance for category membership.

3.4 The exemplar approach

The exemplar approach also sees classification as involving judgments of similarity to stored representations. The object is compared to many stored exemplars which are specific previously encountered instances of the category. If the new object is, say, more similar to exemplar *zebra* than to exemplars of any other it will be classified as a *zebra*. According to the exemplar view, the specification of the category is implicit in its instances; no necessary and sufficient features or even probable features are abstracted; the concept is learned simply by storing examples of the category members.

3.5 Revisiting the classical view of concepts

The definitional or classical view of concepts, described in Chapter 2, posits that concepts possess definitions specifying features 'necessary and sufficient' for the concept. This definition is the summary description of the entire class used in every instance of categorization that proceeds simply by checking for the presence of these features in the entity in question. This view was supplemented by the 'nesting assumption' that the *subordinate* concept, *e.g.*, Oxford ragwort, contains nested within it the defining features of the *superordinate* concept, *e.g.*, ragwort. It is important to note that this relates to hierarchical classification of living things, and

thus reflecting a 'natural' classification. The definitional view does have sufficient room for a role for similarity in understanding concepts:

(i) Similarity may determine how definitions are interpreted.

(ii) Similarity may play a role in a concept's identification protocol.

(iii) Similarity may be an additional factor affecting how definitions or rules are applied in actual classification. (Hahn & Chater, 1997, p. 49)

Smith & Osherson (1984) and Smith *et al.* (1988) describe how recent work on 'common' concepts like 'apple' and 'fish' has led many researchers to conclude that mental representations consist of prototypes. Most proponents of such a view deny that the mental representation of a natural class specifies necessary and sufficient conditions for membership; it is claimed, instead, that the representation specifies properties that are merely characteristic of the class or perhaps only of some exemplars of the class. Prototype theorists usually only assert that entities fall neither sharply in or sharply out of the concept's extension, the boundary between membership and non-membership being inherently 'fuzzy' (Osherson & Smith, 1981, 1982; Smith & Osherson, 1984). These theorists believe that entities can be dealt only with adjective-noun conjunctions – these are concepts such as *candelabra plant* and *horewort* and are important in the categorization of named examples.

3.6 Fuzzy set theory

As mentioned in the previous section, the boundaries between membership and non-membership are fuzzy. Fuzzy set theory (Zadeh, 1965) is of interest to cognitive

scientists because it offers a calculus for combining prototype concepts. A key notion in the application of the theory is that of the *characteristic function* (Equation 3.2),

$$c_A : D \rightarrow [0,1]$$

This function maps entities in the domain of discourse, D, into the real numbers 0 through to 1 in a way that indicates a degree in which the entity is a member of the concept 'A'. Consider the composite concept, *great ragworm.* The question of interest concerns the relation between the characteristic function of a conjunction and those of its constituents. How for example can we specify $c_{G\&R}$, the characteristic function of great ragworm, in terms of $c_G$and c_R?

The answer from Zadeh's (1965) version of fuzzy-set theory is that the conjunction's characteristic function value is the minimum of the constituents' values; *i.e.*, $c_{G\&R}(x)$ is the minimum of either $c_G(x)$ and $c_R(x)$. This is called the *min* rule and our intuition would probably dictate that such a rule would be wrong. In this example, *great ragworm* would have a typicality rating the same as 'great' which is patently untrue since we can think of many things more typical of great than the *great ragworm e.g.*, rulers, armies, Alexander-the-Great, sports teams, Ireland, pop groups, actors and so on. In fact Osherson & Smith (1981) provide many such counter-examples to the *min* rule; however the problem Smith & Osherson (1984) have with the counter-examples is that they are intuitive and that adjective-noun concepts which tend to be the counterexamples of the *min* must have their own type of taxonomy of conjunctions.

All counterexamples of the type: *yellow wagtail* share the following characteristic: the adjective concept, *i.e.*, the property denoted by the adjective, is

negatively diagnostic of the noun, for example being *yellow* counts against an object being a *wagtail*. More precisely, an adjective is negatively diagnostic of a noun to the extent that the applicability of the adjective to the given object decreases the probability that the noun is true description of the object, and the inapplicability of the adjective to the object increases the probability that the noun is true of that object. There also exists the situation where the noun is negatively diagnostic of the adjective. This is particularly true in the case of naming wild plants in English, and to a lesser degree the naming of wild animals in English for example the *burdock* is not a *dock* and *hedgehog* is not a *hog*.

3.7 Conclusion

This chapter, has provided a brief review of what is in fact a huge area of research in education and cognitive science. The relevance to this thesis is that RGA, employed in the empirical studies outlined in Chapters 5 to 8 possess a number of the features associated with Estes (1996) computational model of similarity, which will be outlined in Chapter 4. Using RGA allows some investigation into prototype concepts, which depend on essences, investigations into transformations of kinds, *i.e.*, biological natural kinds (Keil, 1996), and investigations of similarity between learners' conceptions of these transformed kinds. Prior to the aforementioned chapters, Chapter 4 will prepare the ground for introducing RGA by examining concept mapping *per se*.

Chapter 4 Conceptual frameworks in science

> *"The act of mapping was as profound as the invention of a number system* [...] *The combination of the reduction of reality and the construction of an analogical space is an attainment in abstract thinking of a very high order indeed, for it enables one to discover structures that would remain unknown if not mapped."*
>
> A. H. Robinson (1982)

4.1 Introduction to conceptual frameworks

"Conceptual framework" is a generic term used to describe graphic images that present relational information about concepts. Wandersee (1990) states that a *bounded* graphic representation that corresponds to a perceived reality is effectively the process of constructing a map in the geographical sense. However, not all conceptual frameworks can be maps because of the extent of the '*bounded*-ness'. Clearly, maps in the geographical sense are tightly bounded and present relational information objects, features, distance between features, and direction of a physical reality. The earliest known map belongs to a Neolithic community at Mehzirich, Ukraine ca. 10,000 B.C. and consists of lines incised on mammoth bone, Figure 4.1 . It shows a line of habitations along a river, which describes the site at which it was found. Lawson (1997) states that visual representation of an idea or process is generally accepted in both the wider community and in education, and cites the following as effective forms of representation of ideas of varying complexity in everyday life: logos, coats-of-arms, maps of subway systems, flow charts, and road signs; to which can be added geographical maps, historical timelines, concept maps, mind maps, family trees/pedigrees, evolutionary/phylogenetic dendrograms, chemical pathways, equations and formulae, and mathematical formulae.

Figure 4.1 Graphic interpretation of the Mehzirich 'map'[7]

Each of these 'frameworks' involves an encoding of the meaning of what is to be conveyed and the "reader must perform detection, recognition, discrimination and estimation tasks in order to extract the meaning which was encoded" (Wandersee, 1990, p. 924). In this chapter, a variety of conceptual frameworks will be discussed. Of the list of possible conceptual frameworks that were listed above, the most relevant to this thesis, and that which is examined in this chapter, is concept maps.

4.2 An analysis of Novakian concept mapping

In its hierarchical form, the structure of a Novak concept map bears close similarity to the model of *internal semantic network structure* developed by memory researchers during the 1960s as a format for representation of long-term memory *e.g.*, Collins and Quillian (1969). The concept map may be seen as a system for externalising internal memory representation (Lawson, 1997).

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[7] Taken from http://209.82.14.226/history/inventions/figure02.gif last accessed 18th February 2006

Joseph D. Novak has been most commonly associated with the term *concept mapping* although many other workers have been engaged in distinguishing and evaluating different types of visual representation (Fisher *et al.*, 2000). Importantly for workers in the educational domain, Novak attempted to devise a method to score a concept map in order to present concept mapping as a method of summative assessment.

Concept mapping has been defined as "*a two-dimensional hierarchical representation of concepts which indicates the relationship between selected concepts*" (Pankratius & Keith, 1987) and as "*the most important meta-cognitive tool in science education today*" (Mintzes *et al.*, 1997). Concept maps have also been described as a graphic in which the nodes represent concepts, the lines between nodes represent relations and the labels on the lines represent the nature of the relations (Ruiz-Primo *et al.*, 2001). The combination of the two nodes and labelled line is called the proposition — the fundamental unit of the map (Figure 4.2).

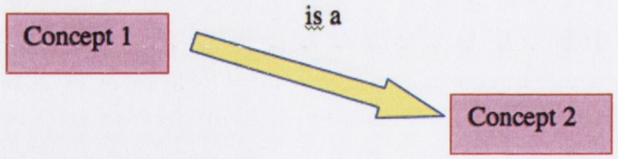

Figure 4.2 The fundamental unit of a concept map

In Figure 4.2, the proposition reads: "concept 1 is a concept 2". This implies that concept 1 is subordinate to concept 2 or concept 2 superordinate to concept 1, despite the downward tilt of the arrow. The direction of the arrow indicates the direction in which the proposition should be read and does not denote a co-ordinate value in mathematical space. The importance of acknowledging the basic unit of

knowledge representation is that it appears to describe a concept map as "*a schematic device for representing a set of concept meanings embedded in a framework of propositions*" (Novak & Gowin, 1984, p. 15). In fact, concept mapping has been described as one of the many types of knowledge mapping (Fisher *et al.*, 2000).

The central feature of Novakian concept maps is the hierarchical structure, which is itself based on the theory of subsumption, *syn.* assimilation or incorporation. Concept mapping has been described as a process of knowledge formation and organization, in which meaningful learning involves the establishment of patterns of relationships among concepts with larger more general patterns (Ausubel, 1963, 1968), and it has also been cited as consistent with constructivist theory (Fisher, 2000). Consistent with constructivist theory, one of the many ways concept maps have been employed in research was in a study using a modified Piagetian clinical interview technique (Novak, 1972).

Novak (1990) recalls that during the 1960s, there was considerable debate in the science education community as to whether or not young children could understand 'abstract' concepts such as 'energy, 'molecule' or 'evolution', the primary limitation being their '*cognitive operational capacity*' (Piaget, 1926). Novak and his co-workers' early work suggested that this limitation might not exist; rather, the main limitation might be the quantity and quality of their relevant knowledge acquired through experience and instruction. They found that primary school children are capable of developing very detailed concept maps, which they can explain intelligently to others (Symington and Novak, 1982). Ultimately, therefore, "*the challenge we face as science educators is primarily how to organize better instructional material and how to help students learn this material*" (Novak, 1990).

In other words, given that one of the main challenges in science education is improving the teaching and learning of science, the claim was that this improvement can be brought about through better knowledge mapping frameworks.

4.3 Classifying concept maps

Concept maps may be categorised or classified into types or forms, which is the basis of a crude form of assessment based on the overall shape of concept maps. Joseph Novak and his co-workers originally classified students into those who held 'categories of understanding' (Hibbard & Novak, 1975) or 'notions of understanding' (Nussbaum & Novak, 1976); however, Novak and his co-workers were interested in more explicit descriptions of concept meanings. Thus they turned to Ausubel's *assimilation theory of cognitive learning* (Ausubel, 1968), and specifically to that part which asserts that new concept meanings were acquired through assimilation into existing concept or propositional frameworks. Novak and his co-workers further borrowed from Ausubel's theory that cognitive structure is organized hierarchically, and that most new learning occurs through derivation or subsumption of new concept meanings under existing concept or propositional ideas. Novak and his co-workers developed the idea of hierarchical, Figure 4.3, representation of concept or propositional frameworks (Novak & Gowin, 1984) which they later described as 'cognitive maps' or 'concept maps' (Novak, 1979, 1980, 1981). Today, the notion of subsumption is not so strongly held by researchers; however, the hierarchical feature has been retained by some (Novak & Gowin, 1984).

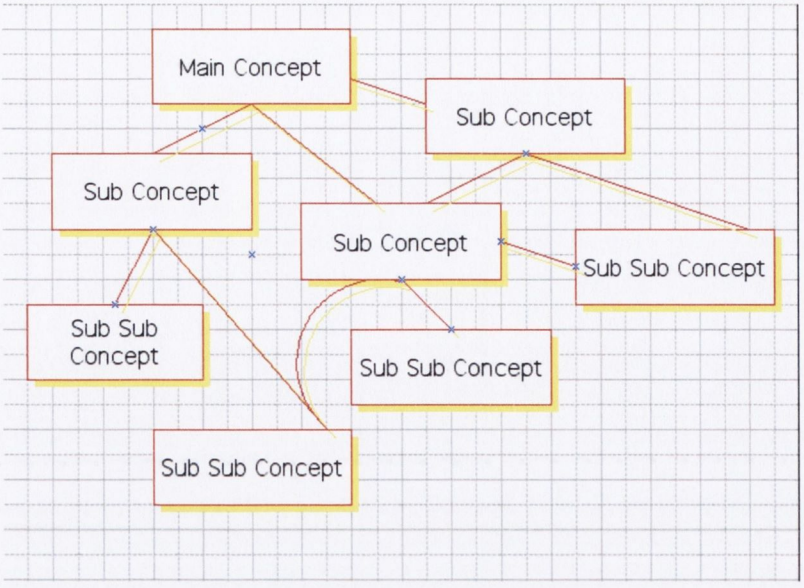

Figure 4.3 A generalized concept map demonstrating hierarchical arrangement

Three 'shapes' of concept maps have been described as part of a qualitative approach to assessment using concept maps (Kinchin, 2000b, 2001; Kinchin *et al.*, 2000). Kinchin and his co-workers described the arrangement of features of a map as 'spokes' or 'radial' (Figure 4.4), 'chains' or linear (Figure 4.5), and 'nets' or 'webs' (Figure 4.6). They assume a developmental progression from spokes through chains to nets. The assumption is further developed when the net shape of concept maps becoming an aim of learning, and thus learners may be actively encouraged to generate net forms of concept maps as an end in itself. This matches with a common assumption that concept map complexity correlates with depth of understanding; but concept map shape may be a form of *noise*: students who have been trained to use concept maps will produce concept maps of a particular shape *as trained*.

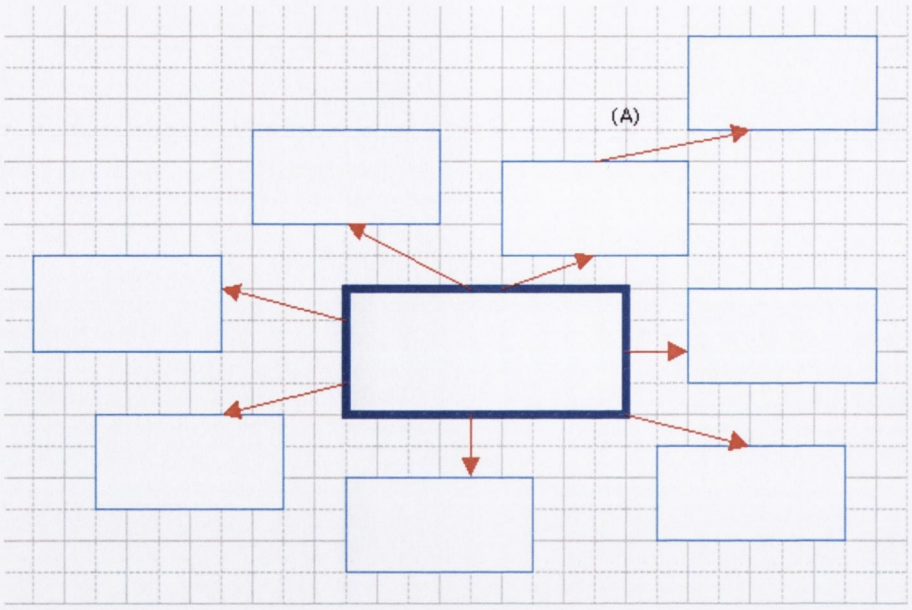

Figure 4.4 A spoke or radial concept map shape

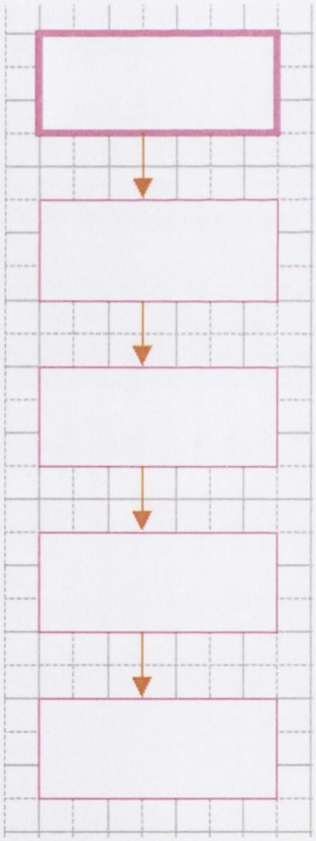

Figure 4.5 A chain or linear concept map shape

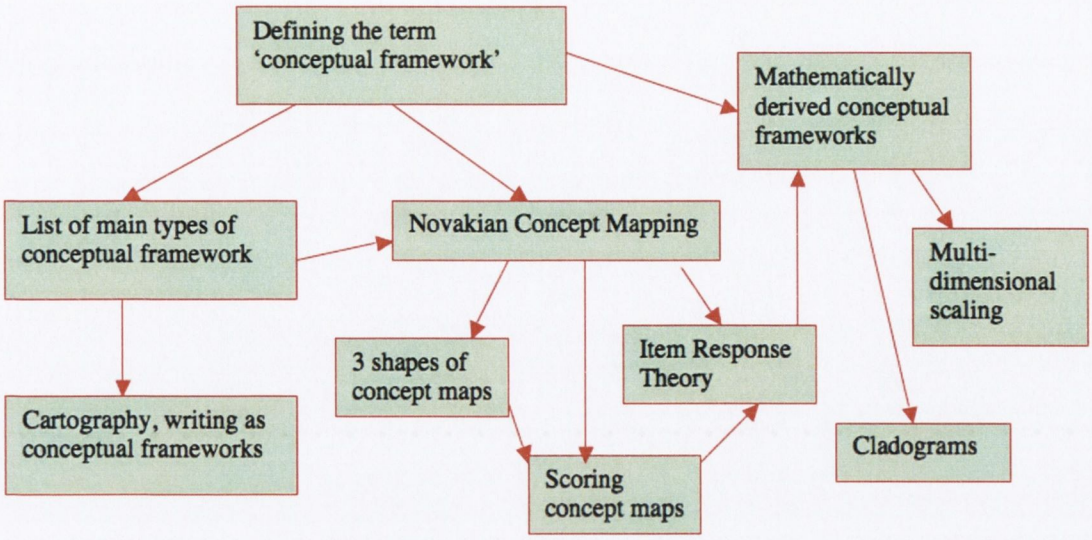

Figure 4.6 A net or web concept map of this chapter

4.4 Types of concept mapping representations

Several methods of representing concept maps have been developed and attempts have been made to analyse them quantitatively. What follows is an overview of the types of concept maps that have been explored in science education.

4.4.1 Daisy diagrams

Stavridou & Solomonidou (1998) developed a system of "Daisy" diagrams, Figure 4.7, to represent the semantic categories that a pupil might use. In these graphs, each number corresponds to the phenomenon marked with the same number. Related phenomena or concepts are enclosed within a line drawn around the corresponding number. In Figure 4.7, there are four 'clusters' of concepts, this techniques allows an attribute or concept to be included in more than one group.

With Daisy diagrams it is possible to follow the conceptual organisation of individual pupils. The problems associated with following such conceptual development of a large number of people were recognised. However, for a class or

group of pupils it would be important to have a more holistic view of a pupil's conceptual organisation and its evolution in time (Stavridou & Solomonidou, 1998).

Linked Concepts:

1, 2, 3, 4,7, 8, 12, 15, 16

9, 13, 19

4, 5, 6, 10, 14, 17, 18

11

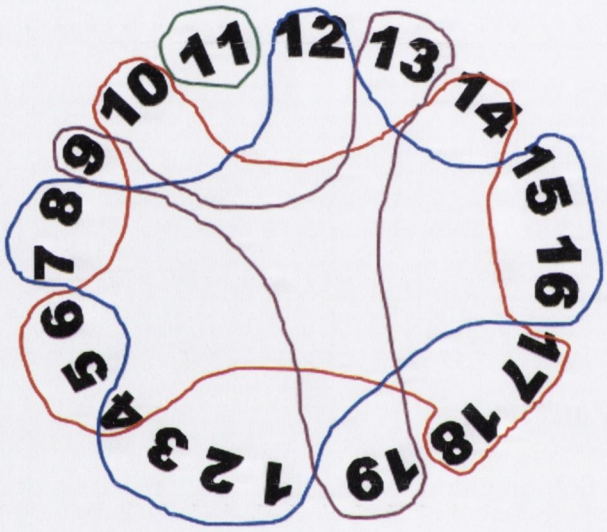

Figure 4.7 Lists of linked concepts represented as integers and the associated daisy graph

4.4.2 Concept circle diagrams

Concept circle diagrams are, in essence, an application of Venn[8] diagrams whereby the concepts are all subsets of the main concept (Figure 4.8). Figure 4.8 displays the relationship between the terms *Platyhelminthes, planarians, trematodes*

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[8] Strictly speaking, concept circles are based on Euler's Circles, the forerunner of Venn diagrams, and Euler himself based his work on the five cases of possible intersection of the Circle of Apollonius (262-190 B.C.)

and *digenea*. *Digenea* are a type of Trematode; Trematodes and Planarians are both types of Platyhelminthes.

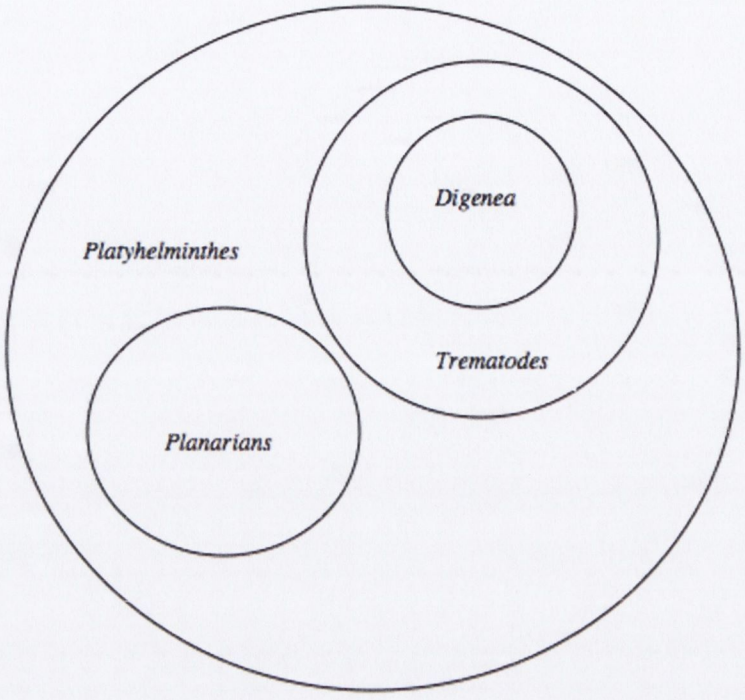

Figure 4.8 An example of a concept circle

4.4.3 Cluster maps or webs

Clustering and webbing are techniques that capture associations between ideas. Figure 4.9 displays a cluster map of a 6th class student's record of a lesson on 'worms'. A variety of concepts are linked by arrows denoting some unspecified association. An adaptation of cluster maps or webs are the commercially promoted Mind Maps® by Tony Buzan (Buzan, 2002).

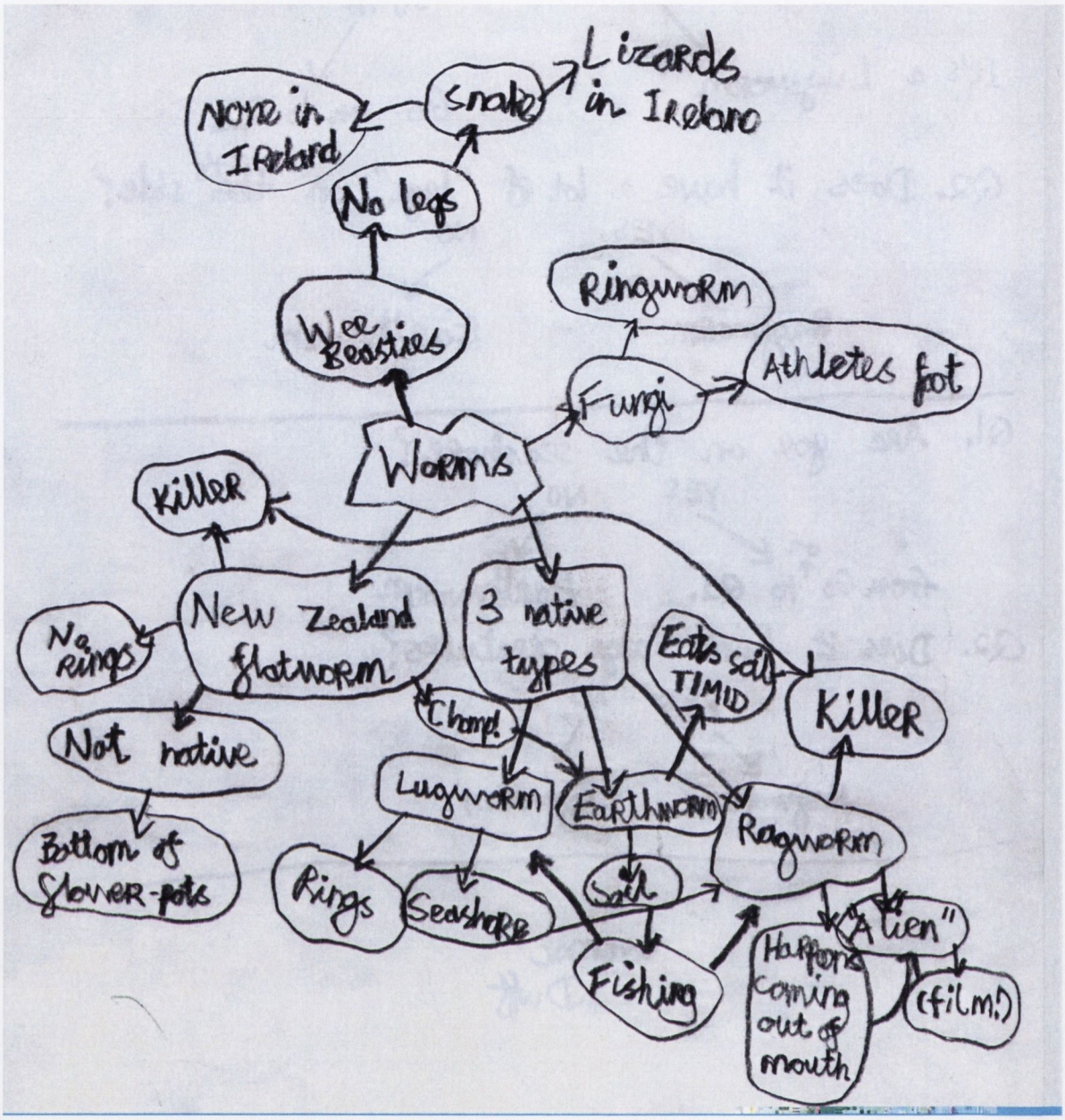

Figure 4.9 A cluster map of a 6th class student's record of a lesson on 'worms'

4.4.4 Fill-in-the map or 'skeleton' maps

Some researchers, *e.g.,* Schau & Mattern (1997) have argued that asking students to draw a map from scratch imposes too high a cognitive demand to produce a meaningful representation of their knowledge. They proposed an alternative technique termed 'fill in the map'.

'Fill-in-the-map' technique provides students with the concept map or some of the concepts and/or linking words have been left out. Students fill in the blank nodes or blank linking lines (*e.g.*, Anderson & Huang, 1989; McClure & Bell, 1990; Schau *et al.*, 1997; Surber, 1984). By imposing a structure and the relations between concepts, it is difficult to know whether or not students' knowledge structures are becoming increasingly similar to those of the experts. Structure of representation however is not the only issue to consider. Usually with fill-in tasks, students are provided with a skeleton map and they select the concepts from a list of concepts. Therefore there is less evidence gathered on students' connected understanding.

4.4.5 Construct-a-map

The 'construct-a-map' technique varies as to how much information is provided by the assessor. The assessor may provide concepts and/or linking words or may ask students to construct a hierarchical or non-hierarchical map. The response format is simply a piece of paper on which students construct a map. Scoring systems vary from counting the number of nodes and linking lines to evaluating the accuracy of propositions. This mapping technique however has been considered problematic for large-scale assessment because students need to be trained to use maps and scoring is difficult and time-consuming (Schau *et al.*, 1997). A number of researchers have given this problem considerable attention, see for example: Ruiz-Primo *et al.* (1996, 1997, 2001).

4.5 Scoring concept maps and concerns regarding validity

One example of attempting to employ concept maps in education has been to devise protocols to apply a score or 'mark' in order to introduce an element of summative assessment. Indeed, as mentioned earlier, early attempts in applying a score to concept maps involved a

summative approach (Novak & Gowin, 1984). In such an approach the score is the sum of individual scores allotted to:

(i) the number of links *per se*: score of 1 per link

(ii) the number of levels or nestings in a hierarchy: score of 5 per level

(iii) the number of cross links: score of 2 or 10 per cross link depending on which version of the protocol one is using, and

(iv) the numbers of examples: score of 1 per example.

This is summarised in the following equality:

$$S_{cm} = n_l + n_n + n_c + n_e \qquad \textit{Equation 4.1}$$

Where:

S_{cm} is the concept map score

n_l is the number of links, each carrying a weighting of 1

n_n is the number of nestings, each carrying a weighting of 5

n_c is the number of cross links, each carrying a weighting of 2 or 10

n_e is the number of examples, each carrying a weighting of 1.

Whereas this summative approach has the benefit of simplicity, there are two main causes of concern in its application. Firstly, although the concept map may provide an impression of structure and a complex structure may appear to indicate a rich understanding of the content relating to the concept map, the score merely reflects a measure of the complexity rather than the quality or richness. Unfortunately it does not provide any comment on the structure of the ideas expressed. Secondly, as mentioned before, students who have been trained to construct concept maps would acquire the scoring rules and aim to maximise their scores through cross-links. The rebuff to the second point might be to say that only the relevant cross-links would be scored. However, the issue of relevance is fraught with difficulties of interpretation

and the decision to state that one link is more relevant than another becomes subjective although a scoring system should be objective.

Another scoring scheme was developed which takes account of (i) the hierarchical structure of the concept map, (ii) identified propositions, and (iii) the actual validity versus implied validity of concept map components (Schreiber & Abegg, 1991). This is summarised in the following equality:

$$X = \left[x - n(b + c)\right] + {}^{b}\!/_{c} \qquad \textit{Equation 4.2}$$

Where:

X is the overall concept map score;

x is the initial tally of points awarded for recognition of hierarchical, propositional and valid constructs on a concept map;

n is the number of strands in a concept map;

b is the summed ratios of number of vocabulary terms to number of hierarchical levels per strand;

c is the summed ratios of number of valid connecting lines to total number of connecting lines drawn.

Although Schreiber & Abegg (1991) attempt to address the issue of taking into account the structure of the concept map, they also assume that the practitioner can determine which links are 'valid' and which are not.

Novakian concept mapping (Markham *et al.*, 1994) has undergone a number of adaptations by different workers (Martin *et al.*, 2000), some of whom developed a system for scoring structural complexity and examining propositional validity; see Equation 4.3 .

$$S_{cm} = n_c + n_r + n_h + n_b + n_l + \left({}^{n_l}\!/_{n_c}\right) \qquad \textit{Equation 4.3}$$

Where:

n_c, is the number of points for concepts, one for each non-redundant concept,

n_r, is the number of points for relationships, one point for each valid, scientifically-acceptable proposition,

n_h, is the number of points for hierarchy, five points for each level of hierarchy,

n_b, is the number of points for branching, one point for the first branching and three points for each additional branching,

n_l, is the number of points for cross-links, ten points for each valid, scientifically-acceptable cross-link.

Equation 4.3 is very closely related to Equation 4.1 in that they are both summations. Aside from a difference in terminology the idea of *interconnectedness* has been added (Martin *et al.*, 2000). In Equation 4.3, interconnectedness is represented as the ratio of the score of cross-links to the score of concepts. This is believed to take account of the 'cohesiveness' of the concept-map, whereas the score for cross-links perhaps only indicates a measure of 'integration' (Martin *et al.*, 2000). However, whatever the nomenclature, the same problem arises of a student who, trained to construct concept maps, may not necessarily understand the concepts contained therein or have 'ability' in the topic.

Another scoring procedure for scoring structural change (Pearsall *et al.*, 1997) which bears some similarity to the basic idea behind Kinchin's method of characterising the structure of concept maps (Kinchin *et al.*, 2000) is the second system described by Martin *et al.* (2000). In Martin *et al.*'s (2000) method, three structural changes in the knowledge frameworks are documented:

(a) *restructuring*, when a concept label is added or deleted from the first hierarchical level of a concept map

(b) *accretion*, when ten or more concept labels are added to a pre-existing concept

(c) *tuning*, when any change to a pre-existing concept results in a modification of its meaning by the addition of constraining or constant variables.

In order to develop a scoring system, each map is compared to its successor (map 1 v. map 2; map 2 v. map 3; map 3 v. map 4; and so on if appropriate) and a score of 1 or 0 is recorded for each instance or non-instance of a structural change event. At length, each student receives a set of scores. Although important in their own right, these features of a concept mapping assessment system do not answer the problem of how one practitioner may decide certain links and/or cross-links are valid and others not so.

In response to problems such as validity and reliability, *item response theory* (IRT) models were employed for scoring concept maps (Liu, 1994). IRT models have been used for scoring and comparing students' achievements even if they do not sit the same test (Hambleton *et al.*, 1991). Traditional IRT models have been extended to graded IRT (Samejima, 1969), thus students' responses to an item no longer have to be scored dichotomously as right or wrong: they can be graded as categories. When IRT is used for scoring concept maps, the four aspects of a concept map, *i.e.*,

- links,
- hierarchies,
- cross-links, and
- examples

(*á la* Novak & Gowin, 1984), are considered 'test-items', and the numbers of links, hierarchies, and examples are considered as students' categorical responses to the 'test-items'. By applying graded IRT models to students' responses, it is possible to obtain students' ability estimates (Liu, 1994). IRT scoring emphasises the overall structure of students' concept maps instead of the 'correctness' of a specific concept

map aspect. The structural characteristics of students' concept maps have been analysed (Wilson, 1993): a 24 x 24 matrix representing the inter-relationships between the 24 concepts was produced and non-parametric multidimensional scaling was applied generating co-ordinates on three dimensions. Importantly, the canonical correlation between the co-ordinates and students' conventional achievement test scores was found to be significant. Liu (1994) claimed that IRT scoring of concept maps is generally valid and reliable and that the correlation between IRT ability estimates and the total concept mapping scores based on Novakian scoring scheme is significant, and thus the Novakian method can be taken to be a reliable indicator of 'ability'.

4.6 Uses and usefulness of concept mapping

Lawson (1997) outlines a number of uses of concept maps. For a teacher the concept map can be used as a means of representing a pattern of relationships in an instructional display, a sort of diagrammatic text. A number of studies with secondary school science students in which the effectiveness of concept map use during learning for a topic has been evaluated (Okebukola, 1990). The preparation of the maps and their updating during study resulted in better performance than the conventional classroom instruction that did not include use of the mapping procedure. Concept maps have been used by Wilerman & MacHarg (1991) as an advance organizer for the 8th grade science students. It was found that the mapping group scored significantly higher on a post-test than the control group did, who did not use the map organizer. On the other hand, no differences in the achievement in comparisons of mapping and control treatments in biology were found by Lehman *et al.*(1985). Others found that the use of concept maps in chemistry resulted in lower scores for

higher ability students than did the conventional teaching procedure (Stensvold & Wilson, 1990). A similar effect on higher ability students' initial post- test performance was noted also (Heinze-Fry & Novak, 1990).

A second use for concept maps is as an evaluation device (Novak and Gowin, 1984). Concept maps have been recommended as curriculum organizers (Starr & Krajcik, 1990). Concept maps have also been used to document changes in understanding of a wide range of scientific notions in a group of students as they move from first grade to top grade (Novak & Musonda, 1991). In one study (Wallace & Mintzes, 1990) undergraduates were trained to produce concept maps prior to beginning their instructional intervention. The quality of the student-produced maps at pre-intervention and post-intervention times were assessed using an 'expert-produced' map as a reference point. Lawson (1997) believes that the Wallace and Mintzes' (1990) method is more straightforward and less prone to problems associated with unreliability.

As stated previously, concept mapping has been employed in a large number of areas within science education. Some of these are: as a learning tool (Horton *et al.*, 1993; Roth & Roychoudhury, 1993); measuring achievement (Pankratius, 1990); reduction of learners' anxiety (Okebukola & Jegede, 1989); integration within curricular design (Nicoll *et al.*, 2001); assessment (Laffey & Singer, 1997; Liu, 1994; McClure & Bell, 1990; Robinson, 1999; Ruiz-Primo & Shavelson, 1996) and self assessment (Stow, 1997) – categories which are not mutually exclusive. Kinchin (2001) (who cites Edmondson, 2000 and Kinchin, 2000a) lists planning, teaching, revision and assessment as uses to which concept mapping can be put in biology. However, he reiterates the view (Brown, 1995) that despite these purported benefits,

concept mapping does not enjoy wide usage in biology. Kinchin (2001) suggests and subsequently demonstrates that the literature is positively predisposed towards concept mapping without addressing 'real' problems associated with its implementation in the classroom.

4.7 Conclusion

The existence of the relationship between the behaviour manifest in the concept map and the internal structure of state of the individual has been questioned (Philips, 1983). However this criticism has been felt to be excessive because the less than perfect representation of cognitive structure is mistakenly interpreted as a lack of such a relationship (Greeno, 1983). Concept mapping techniques do bear a systematic though perhaps 'noisy' relationship to cognitive structure and so can be used as a basis for derivation of inferences about the state of that structure. However few studies have attended to the degree of the noise in this relationship.

Ruiz-Primo *et al.* (2001) state that concept maps provide a 'picture' of how concepts within a given domain are mentally organized/structured by students. With this assessment technique, students are asked to link pairs of concepts in a science domain and label the links with a brief explanation of how the two concepts go together. Although concept maps have been used in large scale as well as classroom assessment, a wide variety of techniques are described as being 'concept mapping' and little is known about their reliability and validity of scores produced by these different mapping techniques (*e.g.*, Ruiz-Primo & Shavelson, 1996). Ruiz-Primo *et al.* (2001) suspect that the observed characteristics of the representation of students' knowledge structures depend to a large extent how the representation is elicited.

Simply put, the method used to ask students to represent their knowledge can affect the representation they provide as well as the scores they obtain.

The differences in concept map assessment, with respect to three components — task, response format, and scoring system — revealed the enormity of variations in mapping techniques used in research and practice (Ruiz-Primo *et al.*, 2001). Characteristics of these three aspects hold the key for tapping what concept map-based assessments are intended to evaluate: *knowledge structure,* or *connected understanding*. The assessment task, for example can vary in its efficacy in determining these features through constraints, or *directedness*, it imposes on a student eliciting the representation of structural knowledge..

Notwithstanding such scoring procedures as described above, the reliability and validity of concept map scoring techniques have been questioned. The scorer must ascertain if the links, nestings and examples are 'valid' — which is problematic, if not subjective. The process of determining what aspects of the concept map are valid has been criticised, and doubt has been expressed whether one can be consistent in such a determination (Kinchin, 2001). Generally, this form of quantitative approach has been criticised (Caine & Caine, 1994; White & Gunstone, 1989). Importantly, it has also been pointed out that teachers may adopt concept mapping as a means of forcing the learners' perceptions — in other words 'teach to the test' — to fit the received correct true conceptions and may paradoxically serve as the antithesis of the 'human constructivist' that underlies the use of concept mapping (Mintzes *et al.*, 1997).

Chapter 5 Repertory grid analysis: principles, methods and applications to biological natural kinds concepts

> *We can arrange events according to some issue – or construct – placing those to which one pole of the issue is more appropriately applied on the one side and those to which the other pole is more applicable on the other. Having done that, we can scramble the events and rearrange them in terms of another construct. As this rearranging proceeds, each event becomes locked into psychological space in greater depth. That is to say, an event seen only in terms of its placement on one dimension is scarcely more than a mere datum. And about all you can do with a datum is just let it sit on its own continuum. But as the event finds its place in terms of many dimensions of consideration it develops psychological character and uniqueness.*
>
> *Kelly (1969, p. 118)*

Figure 5.1 represents the concept map for this chapter. In Chapter 1, the author introduced George Kelly as the originator of the methodology that is employed throughout this work, namely repertory grid analysis (RGA). In this chapter, Kelly's biography and theory will be outlined as preparatory to the first employment by the author of Kelly's technique. This chapter will introduce the practice of RGA by applying it to a small (n=11) classroom based study of post-primary students' constructions of six specified mammals. This preliminary study will be presented using three forms of RGA, namely, *Bannister-Fransella analysis, Bieri analysis,* and *coordinate grid analysis*.

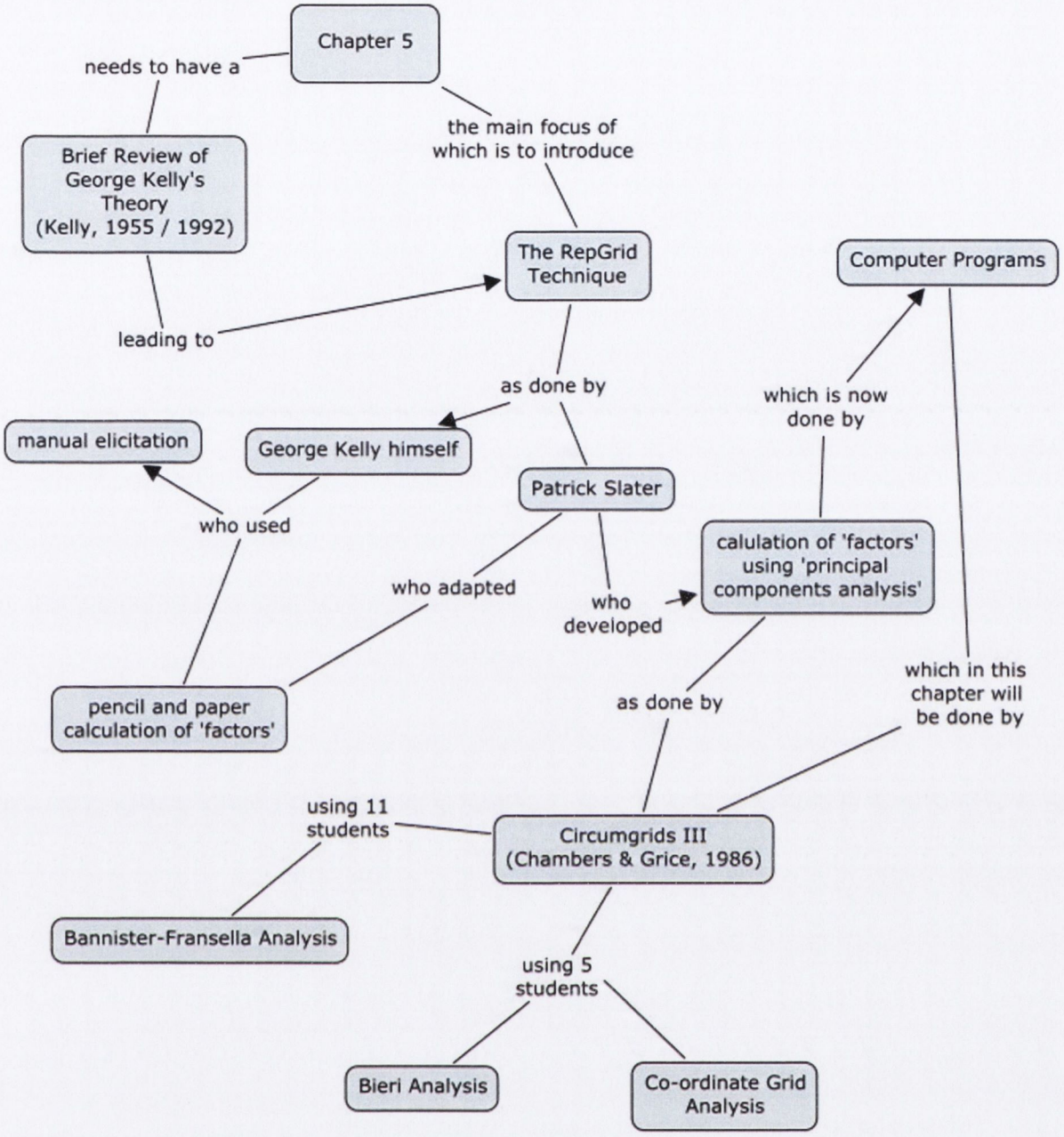

Figure 5.1 A concept map of Chapter 5 done by CMap Tools™

5.1 The work of George Alexander Kelly

Through presenting a brief time-line of G.A. Kelly's life, it is assumed that the theory he was ultimately to produce was influenced in part by his own personal experiences, though it would be purely speculative to suggest how great an influence any one of the experiences had on the formation of his theory.

5.1.1 Biography

George Kelly was born on 28th April, 1905, on a farm near Perth, Kansas. He was the only child of Theodore and Elfleda Kelly. His father, possibly of Irish descent, was originally a Presbyterian minister who had taken up farming on his doctor's advice. His mother was a former school teacher. Because of his father's circumstances, his early education was sporadic and had to be supplemented by his parents. Eventually, he received a bachelor's degree in 1926 in physics and mathematics from Park College, followed with a master's degree in sociology from the University of Kansas. After a number of part-time teaching posts in various states, he received a fellowship to go to the University of Edinburgh, where he received a bachelor of education degree in psychology under Sir Godfrey Thomson. In 1931, he received his doctor's degree in psychology from the State University of Iowa.

During the depression, he worked at Fort Hays Kansas State College, where he developed his clinical techniques. During World War II, Kelly served as an aviation psychologist with the Navy, followed by an academic post at the University of Maryland. In 1946, he left for Ohio State University and became the director of its clinical program. It was here that he wrote his two-volume work, *The Psychology of Personal Constructs* (1955). In 1965, he began a research position at Brandeis

University, where Maslow was working. However, he died soon afterward, on 6th March, 1967.

5.1.2 The origins of Kelly's theory

Kelly had noticed early in his career as a clinical psychologist that scientists and therapists often displayed a peculiar attitude towards people. While they thought quite well of themselves, they tended to look down on their subjects or clients (Boeree, 2006). While they saw themselves as engaged in the fine arts of reason and empiricism, they tended to see ordinary people as the victims of their sexual energies or conditioning histories. But Kelly, with his experience with Kansas' students and farm people, noted that these ordinary people were trying to understand what was going on in their own lives. What truly mattered to these people was that they had an explanation of their difficulties, and that they had a way of understanding them. He discovered that, whereas almost any order and understanding that came from an authority figure was accepted — an interesting fact in itself — order and understanding that came out of the patients' own lives or culture, was even better.

5.1.3 Man[9] as scientist

The fact that Kelly's patients were trying to find ways of understanding themselves, and their perception of the world, struck Kelly as scientific. To consider the 'common man' as a scientist was something of a leap in Kelly's day and his preference to visualise the human being as the scientist is a departure from his colleagues' perception of human beings. Kelly epitomises his colleagues' view of a person as an

---

[9] Here, the term man is used in the generic sense, as it was intended by George Kelly.

organism driven in "*gluttonous pursuit of sustenance and shelter*", whereas the scientist's ultimate aim is to predict and to control. What if the ordinary human being living out his or her life behaves like a scientist having theories, testing hypotheses, weighing experimental evidence? So people, i.e., ordinary people, are scientists, too. The have constructions of their reality, like scientists have theories. They have anticipations or expectations, like scientists have hypotheses. They engage in behaviors that test those expectations, as scientists do experiments. They improve their understandings of reality on the bases of their experiences, like scientists adjust their theories to fit the facts. From this metaphor comes Kelly's entire theory, a metaphor Kelly described as his 'fruitful metaphor'.

Later workers have sought to include the learner under the category of scientists similarly *e.g.* "the pupil as scientist" by Rosalind Driver (Driver, 1983) and "the child as scientist" by Jean Piaget (Oxford, 1997). However, there is some doubt as to whether a child really could be described a scientist in the full sense of the word rather than performing behaviours similar to scientists and approaching naive theories rather than working from fully constructed scientific theories.

Out of these insights, Kelly developed his theory and philosophy. The philosophy he called *constructive alternativism*. Constructive alternativism is the idea that, while there is only one consistent objective reality, reality is always experienced from different perspectives, or *alternative constructions*. Every human has a construction of what the world is like and some constructions are better than others. A teacher's may be better than that of her/his pupils. Yet no-one's construction is ever complete, because the world is too complicated, too big, for any one person to have the 'perfect' perspective. And no-one's perspective is ever to be completely ignored.

Each perspective is, in fact, a perspective on the ultimate reality, and has some value to that person in that time and place. In fact, Kelly says, there are an infinite number of alternative constructions a person may take towards the world, and if one is not doing a very good job, we can take another.

5.1.4 The importance of prior knowledge

Kelly (in the posthumous reprint of his classic work of 1955) states categorically that "all thinking is based in part on prior convictions" (Kelly, 1992, p. 5). This serves as a starting point for constructivist thinking in science education practice, and current perspectives in cognition and learning in general describe the learner as actively and continually constructing internal models of the world which are used in making sense of personal experience (Brook *et al.*, 1989, p. 63). Even before entering formal science education, children have been constructing their own ideas of how they think the world works, and they may have constructed models that provide an alternative explanation to that given in formal science (Driver *et al.*, 1985). When Brook *et al.* (1989) and Driver *et al.* (1985) speak of making sense of experience, the kind of experience they are speaking about is physical, whereas Kelly was concerned with self-perception and social experience (Kelly, 1992). However, whereas such mental domains must be treated differently in processing, there are commonalities across these domains such as:

- experience can be represented,
- prior experience always has some role to play,
- the experience is processed in part by classificatory processes.

5.1.5 The role of sensing and responding

Living things are often described as "sensitive and responsive": one of the so-called Seven Characteristics of Life taught in post-primary biology, in contrast to the non-living thing. Kelly views our psychological faculties as a system of sensing and responding to our environment, constructs being the outcomes of these processes. However, he goes further by stressing the creative capacity of the living thing to represent the environment rather than merely responding to it. Because we can represent the environment we place alternative constructions upon it (Kelly, 1992, p. 6) and if we do not like them we can do something about the situation.

A person can delude themselves in what (s)he may perceive as existing; however, the perception does exist. There is a distinction between what is conceived and perceived: the concept and percept respectively (Kelly, 1992, p. 30). Humans interpret the world through mental filters or templates, which they create in an attempt to fit over the realities of the world. As such, Kelly appears to be mirroring David Marr's thesis of how humans see the world as a scanning iteration of template fitting (Marr, 1982), whereby the fitting of the correct template registers 'recognition'. Yet without such patterns, the world appears to be such an undifferentiated homogeneity that man is unable to make any sense of it. A poor fit is often more helpful than no fit at all.

5.1.6 Constructs and elements

Kelly gave the name *constructs* to those patterns that are tentatively used as ways of construing the world and which enables humanity and other animals to chart a course of behaviour. In general humans seek to improve their understanding of the world by

increasing their repertory or repertoire of constructs; by altering them to provide better fits and by subsuming them with superordinate constructs or systems (Kelly, 1992, p. 7). The more constructs held, the more accurate and fine-tuned the recognition of features concerning the world becomes; a fact particularly relevant to BNKCs[10].

A construct is a representation of the universe, a representation manufactured by a living creature and then tested against the reality of the universe. The universe is essentially a course of events, in which entities are encountered and experience is challenged: the testing of a construct is a testing against the re-occurrence of such events, the entities encountered during those events and the way in which experience is confronted. A construct which is more viable than others has a higher predictive efficiency (Kelly, 1992, p. 9). But there are times when a person hesitates to experiment because (s)he dreads the outcome, with the fear that the conclusion of the experiment would place him/her in ambiguous position when (s)he would not any longer be able to predict and control. Kelly, somewhat flippantly restated this fear as being caused by those in a situation where *'he does not want to be caught with his constructs down'*.

Kelly (1992, p. 95) defined elements as *'the things or events, which are abstracted by a construct'*. In other words, if I have a construct *zebra*, the *zebra* has things that characterise it such as *stripes*, but they are abstracted in that any *stripes* will not do, they must be a special sort and have some relevance to *zebra*.

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[10] Biological natural kinds concepts; *cf.* Chapter 2

5.1.7 The geometry of psychological space

George Kelly's background in mathematics, coupled with a particular interest in multi-dimensional geometry and experience in navigation, lead him to formulate his theory in terms of Euclid's Elements. Kelly summarised his theory in a Euclidian paradigm with the *fundamental postulate* and *eleven corollaries*, terming the primitives involved *elements* and *constructs*. Thus Kelly presented his theory as a geometry of psychological space (Kelly, 1969). *The Fundamental postulate* is that *a person's processes are psychologically channelized by the ways in which he anticipates events* (Kelly, 1992, p. 46). Subject to this postulate are the eleven corollaries, which apply in part to this thesis. To start with, the construction corollary (Kelly, 1992, p. 50) states that *a person anticipates events by construing their replications*. However, constructions and their replications can change over time or adaptively as expressed by the experience corollary: *a person's construct system varies as (s)he successively construes the replications of events*. Recognising BNKCs involves anticipation to the extent that if the creature represented were to be in the presence of the recognising subject, the subject anticipates the behaviour, risk and consequences of engaging with the creature that informs her/his recognition. Furthermore, this process differs from person to person, thus the individuality corollary states that *persons differ from each other in their constructions of events*. However, there are similarities to other peoples' constructions; hence the commonality corollary: *to the extent that one person employs a construction of experience which is similar to that employed by another her/his psychological processes are are similar to those of the other person*.

The taxonomic, abstraction, or subsumption, hierarchy between concepts is Kelly's (1992) organisation corollary: each person characteristically evolves, for his convenience in anticipating events, a construction system embracing ordinal relationships between constructs. Constructs are constrained by a number of factors which may be global in that most people have them and individual, consistent with the individuality corollary, in that they are specific to one person; hence the modulation corollary: the variation in a person's construction system is limited by the permeability of the constructs within whose range of convenience the variants lie. Figure 5.2 shows the main features of Kelly's idea of psychological space. A construct is a dichotomous reference axis. It defines a family of planes orthogonal to it that divide the space whereas this division defines the dichotomous poles of the construct: each construct involves two poles, one at each end of its dichotomy and even though Kelly's geometry is not metrically defined, he has no problem in using the defined constructs to generate a metric (Shaw & Gaines, 1995).

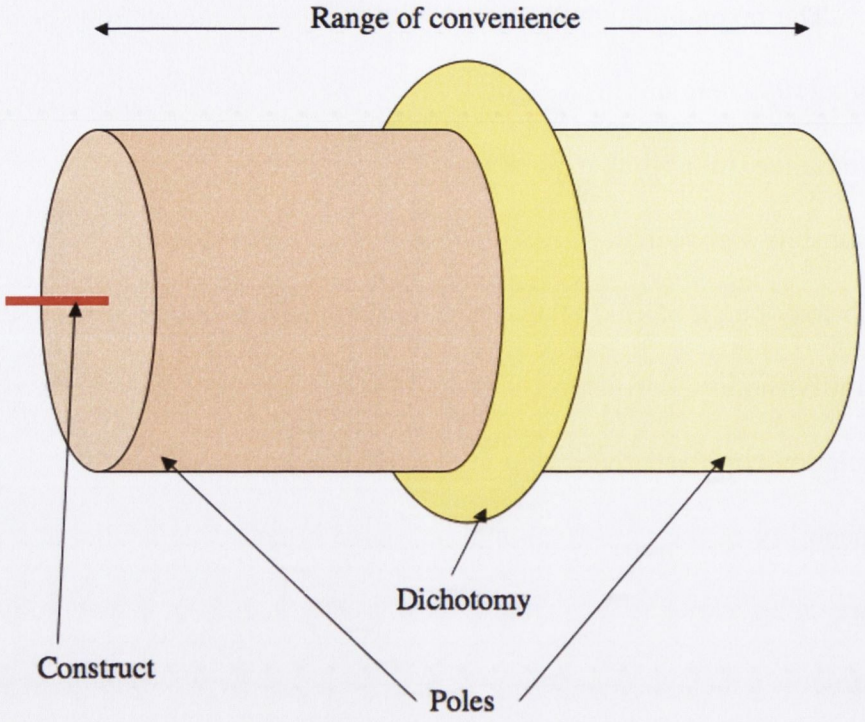

Figure 5.2 The structure of Kelly's psychological space

The range of convenience is the 'area' between two orthogonal planes to the construct axis. The range of convenience can, in effect, be used as a scale where a series of orthogonal planes form the points on the scale. Thus the dichotomy, itself an orthogonal plane, is the point midway between the poles of a construct. For example, the following construct can be envisaged with two poles and the symbol | denoting the dichotomy between the poles:

Horse ------|------ *Not Horse*

(*i.e.*, that which is horse-like) (*i.e.*, that which is not horse-like)

On the axis, a scale which is usually a ranking scale, can be placed:

Horse *1-2-3-|-4-5-6* Not Horse

(*i.e.*, that which is horse-like) (*i.e.*, that which is not horse-like)

However, only one rank is allotted per orthogonal plane, which are defined by the elements such as *general horse shape* as displayed below, thus the rank allocated to a point on a scale is a measure of the relevance of a defining feature to the construct:

General horse shape

Horse 1----|----- *Not Horse*

(*i.e.*, that which is horse-like) (*i.e.*, that which is not horse-like)

The example above is, in effect, a propositional statement or statement of intensional logic: *general horse shape* is the element that best characterises the construct *horse*. An iterative succession of similar propositional statements concerning a number of elements will generate a table of ranks until ultimately a matrix or *grid* is formed.

5.1.8 Grids

The term *grid* is used in a number of ways in different contexts, for some, 'grid' is a generic term for a number of rating-scale protocols (Jankowicz, 2004) or as a way of bringing mathematics into psychological theory, a means of expressing Kelly's theory of personal constructs in action (Fransella *et al.*, 2004). Physically, it represents a table of numbers characterised by columns and rows. The numbers may represent ratings, ranks or scores of relevance or the column to row signifiers (Table 5.1). In Table 5.1, the elements are titular to the columns and the constructs are titular to the rows, though this is not an absolute rule — the opposite may be done. In this example each element is ranked once against each construct; thus, in each column only one 1,

2, 3, 4 and 5 appears. For each construct, the elements can occupy the same rank; thus for *Construct 1*, *Element 2* and *Element 3* both occupy the rank of 4 and it happens that none of the elements gain a rank of 5. Some protocols insist on one rank per cell in a row or column or both; furthermore some protocols allow some cells to remain unranked, however this latter case may have implications for computer software dealing with the table as a single mathematical entity, *i.e.*, a matrix. A repertory grid can be *thought* to be simply a set of ratings, but only as an expedient mental device. A grid is a representation of the relationships between elements and constructs and whereas concept maps tend to represent relationships of the 'IS A' type, repertory grids represent relationships that define the degree of 'IS A', thus, an example from Table 5.1 could be: *Element 2 or Element 4* is most important in characterising *Construct 2*. We can say this because on the second row, the ranks given under element 2 and element 4 are both '1', *i.e.*, the highest rank.

Table 5.1 *An example of a completed grid*

	Element 1	Element 2	Element 3	Element 4	Element 5
Construct 1	3	4	4	2	1
Construct 2	2	1	2	1	3
Construct 3	5	2	1	5	5
Construct 4	1	3	3	3	2
Construct 5	4	5	5	4	4

In addition, because the rating system defines a rank order, then there is judgement of the other elements. To state that one thing is 'most important' is an evaluation that the other things are not so.

5.1.9 Kelly's repertory grid method

George Kelly's method for carrying out repertory grid analysis will be given different treatments in this chapter. In this section, a simplified manual method for deriving a completed repertory grid (or "RepGrid" as they are commonly called) is outlined as a stepwise protocol (after Anon., 2006a). How the grid is analysed will not be dealt with here because Kelly was working before the advent of computer facilitated statistical packages and his manual method of calculating 'factors' was not used in this thesis; it is however outlined in Appendix 5.1.

Step 1. The individual or group begins with an empty repertory grid (Figure 5.3), pen or pencil, and between five to eight blank index cards.

	Element 1:	Element 2:	Element 3:	Element 4:	Element 5:
Construct 1:					
Construct 2:					
Construct 3:					
Construct 4:					
Construct 5:					

Figure 5.3 An empty grid

Step 2. Then the elements are written across the top of the grid.

Step 3. After this, the subjects write numbers on one side of the cards, which correspond with the elements at the top of the grid.

Step 4. The cards are turned face down, shuffled, and then three cards are drawn at random.

Step 5. The subject(s) mark on the grid which three elements were drawn with an "X". They then decide: "*Out of the three elements chosen, which two seem to have something more in common with each other?*" These two elements are connected with a line.

Step 6. Always on the left side of the grid, the subject will describe what aspect these two elements share. On the right side, they will express what it is that makes the third element different from the other two. (If this is too difficult, people are allowed to write something they believe to be the opposite of the left hand construct).

Step 7. Finally, the elements are rated to the constructs. Each element is rated to the constructs on a scale of one to five, for example, with the left construct as "1" and the right construct as "5".

Once the first row has been rated, the individual or group turn the three cards over, shuffle them, and begin the process all over again. They may reshuffle in the case of drawing the same three-card combination as before.

The outcome of this procedure is a table of integers called a matrix or grid as discussed before.

5.2 Slater's repertory grid method

Fransella *et al.*, (2004, p. 93) relate how Patrick Slater published a monograph entitled: "The principal components of a repertory grid" (Slater, 1964) based on matrix algebra and co-ordinate geometry. They believe that the title is misleading since 'principal components' is a generic term and that what is actually done is 'Singular Value Decomposition' (also known as Eckart-Young Decomposition) which by definition is a form of principal components analysis of correlation matrices. However, the importance of Slater's work was that he was the first to see that this mathematical procedure could be applied to Kelly's RepGrid data, and his method of analysis became the 'gold standard' of research and practice using Repertory Grids (Fransella *et al.*, 2004, p. 94). Further, a two-dimensional spatial representation of the constructs and elements became, and remains, the accepted way of viewing the grid.

Slater (1972) discusses and demonstrates that the scatter of elements plotted in construct space can have an ellipse fitted around the cluster even when random numbers are used, in reality this means that the values of the elements are changed into co-ordinates and the constructs form the axes. He points out that the main problem to be overcome in doing this is where to place the origin which is be subject to a mathematical rule (Slater, 1972). The methods investigated in this thesis aim to derive graphical and structural representations of scientific thought and specifically the schema of classification that typically involves the elicitation of numerical data so that a grid or matrix is constructed. The graphics produced are technically known as Representations of Singular-Value Decompositions.

Whereas Kelly's original grid employed binary data involving ticks and blanks as described in the previous section, work subsequent to Kelly uses data in the form of

ranks or scores based on perceived similarity or relevance of each construct to each other or to an internalised, or perhaps idealised, norm. The author was interested in the associations between the constructs and specifically the associations made by science learners. Kelly used the number of ticks and blanks that matched as a measure of association. Association is a special form of classification and RGA can be used to study the associative frameworks that exist in the minds of the learners, of which one type is classification.

5.3 Distinguishing a non-equid from equids

5.3.1 Elicitation of constructs

The first step in RGA and related techniques is the elicitation of the constructs and elements. Typically this is in the course of an interview but other means can be employed, such as a questionnaire. The latter method was chosen in this research because large numbers of subjects, *i.e.*, large class groups of students, were employed in the project and attempting to interview such a such number of students would have created logistic problems in the schools used for this study. A further consideration is the ethical constraint of interviewing children one-to-one. In one school, this is prohibited and all students must be accompanied by at least one peer. Thus, the student sample would have been halved since the chaparone would have obtained information in listening to the interview of his peer that would have rendered his/her interview as invalid. However, in the early stage of the project a small number (n=11) were asked if they would volunteer during a 5th year (16/17 years old) to take part in the study.

George Kelly originally developed repertory grid analysis as an interview technique. However, Kelly was attempting to uncover psychiatric patients' alternative roles and the relationships between the repertoire or repertory of 'roles' of key figures in the patients' lives. This requires in depth interviewing during hour-long consultations. In this thesis, the author had permission to enter classrooms and administer questionnaires during a science class period. Permission for in-depth interviews would not have been granted. However, the seemingly impoverished data obtained from students was relatively rich and principal components analysis ensures that key data is not lost during 'reduction'. Factors such as these influenced the author to choose questionnaires over interviews; however, the questionnaires were designed in such a way that they were a printed form of interview. One final point is that Circumgrids III operated as an interactive interview scenario, but as stated above, only eleven students were used in this study.

Besides making the interview versus questionnaire choice, the researcher has to choose the mode of elicitation of the constructs and elements. Table 5.2 lists some methods. In this part of the project, a series of discussions with the students had taken place on what constituted a mammal, and specifically, a horse as opposed to other mammals. One part of the discussion had been on whether horses ever have stripes in any way similar to a zebra. One of the students, *ACSCL5*, was an equestrian: this fact was used to infer that she had some expert knowledge concerning horses obtained outside of school. *ACSCL5* was able to correct the misconceptions of her peers in producing photographs of horses and donkeys with stripes on their legs. This phenomenon is also discussed in Darwin's *Origin of the Species* (Darwin, 2001). She was also able to elude to the presence of a vestigial hoof in the inside leg of the horse

called a chestnut but was not able to say for sure if other equids possessed them. The discussion on stripes echoed Keil's study with younger children on transformations concerning tigers and what happens if a child is presented with a picture of a tiger minus its stripes (Keil, 1996). Later, a study was designed that involved a questionnaire taking account of such perceptually dissonant creatures. It is an interesting question of how humans work through such dissonance when presented with an unusual perceptual stimulus.

Table 5.2 *Means of deriving the concepts and features used in a RGA study.*

Elicitation of concepts	Elicitation of features
Provided by facilitator	Provided by facilitator
Concepts brainstormed	Provided by facilitator
Concepts picked from a list	Provided by facilitator
Concepts brainstormed	Features picked from a list
Concepts brainstormed	Features brainstormed
Concepts picked from a list	Features picked from a list
Concepts picked from a list	Features brainstormed
Provided by facilitator	Features picked from a list
Provided by facilitator	Features brainstormed
Triadic system: presented with three concepts or features and prompted to pick the odd one out. The reason why the odd one out is different from the other two frames a description of a feature.	Triadic system: presented with three concepts or features and prompted to pick the odd one out. The reason why the odd one out is different from the other two frames a description of a feature.

In the description of the studies that follow, the constructs were exclusively provided by the facilitator; however the elements were derived from an exhaustive process of eliciting ideas from the students concerning characteristic features of horses and their allies, *i.e.*, members of family *Equidae*, commonly called 'equids', a more correct term than 'equid'. Thus the following list of features was drawn up partially used in the first study 'of 5 equids and a goat' and fully in the 2nd study 'of equids'.

5.3.2 Bannister-Fransella analysis

Bannister-Fransella analysis is a comparison of the same elements and constructs of two grids. It is so-named after its progenitors Don Bannister and Fay Fransella whose

work was firmly grounded in clinical psychology and who were instrumental in applying the theory of personal construct psychology arising from George Kelly's work.

In this study, Circumgrids III (Chambers & Grice, 1986, 1987), a freeware MSDOS programme, was employed to elicit grids and perform the analyses. The students used the computer on an individual basis with the author checking periodically that the students were using the program properly.

A small classroom-based study resulting from questionnaire based work was devised that sought to examine science learners' (n=11) conceptions of a group of living kinds that belonged to an overall essence-founded concept of equid. In this study the constructs *horse, pony, donkey, mule, zebra* and *goat* were given to the students. It was hypothesized that the students would (i) clearly distinguish goat from the other animals; and (ii) would show a variation in the way they distinguished between the four equids. Thus, the study was used to discover if these two hypotheses could be reflected in the structure of the students' grids and in their subsequent analysis.

The program prompts the user for a number of details as listed in Table 5.3 .

Table 5.3 *Information given to each student on a 'crib' sheet to enter into the Bannister-Fransella program*

Input Required	Responses given by each student
Number of constructs	6
Names of constructs	horse, pony, donkey, mule, zebra, goat
Number of elements	6
Names of elements	Stripes, thick neck, hardly any mane or tail, horse shape, chestnut, short face or small head
Y/N data to be entered interactively	Y

Once this information is entered, the learner is asked to type the letter that is most '...' (A construct is named here). This is repeated for each construct to produce a matrix, which can be represented in a simple table or spreadsheet. The procedure is then done a second time, since recall that this analysis is to compare two grids. The raw grids are presented in Tables 5.4, 5.7, to 5.16 for the eleven students respectively. Table 5.5 and Table 5.6 display parts of the output for one student ACSBF5.

Table 5.4 *The grids produced by ACSBF5*

	Element 1: stripes	Element 2: thick neck	Element 3: hardly any mane or tail	Element 4:horse shape	Element 5: chestnut	Element 6: short face or small head
Construct 1: horse	6	3	5	1	2	4
Construct 2: pony	6	3	5	1	4	2
Construct 3: donkey	6	2	5	1	3	4
Construct 4: mule	6	3	4	1	2	5
Construct 5: zebra	1	4	5	2	6	3
Construct 6: goat	6	2	3	5	4	6
Construct 1: horse	6	3	5	1	2	4
Construct 2: pony	6	2	4	1	3	5
Construct 3: donkey	5	2	5	1	3	4
Construct 4: mule	6	3	5	1	4	2
Construct 5: zebra	1	3	5	2	6	4
Construct 6: goat	6	4	3	5	2	1

There are two things that can be done with these grids: one, they can be visually scanned to see where the difference in ranks are for respective constructs or elements. And, second, a difference matrix can be produced (Table 5.4) by subtracting cell b_{rc} from a_{rc} where a and b are the contents of the cell in the first and second test and rc are the row and column numbers, so that one subtracts the contents of the cell of the first row in the first column in test 2 from the contents of the cell of the first row in the first column in test 1.

Table 5.5 *Difference matrix for ACSBF5*

0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	1.00	0.00	1.00	-3.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	-1.00	0.00	-2.00	3.00
0.00	1.00	0.00	0.00	0.00	-1.00
0.00	-2.00	0.00	0.00	2.00	5.00

Table 5.5 provides an immediate appraisal of which constructs or elements are treated most consistently by the learner and which forced a re-think before or during the second administration of the test. In three cells in Table 5.5, an extreme difference of three was found in three cells, at the intersection of *pony* and *short face; mule* and *short face;* and *goat* and *short face*. Furthermore the program calculates the sums of the absolute differences of the rows, columns and the total of the absolute differences (Table 5.6).

Table 5.6 *Sums of the differences*

Sums of the absolute differences of the rows	0.00	6.00	0.00	6.00	2.00	9.00
Sums of the absolute differences of the columns	0.00	4.00	2.00	0.00	5.00	12.00
Total of the absolute differences	46.00					

Table 5.6 indicates the constructs with the greatest instability with ACSBF5, namely, *goat* at 9.00, *pony* at 6.00 and *mule* at 6.00. One possible hypothesis was that *pony* and *mule* were the most variable of constructs, and difficult to characterise, because *pony* is a variant of *horse* itself, and thus difficult to distinguish from it using the limited elements provided; and *mule* is a hybrid of *horse* and *donkey*. *Goat*

carried the highest absolute difference indicating that this construct caused the greatest difficulty in rating, hardly surprising since the element array was generated around the concept of equids. These differences cannot be treated as if it were a score; it is merely the sum of the differences of the rows and because all the cells of the original grids are used, then when a change occurs in one place there is a corresponding change in another.

Table 5.7 *The grids and difference matrix produced by ACSSG5*

	Element 1: stripes	Element 2: thick neck	Element 3: hardly any mane or tail	Element 4:horse shape	Element 5: chestnut	Element 6: short face or small head
Construct 1: horse	6	3	5	1	2	4
Construct 2: pony	6	3	5	1	4	2
Construct 3: donkey	5	2	4	1	6	3
Construct 4: mule	6	1	3	2	5	4
Construct 5: zebra	1	3	4	2	6	5
Construct 6: goat	6	4	2	3	5	1
Construct 1: horse	6	3	5	1	2	4
Construct 2: pony	6	3	4	1	5	2
Construct 3: donkey	6	3	4	1	5	2
Construct 4: mule	6	2	4	1	5	3
Construct 5: zebra	1	3	4	2	6	5
Construct 6: goat	6	5	2	3	4	1
Construct 1: horse	0	0	0	0	0	0
Construct 2: pony	0	0	1	0	-1	0
Construct 3: donkey	-1	-1	0	0	1	1
Construct 4: mule	0	-1	-1	1	0	1
Construct 5: zebra	0	0	0	0	0	0
Construct 6: goat	0	-1	0	0	1	0

Table 5.8 *The grids and difference matrix produced by ACSON5*

	Element 1: stripes	Element 2: thick neck	Element 3: hardly any mane or tail	Element 4:horse shape	Element 5: chestnut	Element 6: short face or small head
Construct 1: horse	6	3	4	1	2	5
Construct 2: pony	6	3	4	2	5	1
Construct 3: donkey	6	4	2	1	5	3
Construct 4: mule	6	4	2	1	5	3
Construct 5: zebra	1	3	2	4	6	5
Construct 6: goat	6	4	2	3	5	1
Construct 1: horse	6	3	4	1	2	5
Construct 2: pony	6	4	2	1	5	3
Construct 3: donkey	6	4	2	3	5	1
Construct 4: mule	6	3	2	1	5	4
Construct 5: zebra	1	3	2	4	6	5
Construct 6: goat	6	4	2	3	5	1
Construct 1: horse	0	0	0	0	0	0
Construct 2: pony	0	-1	2	1	0	-2
Construct 3: donkey	0	0	0	-2	0	2
Construct 4: mule	0	1	0	0	0	-1
Construct 5: zebra	0	0	0	0	0	0
Construct 6: goat	0	0	0	0	0	0

Table 5.9 *The grids and difference matrix produced by ACSAS5*

	Element 1: stripes	Element 2: thick neck	Element 3: hardly any mane or tail	Element 4:horse shape	Element 5: chestnut	Element 6: short face or small head
Construct 1: horse	5	3	6	1	2	4
Construct 2: pony	6	1	5	3	2	4
Construct 3: donkey	1	6	5	3	2	4
Construct 4: mule	6	3	5	1	2	4
Construct 5: zebra	1	3	5	2	6	4
Construct 6: goat	6	3	5	1	2	4
Construct 1: horse	6	3	5	1	2	4
Construct 2: pony	5	3	6	1	2	4
Construct 3: donkey	5	2	6	1	4	3
Construct 4: mule	6	3	5	1	2	4
Construct 5: zebra	2	4	5	1	6	3
Construct 6: goat	5	3	6	1	2	4
Construct 1: horse	-1	0	1	0	0	0
Construct 2: pony	1	-2	-1	2	0	0
Construct 3: donkey	-4	4	-1	2	-2	1
Construct 4: mule	0	0	0	0	0	0
Construct 5: zebra	-1	-1	0	1	0	0
Construct 6: goat	1	0	-1	0	0	0

Table 5.10 *The grids and difference matrix produced by ACSFO5*

	Element 1: stripes	Element 2: thick neck	Element 3: hardly any mane or tail	Element 4:horse shape	Element 5: chestnut	Element 6: short face or small head
Construct 1: horse	6	3	4	1	2	5
Construct 2: pony	6	2	4	1	3	5
Construct 3: donkey	6	1	2	4	5	3
Construct 4: mule	6	2	1	4	5	3
Construct 5: zebra	1	4	3	2	6	5
Construct 6: goat	6	3	2	5	4	1
Construct 1: horse	6	3	5	1	2	4
Construct 2: pony	6	4	5	1	2	3
Construct 3: donkey	6	5	2	1	4	3
Construct 4: mule	6	4	1	3	5	2
Construct 5: zebra	1	4	5	3	6	2
Construct 6: goat	6	3	2	4	5	1
Construct 1: horse	0	0	-1	0	0	1
Construct 2: pony	0	-2	-1	0	1	2
Construct 3: donkey	0	-4	0	3	1	0
Construct 4: mule	0	-2	0	1	0	1
Construct 5: zebra	0	0	-2	-1	0	3
Construct 6: goat	0	0	0	1	-1	0

Table 5.11 *The grids and difference matrix produced by ACSSS5*

	Element 1: stripes	Element 2: thick neck	Element 3: hardly any mane or tail	Element 4:horse shape	Element 5: chestnut	Element 6: short face or small head
Construct 1: horse	6	3	5	1	2	4
Construct 2: pony	6	4	5	1	2	3
Construct 3: donkey	6	3	2	1	4	5
Construct 4: mule	6	2	3	1	4	5
Construct 5: zebra	1	2	3	5	4	6
Construct 6: goat	6	5	4	1	3	2
Construct 1: horse	6	3	5	1	2	4
Construct 2: pony	6	3	5	1	2	4
Construct 3: donkey	6	4	2	1	3	5
Construct 4: mule	6	3	5	1	2	4
Construct 5: zebra	1	3	5	4	2	6
Construct 6: goat	6	5	3	1	4	2
Construct 1: horse	0	0	0	0	0	0
Construct 2: pony	0	1	0	0	0	-1
Construct 3: donkey	0	-1	0	0	1	0
Construct 4: mule	0	-1	-2	0	2	1
Construct 5: zebra	0	-1	-2	1	2	0
Construct 6: goat	0	0	1	0	-1	0

Table 5.12 *The grids and difference matrix produced by ACSTK5*

	Element 1: stripes	Element 2: thick neck	Element 3: hardly any mane or tail	Element 4:horse shape	Element 5: chestnut	Element 6: short face or small head
Construct 1: horse	5	4	6	1	3	2
Construct 2: pony	6	4	5	1	3	2
Construct 3: donkey	5	3	6	2	4	1
Construct 4: mule	2	6	5	1	4	3
Construct 5: zebra	1	3	4	2	6	5
Construct 6: goat	5	1	6	4	3	2
Construct 1: horse	5	4	6	1	3	2
Construct 2: pony	6	4	5	1	3	2
Construct 3: donkey	6	3	5	1	4	2
Construct 4: mule	6	5	3	1	4	2
Construct 5: zebra	1	5	4	2	6	3
Construct 6: goat	6	1	5	3	4	2
Construct 1: horse	0	0	0	0	0	0
Construct 2: pony	0	0	0	0	0	0
Construct 3: donkey	-1	0	1	1	0	-1
Construct 4: mule	-4	1	2	0	0	1
Construct 5: zebra	0	-2	0	0	0	2
Construct 6: goat	-1	0	1	1	-1	0

Table 5.13 *The grids and difference matrix produced by ACSAF5*

	Element 1: stripes	Element 2: thick neck	Element 3: hardly any mane or tail	Element 4:horse shape	Element 5: chestnut	Element 6: short face or small head
Construct 1: horse	6	2	5	1	4	2
Construct 2: pony	6	3	5	1	4	2
Construct 3: donkey	6	2	5	1	4	3
Construct 4: mule	6	2	5	1	4	3
Construct 5: zebra	1	4	5	2	6	3
Construct 6: goat	6	4	5	1	2	3
Construct 1: horse	6	3	5	1	2	4
Construct 2: pony	6	4	3	1	2	5
Construct 3: donkey	6	3	5	1	2	4
Construct 4: mule	6	3	5	1	2	4
Construct 5: zebra	1	4	5	2	3	6
Construct 6: goat	6	3	5	1	2	4
Construct 1: horse	0	0	0	0	0	0
Construct 2: pony	0	-2	2	0	1	-1
Construct 3: donkey	0	0	0	0	0	0
Construct 4: mule	0	0	0	0	0	0
Construct 5: zebra	0	-1	0	0	1	0
Construct 6: goat	0	0	0	0	2	-2

Table 5.14 *The grids and difference matrix produced by ACSLS5*

	Element 1: stripes	Element 2: thick neck	Element 3: hardly any mane or tail	Element 4:horse shape	Element 5: chestnut	Element 6: short face or small head
Construct 1: horse	6	4	5	1	2	3
Construct 2: pony	6	4	5	1	2	3
Construct 3: donkey	6	2	3	1	4	5
Construct 4: mule	6	2	4	5	3	1
Construct 5: zebra	1	4	5	2	6	3
Construct 6: goat	6	2	1	4	3	5
Construct 1: horse	6	4	5	1	2	3
Construct 2: pony	6	4	5	1	2	3
Construct 3: donkey	6	3	5	2	1	4
Construct 4: mule	6	3	4	5	1	2
Construct 5: zebra	1	4	5	2	6	3
Construct 6: goat	6	2	1	4	5	3
Construct 1: horse	0	0	0	0	0	0
Construct 2: pony	0	0	0	0	0	0
Construct 3: donkey	0	0	0	0	0	0
Construct 4: mule	0	-1	-1	1	-2	3
Construct 5: zebra	0	0	0	2	0	-2
Construct 6: goat	0	0	-1	-1	0	2

Table 5.15 *The grids and difference matrix produced by ACSCL5*

	Element 1: stripes	Element 2: thick neck	Element 3: hardly any mane or tail	Element 4:horse shape	Element 5: chestnut	Element 6: short face or small head
Construct 1: horse	5	4	6	1	2	3
Construct 2: pony	5	4	6	1	2	3
Construct 3: donkey	4	1	3	2	6	5
Construct 4: mule	4	1	2	3	6	5
Construct 5: zebra	1	3	2	4	6	5
Construct 6: goat	5	4	2	3	6	1
Construct 1: horse	5	4	6	1	2	3
Construct 2: pony	5	4	6	1	2	3
Construct 3: donkey	5	1	4	2	6	3
Construct 4: mule	5	2	1	4	6	3
Construct 5: zebra	1	5	2	3	6	4
Construct 6: goat	5	3	1	4	6	2
Construct 1: horse	0	0	0	0	0	0
Construct 2: pony	0	0	0	0	0	0
Construct 3: donkey	-1	0	-1	0	0	2
Construct 4: mule	-1	-1	1	-1	0	2
Construct 5: zebra	0	-2	0	1	0	1
Construct 6: goat	0	1	1	-1	0	-1

Table 5.16 *The grids and difference matrix produced by ACSLG5*

	Element 1: stripes	Element 2: thick neck	Element 3: hardly any mane or tail	Element 4:horse shape	Element 5: chestnut	Element 6: short face or small head
Construct 1: horse	6	3	5	1	2	4
Construct 2: pony	6	2	4	1	3	5
Construct 3: donkey	6	4	3	1	2	5
Construct 4: mule	6	3	5	1	2	4
Construct 5: zebra	1	3	6	2	5	4
Construct 6: goat	6	4	1	2	5	3
Construct 1: horse	6	3	5	1	2	4
Construct 2: pony	6	5	3	1	2	4
Construct 3: donkey	6	3	2	1	4	5
Construct 4: mule	6	3	5	1	2	4
Construct 5: zebra	1	3	6	2	5	4
Construct 6: goat	6	2	1	5	4	3
Construct 1: horse	0	0	0	0	0	0
Construct 2: pony	0	0	1	0	-1	0
Construct 3: donkey	-1	-1	0	0	1	1
Construct 4: mule	6	2	4	1	5	3
Construct 5: zebra	1	3	4	2	6	5
Construct 6: goat	6	5	2	3	4	1

5.3.3 Discussion of the grids

Because no two grids are identical, *i.e.*, no-one achieved a *total of the absolute differences'* score of zero, the grids allude to the constructivist idea whereby the sentient being is constantly constructing and reconstructing their understanding. The *sums of the absolute differences of the rows*, i.e., constructs, and the *sums of the absolute differences of the columns*, i.e., elements, give an idea where students' greatest degree of inconsistency between the two tests lies. Certain constructs emerge as proving difficult to process, i.e., having the greatest sums of the absolute differences of the rows. These are typically *pony, donkey* and *mule*. The largest *sums of absolute differences of the rows* and *columns* were produced by *ACSBF5* who was diagnosed with ADHD and was known to have been prescribed Ritallin™, and *ACSAS5* who had *hydrocephalus* and who had difficulty focussing on academic tasks. The large sums of absolute differences show that these students changed their minds more radically than the other students. To demonstrate actual disordered thought a measure must be used to distinguish a 'change of mind' from flighty thought. Bannister-Fransella analysis calculates two measures which assist the researcher in determining whether the differences in the grids are due to disordered thought or not. They are termed *intensity* and *consistency*.

5.4 Comparing grids

RGA can readily charactarise the structure of a student's conceptual knowledge on an individual basis. In the general educational context of teaching, learning and assessing it is desirable and common practice to perform a group overview and have some norm with which students can be compared.

5.4.1 Intensity and consistency

Each construct can be compared with each other by first calculating Spearman's ρ, Equation 5.1, and ranking the ρs calculated (Table 5.16).

$$\rho = 1 - \frac{6\Sigma d^2}{n^3 - n} \qquad \textit{Equation 5.1}$$

where

ρ = Spearman's *rho*

n = the number of constructs

d = difference in ranks between the two administrations in one comparison

From this the intensity is calculated. Intensity is found manually by Equation 5.2 (Fransella and Bannister, 1977), Spearman's ρ is squared, multiplied by 100 for each comparison and then summed for the whole set of comparisons. The table of the output that forms part of the calculation of the intensities is shown in Table 5.17 . The intensities, I, and consistencies of each subject are given in Table 5.18 .

$$I = \Sigma\left(\rho^2 \times 100\right) \qquad \textit{Equation 5.2}$$

Table 5.17 *A table of the ρs and ranks for both attempts of the procedure for ACSON5 as produced by Circumgrids III*

	TEST 1		TEST 2	
Constructs	rho	Rank	rho	rank
1 - 2	0.77	2.5	0.60	6.5
1 - 3	0.43	8.5	0.60	6.5
1 - 4	0.49	6.5	0.66	4.0
1 - 5	-0.26	14.0	-0.26	14.0
1 - 6	0.09	11.5	0.14	10.0
2 - 3	0.77	2.5	1.00	1.0
2 - 4	0.60	4.0	0.94	2.5
2 - 5	-0.14	13.0	-0.03	12.5
2 - 6	0.54	5.0	0.60	6.5
3 - 4	0.83	1.0	0.94	2.5
3 - 5	0.37	10.0	-0.03	12.5
3 - 6	0.49	6.5	0.60	6.5
4 - 5	0.09	11.5	0.09	11.0
4 - 6	0.43	8.5	0.37	9.0
5 - 6	-0.37	15.0	-0.54	15.0

In general, the more disparate the constructs, thus lowering their correlations, the more complex is the person's construct system. In terming this measure 'intensity', Bannister was drawing on George Kelly, "*for whom a construct used in a 'tight' way was one that leads to unvarying predictions, whereas one used in a 'loose' way leads to varying predictions*" (Fransella *et al.*, 2004, p. 140). However, in order to avoid those with a thought disorder being construed as very cognitively complex, Bannister went further and used the test-retest correlation as a second measure, this he

termed 'consistency'. Table 5.18 also displays these consistencies for the group study. A simple comparative test of means, such as the Student's t-test, of the intensities could form the basis of investigating the learners' changes in thinking (Table 5.19). Notwithstanding the validity of such an approach, more work needs to be done to determine in the first instance the appropriateness of finding the mean of a set of intensities. Rather than develop this further, the author examined the possibility of averaging the grids themselves.

Table 5.18 *Intensity and consistency scores for the subjects produced by Circumgrids III*

Student	Intensity of test 1	Intensity of test 2	Consistency
ACSCL5	423	429	0.88
ACSLG5	375	518	0.92
ACSON5	502	484	0.87
ACSLS5	310	445	0.84
ACSAF5	819	878	0.74
ACSAS5	494	844	0.73
ACSSS5	678	633	0.76
ACSFO5	370	353	0.92
ACSTK5	434	579	0.82
ACSBF5	281	511	0.56
ACSGC5	442	421	0.81

5.4.2 Averaging grids

The original grids produced by Circumgrids III were entered into an Excel spreadsheet and a separate sheet was made for the ranks for each element. The ranks were averaged to produce the average ranks for an element. These were then reassembled to create an averaged grid, shown in Table 5.19.

Table 5.19 *Microsoft Excel output of paired two-tail Student's t-test*

	Test 1	Test 2
Mean	466.18	554.09
Observations	11.00	11.00
Pearson Correlation	0.71	
T Statistic	-2.33	
P value (T<=t) two-tail	0.042	
T Critical two-tail	2.23	

This approach is advocated by Fransella *et al.* (2004) but there must be a considerable loss of detail in finding the average of ranks, and then rounding to one significant figure in order to use this new grid (see Table 5.20). Many of the averaged ranks were of the order of 1.5, which was rounded by convention to 2. A repertory grid programme that allows partial integer ranking needs to be developed; however an alternative would be to set the range of the data as 1-to-11, with alternate ranks being the median ranks. This procedure was done twice because originally there were two tests completed. In the following outputs the averaged grids are displayed, Tables 5.19, and in 5.20.

Table 5.20 *Two grids of the average of the eleven subjects' grids*

	Horse shape	chestnut	neck / throat	face / head	mane / tail	stripes
Horse	1.000	2.455	3.273	3.818	4.818	5.727
Zebra	2.545	5.727	3.273	3.545	4.000	1.000
Pony	1.455	3.091	3.364	2.909	4.636	5.909
Donkey	1.636	4.273	2.636	3.091	3.818	5.182
Mule	1.909	3.909	2.545	3.364	3.545	5.455
Goat	3.182	3.636	3.364	2.182	3.091	5.818
Horse	1.000	2.273	3.182	3.636	5.091	5.818
Zebra	2.455	5.273	3.909	3.545	4.091	1.091
Pony	1.000	3.000	3.364	3.182	4.545	5.818
Donkey	1.364	3.909	2.818	3.091	4.091	5.818
Mule	1.818	3.636	2.909	3.364	3.545	5.909
Goat	2.909	4.000	3.364	2.545	2.909	5.818

Note that in Table 5.20, the numbers are approximate ranks rather than scores and, for the construct *horse, horse shape* is the most important element. For *zebra, stripes* is the most important (and least important with respect to horse). For *pony, horse shape* is most important also, but in the first grid, a 'rank' of 1.455 differentiates it from *horse* (1.000), with *donkey* (1.636) and *mule* (1.909) following. *Goat* had the numerically high 'rank' (3.182) for *horse shape* – its characteristic element being *face/head.* Such a table as Table 5.20 does display a basic form of classificatory information whereby the averaged ranks can be used to specify a level of similarity. We see that *zebra* and *goat* are outliers, *zebra* because of the constraining effect of *stripes*, and the *goat* because of its non-equid perception; the other equids have a broad similarity and are relatively difficult to separate using the

elements provided. It is recommended for later work, as we shall see, that the tabular data be represented in a visual way that does not impinge on the richness of the original data.

Table 5.21 *Two averaged grids rounded to one significant figure*

	Horse shape	chestnut	neck / throat	face / head	mane / tail	stripes
Horse	1	3	3	4	5	6
Zebra	3	6	3	4	4	1
Pony	2	3	3	3	5	6
Donkey	2	4	3	3	4	6
Mule	2	4	3	3	4	6
Goat	3	4	3	3	2	6
Horse	1	2	3	4	5	6
Zebra	3	5	4	4	4	1
Pony	1	3	3	3	5	6
Donkey	1	4	3	3	4	6
Mule	2	4	3	3	4	6
Goat	3	4	3	3	3	6

The averaged grids (Tables 5.20 – 5.21) were produced using the Banister-Fransella data, which consists of integers only that allows only one numerical rank per element, whereas other programs such as RepGrid 2.0 allows multiple allocations of elements to a single ranking position on a *construct – not construct* axis. In Bannister-Fransella analysis, there is a forcing of ranking, the student must enter ranking for all the constructs relative to all the elements, omissions are not permitted. It is possible to build a grid in the Bannister-Fransella style by ensuring one rank integer per element. The rows and columns are ordered so that similar ranks across the rows and columns

are lined-up together. This is a simple visual form of cluster analysis. The first mathematical manipulation of the grids is cluster analysis proper.

5.4.3 Conclusion to Bannister-Fransella analysis

We have see in these brief examples how the researcher may use the Bannister-Fransella analysis for a class group employing the use of a computer package. New information can be generated by some of the outputs while other information may be lost. Thus the researcher must use certain outputs judiciously and be clear what her/his intentions are at the start of the study. The impact of allowing subjects to enter one integer per score versus a freer open scoring and the limitations of averaging the grids produced was discussed. Whereas the elicitation of grids by thinking about the relationship of elements in identifying constructs was examined in Bannister Fransella Analysis, the next section will concentrate on the constructs only. Here constructs are compared against constructs in an analysis called Co-ordinate Grid Analysis.

5.5 Coordinate grid analysis (CGA)

CGA aims to compare construct against construct at first sight, this may seem a simpler procedure than the Bannister-Fransella analysis. However, such a technique was not thought of until long after Kelly's original method. Coordinate grid analysis was invented in the early 1980s by Bill Chambers (Grice, 2003). However CGA has received surprisingly little attention except in a small number of papers discussing the technical performance of CGA (*e.g.*, Grice & Hopper, 2002). CGA is a repertory grid procedure in which the person completing the grid ranks a set of constructs in terms of their general similarity to one another. Each of the constructs is ranked against all the constructs. Of the original set of eleven students, six carried out the CGA, and they performed the analysis with the assistance of the information provided in Table 5.22 .

Table 5.22 *Information given to each student on a 'crib' sheet to enter into the coordinate grid program*

Input Required	Responses given by each student
Number of constructs	6
Names of constructs	horse, pony, donkey, mule, zebra, goat
Y/N data to be entered interactively	Y

The user is then prompted by a series of questions of the form: 'what construct *x* is most like construct *y*?' as follows:

```
Type the letter of the figure or construct that is, in general, most
similar to:  "zebra"
```

This is repeated until each construct has been ranked against each other one. This is a relevance measure since the focus of the question is a construct and that

which is being related to the construct are the other constructs in the array. Table 5.23 shows one such resulting grid which the package labels 'Explicit Ranks: The Grid'. In other words these are the ranks made explicit.

Table 5.23 *An example of a grid produced by ACSLG5 with column sums appended ad posterior*

		a	b	c	d	e	f
a.	Horse	1	5	4	3	6	2
b.	Donkey/ass	3	1	2	5	6	4
c.	Mule	3	2	1	5	6	4
d.	Zebra	3	5	4	1	6	2
e.	Goat	4	2	3	6	1	5
f.	Pony	2	4	3	5	6	1
	Column Sums	16.00	19.00	17.00	25.00	31.00	18.00

5.5.1 Calculation of logical inconsistencies

The CGA part of Circumgrids III then calculates the implicit ranks, Table 5.24, from the table of correlations. Unfortunately, a print-out of the implicit ranks is not part of the output itself. The implicit ranks matrix represents the overall degree of similarity between any particular pair of concepts in the context of the entire grid. As Grice (2003) states, their main purpose is to calculate the logical inconsistencies by subtracting the explicit ranks from the implicit ranks (Table 5.25).

Table 5.24 *Grid of implicit ranks produced by ACSLG5*

		a	b	c	d	e	f
a.	Horse	1.0	5.0	4.0	2.5	6.0	2.5
b.	Donkey/ass	5.0	1.0	2.0	6.0	4.0	3.0
c.	Mule	4.0	2.0	1.0	6.0	5.0	3.0
d.	Zebra	2.0	5.0	4.0	1.0	6.0	3.0
e.	Goat	5.0	2.0	3.0	6.0	1.0	4.0
f.	Pony	2.0	4.5	3.0	4.5	6.0	1.0

Table 5.25 *Logical inconsistencies per rank produced by ACSLG5*

		a	c	c	d	e	f
a.	Horse	0.0	0.0	0.0	-0.5	0.0	0.5
b.	Donkey/ass	2.0	0.0	0.0	1.0	-2.0	-1.0
c.	Mule	1.0	0.0	0.0	1.0	-1.0	-1.0
d.	Zebra	-1.0	0.0	0.0	0.0	0.0	1.0
e.	Goat	1.0	0.0	0.0	0.0	0.0	-1.0
f.	Pony	0.0	0.5	0.0	-0.5	0.0	0.0

A curious feature of CGA is that Table 5.25 is not symmetrical as in the case of a table of correlations. This is because there have been two comparisons in effect and the rank assigned by the student was not the same in both cases.

When the student was asked: `Type the letter of the figure or construct that is, in general, most similar to: "zebra"` if the construct was *horse*, a rank was given by the order the student typed the letter for horse in relation to the *zebra*. However, when the question was: `Type the letter of the figure or construct that is, in general, most similar to: "horse"` the student may not have assigned the same rank when the construct being compared to *horse* was *zebra*.

The Circumgrids III output states, that "a negative number in this matrix means that the construct forming the column has been underestimated in similarity to the construct forming the row. Likewise, a positive number would represent an overestimation of similarity between the two respective constructs". Grice (2003) states that the logical inconsistencies matrix is one of two primary matrices produced by the coordinate grid procedure: the second, the integrative complexity matrix, is discussed on p. 108ff. Chambers (1986) suggests that values departing from zero represent points of conflict in the person's construct system. The fact that inconsistencies occur in this procedure indicates that the students' perceptions of these animals are not perfectly consistent in logical terms and single features may override a computational approach to these constructs. In other words, rather than each construct being perceived as a result of the consideration of many features, one feature takes precedence. As a result, this one feature is different for different constructs when they are compared to each other, *e.g.*, *horse* to *zebra* and *zebra* to *horse*, and an inconsistency arises. As we shall see later in the sections concerning comparing individuals and groups, comparisons are not reciprocal, a *zebra* is horse-like in that a general horse appearance could be true for this comparison; but to say a *horse* is zebra-like might be more difficult since in thinking about *zebra*, stripes is constraining and one wonders how stripes relate to *horse*.

Table 5.26 *Inconsistency sums per row and column*

		Inconsistency Sums Per Row	Inconsistency Sums Per Column
a.	Horse	1.0	5.0
b.	Donkey/ass	6.0	0.5
c.	Mule	4.0	0.0
d.	Zebra	2.0	3.0
e.	Goat	2.0	3.0
f.	Pony	1.0	4.5

The row sums (Table 5.26) can be used to identify concepts that encountered a large number of inconsistencies when they served as the targets during the original grid administration. In calculating the sums, the sign of the inconsistency in Table 5.25 is ignored, otherwise the peculiar situation of gaining an inconsistency sum of zero could occur even when the individual inconsistencies were –4 and 4 and summed. A large row sum could hence signify a particular 'victim' (Grice, 2003) in the grid, that is, a concept that was the target of numerous over- and under- estimates of similarity. The column totals can be used to identify possible 'aggressors' (Grice, 2003) in the grid. These are concepts associated with a large number of inconsistencies when ranked to other targets, *i.e.*, concepts in the original grid administration. Thus in the example here, *donkey/ass* is a victim, and *horse* and *pony* aggressors. A grand total logical inconsistency of 16 is given by the software; this indicates the overall degree of conflict in the coordinate grid. A value of 0 indicates no conflict; but as Grice (2003) states, no norms exist as yet for what constitutes either a particularly high or low logical inconsistency score. The integrative complexity matrix (Table 5.27) is the

second of two primary matrices produced by the CGA as mentioned earlier. As the title implies, the matrix indicates how 'richly' each concept has been integrated into a framework consisting of all the concepts in the grid. Values of zero indicate a rich integration, values departing from zero, not. In this example, consisting mostly of equids, the non-equid, *goat*, shows the least integration (which is not surprising).

Table 5.27 *Integrative complexity per ranks*

		a	b	c	d	e	f
a.	Horse	0	2	1	0	2	0
b.	Donkey/ass	-2	0	0	0	4	0
c.	Mule	-1	0	0	1	3	1
d.	Zebra	0	0	-1	0	0	-3
e.	Goat	-2	-4	-3	0	0	-1
f.	Pony	0	0	-1	3	1	0

Grice (2003) points out that the total integrative complexities (Table 5.28) are more readily interpreted. Here too *goat* stands out as having the least complex integration.

Table 5.28 *Total integrative complexity per construct*

		Total Integrative Complexity per Construct
a.	Horse	5
b.	Donkey/ass	6
c.	Mule	6
d.	Zebra	4
e.	Goat	10
f.	Pony	5

5.5.2 Principal components analysis (PCA)

Principal Axes/Components or Factor Analysis of Correlations can be carried out. It is first important to note that in CIRCUMGRIDS III, principal components analysis is synonymous with the term factor analysis of correlations but this is not the same as factor analysis *sensu stricto*. Principal axes/components analysis (PCA) is a mathematical technique that transforms an original set of variables into a set of uncorrelated variables that represents most of the information in the original set of data, and that may consist of two, three or more uncorrelated variables depending on the original data. This follows from an idea originally conceived by Pearson (1901) and Hotelling (1933); as discussed in Dunteman (1989). Dunteman (1989) states that the technique has been applied to virtually every substantive area including biology, medicine, chemistry, meteorology, and geology, as well as the social sciences. He believes that the goal of PCA is similar to factor analysis (FA); and other multivariate

protocols such as discriminant analysis (DA) and canonical correlation analysis (CCA) (Table 5.29).

Table 5.29 *Table summarizing the key features of four multivariate protocols*

PCA	FA	CCA
Linear combinations of correlated variables. Appendix 5.2 outlines the manual elicitation of trial vectors, which is the first stage of principal components analysis.	May have an underlying statistical model that partitions the total variance. FA is often used to explore data to determine whether a model is at work in the first place.	Linear combinations of correlated variables. Focusses on the relationships between two variable sets, derives a linear composite from each variable set such that the correlation between the two derived composites is maximised.

From Table 5.29, we see that the major difference between PCA and FA, and significant for this current work, is that PCA has no underlying statistical model of the observed variables and focuses on explaining the total variation in the observed variables on the basis of a relatively few underlying factors. The starting point for PCA is the correlation matrix (Table 5.30) that is calculated from the original grid.

Table 5.30 *Correlation matrix*

a.	Horse	0.84	0.09	0.14	0.77	-0.77	0.77
b.	Donkey/ass	0.09	0.89	0.94	-0.14	0.14	0.43
c.	Mule	0.14	0.94	0.90	-0.09	0.09	0.49
d.	Zebra	0.77	-0.14	-0.09	1.00	-1.00	0.43
e.	Goat	-0.77	0.14	0.09	-1.00	1.00	0.43
f.	Pony	0.77	0.43	0.49	0.43	-0.43	0.76

From Table 5.30 the eigenvalues, percent values of the eigenvalues, and eigenvectors are calculated (Table 5.31) and the subsequent principal axes loadings (Table 5.32). Table 5.32 shows three loadings, and PCA may extract many more. However, the author in the main used only the first two. The rationale for this practice is that most of the variance is accounted for by the first two loadings. In Table 5.31, the first eigenvalue (3.06) accounts for 50.96% of the variance and the second eigenvalue (2.13) accounts for 35.49% of the variance. Conventionally, the researcher considers eigenvalues of 1 or more. The third eigenvalue is less than 1 and the percent value of the eigenvalue is relatively very small (5.68%).

Table 5.31 *Eigenvalues, percent values of the eigenvalues*[11]*, and eigenvectors*

	EIGENVALUES	3.06	2.13	0.34
	PERCENT VALUE OF THE EIGENVALUES	50.96	35.49	5.68
		EIGENVECTORS		
a.	Horse	0.52	-0.00	0.44
b.	Donkey/ass	0.09	0.64	-0.29
c.	Mule	0.12	0.64	-0.26
d.	Zebra	0.52	-0.24	-0.40
e.	Goat	-0.52	0.24	0.40
f.	Pony	0.41	0.28	0.58

Table 5.32 *1st, 2nd and 3rd Principal Axes Loadings*

		1st Loading	2nd Loading	3rd Loading
a.	Horse	0.90	-0.00	0.26
b.	Donkey/ass	0.15	0.93	-0.17
c.	Mule	0.21	0.93	-0.15
d.	Zebra	0.91	-0.34	-0.23
e.	Goat	-0.91	0.34	0.23
f.	Pony	0.72	0.41	0.34

Typically, the first and second loadings are plotted as co-ordinates on a Cartesian plane, *i.e.,* Euclidian space (Figure 5.4) – the third are not included or used when the eigenvalue that generated them was less than 1. This has the effect of producing a scatter-graph of the constructs. In Figure 5.4 all the equids appear in the upper right

[11] Properly, this should be the variance rather than "percent value of the eigenvalues".

quadrant, whereas goat appears in a separate quadrant altogether. Here, constructs are typically construed as vectors, so one would manually draw lines through the points and the origin. In this way, donkey/ass and mule form a small cluster close to horse, with zebra and pony as distinct entities – the former, presumably, because of its constraining feature, its stripes – and the latter because in this person, it represented something distinctive.

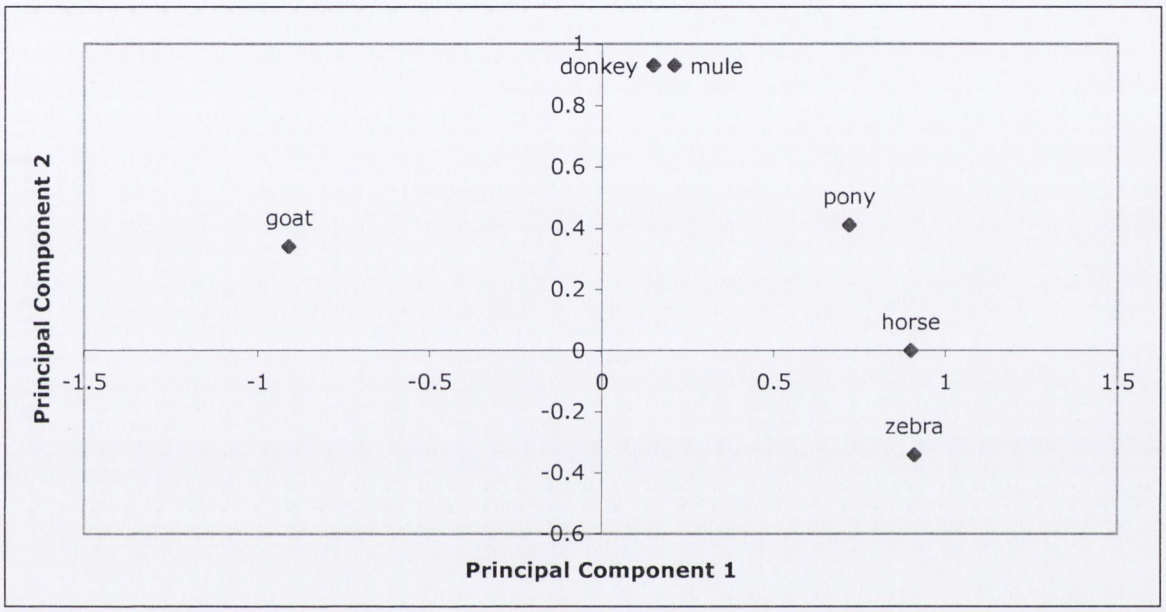

Figure 5.4 Plot of the first and second principal axes loadings (components) as a scatter-graph of ACSLG5[12]

In Figure 5.4, the constructs appear as a spread of points on a Cartesian plane. In interpreting such a diagram, one must follow the rule that comparing differences in position should be done by measuring the so-called City Block Distance. It is important to note that it is the relative positions of the constructs that are important. Note that their absolute positions on the PCA graphs, *e.g.*, *goat* may appear in any of the four quadrants, as can the other constructs. However, in almost all cases, for

[12] drawn in MS EXCEL™

example, the separation of *goat* and *zebra* is very large. In Figure 5.4 *goat* is furthest from the core of equid perception for this person, as expected, who treats *goat* as a very distinct class. Thus the problem with varietals, they may vary so far from the archetype to be rendered distinct. In reality this can actually happen in the genesis of new species. *Pony*, like *zebra*, is also constrained by a single feature; in this case a feature such as *small face* and *thick neck* as significant features, which in turn apply well to *goat*, hence they appear in shared mental space. Figure 5.5 to 5.9 provide further examples of the PCA plots for other students.

Furthermore, the principal components plots can be considered to be a type of concept map – in that key concepts are located in two dimensional space joined by inferences, which, in the case of these plots are 'invisible' being the distances between the plotted points. Thus the plots are also akin to geographical maps in the sense of having landmarks plotted at co-ordinates. The space represented in the Cartesian plane is a psychological space and George Kelly believed that such plots were maps to the mind.

By examining the plots one can infer something about the conceptual structure of the students *e.g.*, in Figure 5.5, the student was not wholly constrained in thinking about the zebra stripes as the *zebra* is part of the broad right hand cluster of the plot. Also, this student placed *mule* with *goat* in the area of the plot furthest away from the representation of equids. In Figure 5.6, the student does the same, but places *pony* and *donkey* in a cluster and creates a third cluster of *zebra* and *horse* (thus *zebra* is not wholly constrained by stripes). In Figure 5.7, the students does not seem to have created a clustered system at all, all the concepts seem dispersed, though *mule* and *donkey* are closest. In Figure 5.8, ACSAN5 produced a more tightly defined plot than

that in Figure 5.4 – the cluster *horse/pony/zebra* is tighter and *donkey/mule* is superimposed. In Figure 5.9, *horse/pony/horse* forms a tight cluster with *goat, zebra* and *mule* forming outliers. This student, then, is expressing a difference in how they think from ACSAN5 but a similarity with ACSTK5 and ACSLG5.

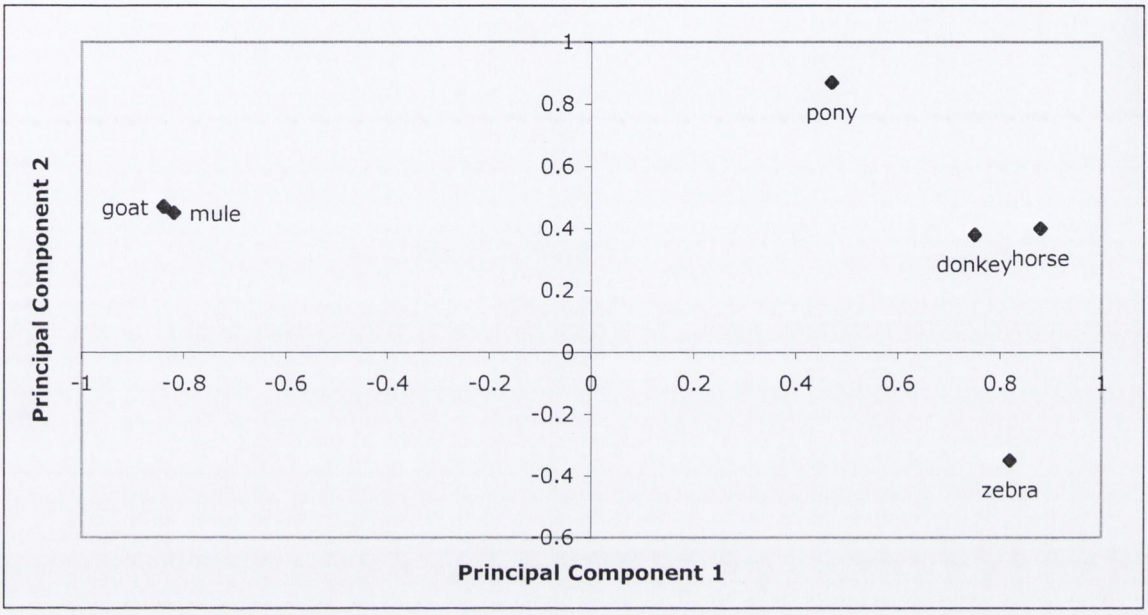

Figure 5.5 Plot of the first and second principal axes loadings (components) as a scatter-graph of ACSTK5

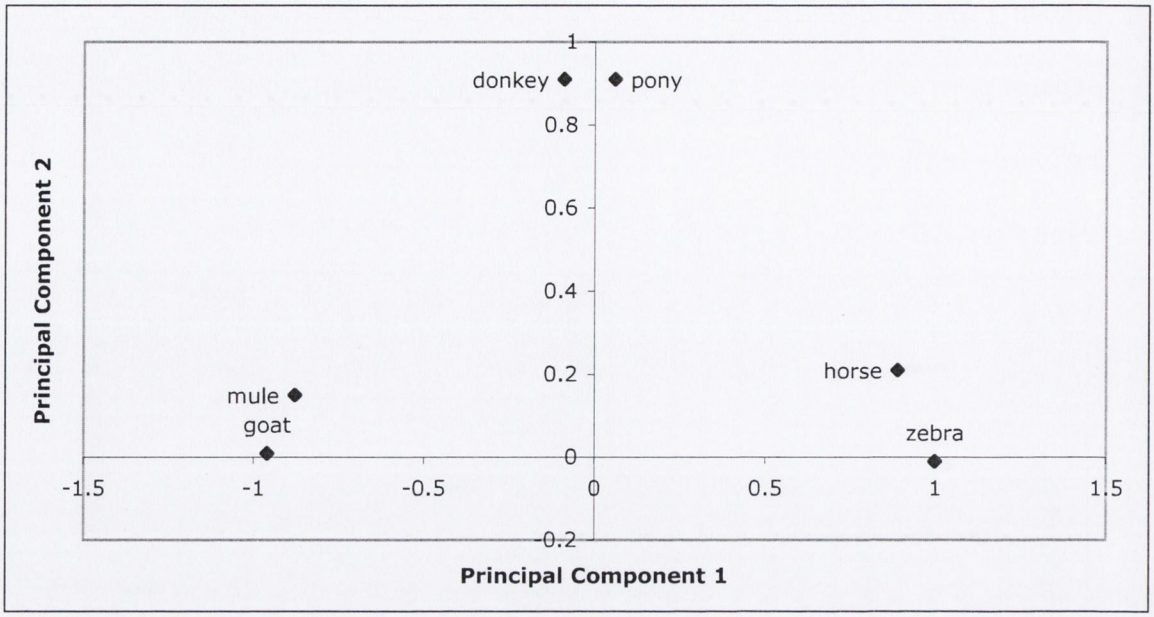

Figure 5.6 Plot of the first and second principal axes loadings (components) as a scatter-graph of ACSAF5

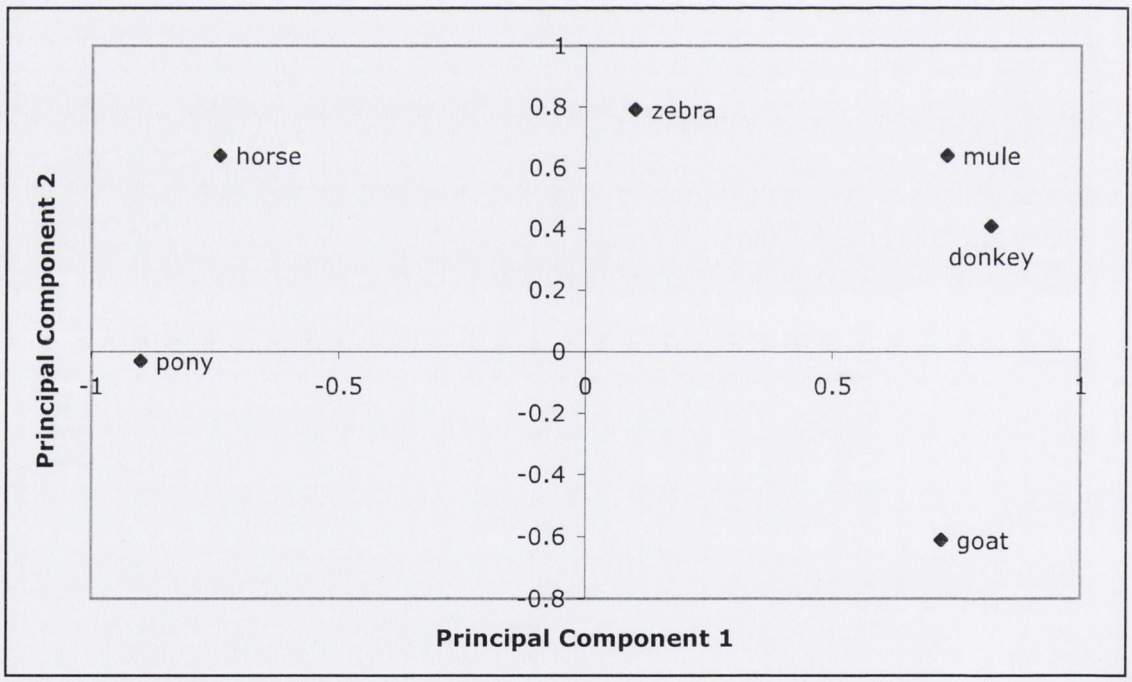

Figure 5.7 Plot of the first and second principal axes loadings (components) as a scatter-graph of ACSLS5

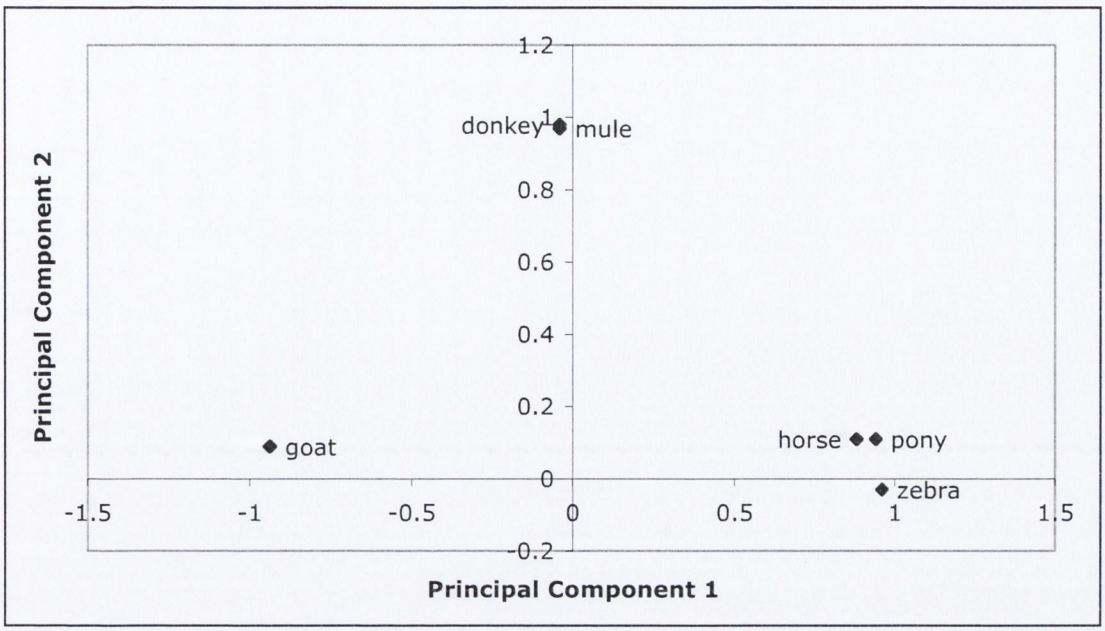

Figure 5.8 Plot of the first and second principal axes loadings (components) as a scatter-graph of ACSAN5

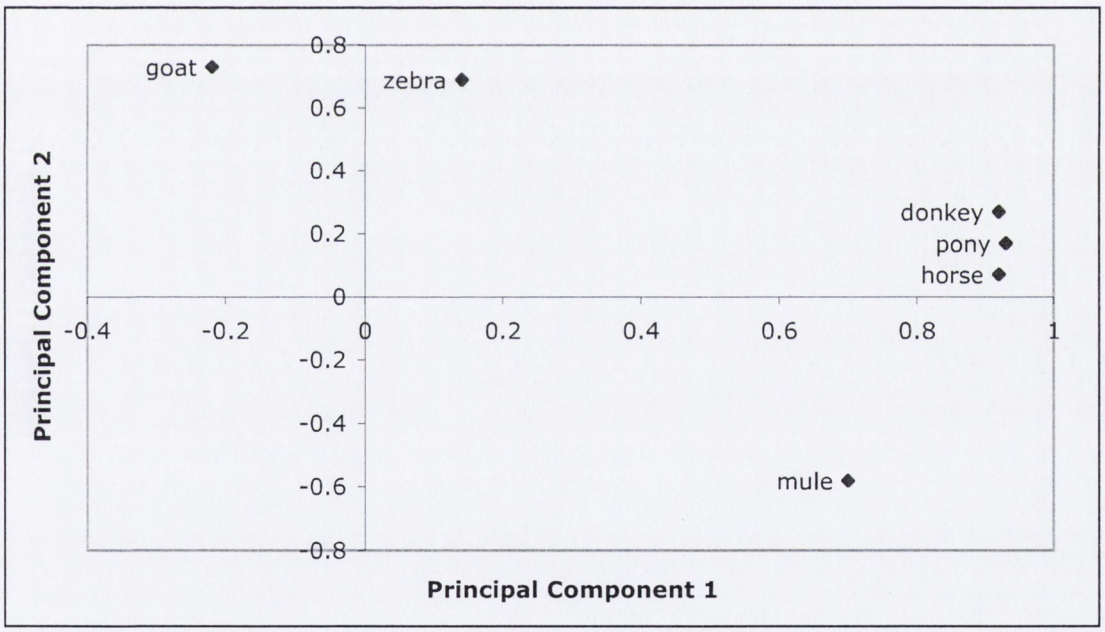

Figure 5.9 Plot of the first and second principal axes loadings (components) as a scatter-graph of ACSON5

5.5.3 Comparing grids in CGA.

In the previous section on Bannister-Fransella analysis, the original grids were averaged and this was deemed undesirable since the resulting decimals had to be

rounded off to 1 significant figure as an integer in order for the 'repgrid' programs to permit data to be entered. Another opportunity for 'averaging', of course is to work out the principal component loadings for each person, and then find the average of the class group to give an overview of the class. A third possibility is to find the city-block distances (Equation 5.3) between the co-ordinates, *i.e.*, loadings of the PCA graphs and plot these on a bar-chart (Figure 5.10). This is the logical conclusion of the PCA method since the positions of the points on the PCA plot are relative. A fuller account of the differences between Euclidean and city-block distances is given in Gärdenfors (2004, p. 17ff).

$$d_c(x,y) = |x_1 - y_1| + |x_2 - y_2| \qquad \textit{Equation 5.3}$$

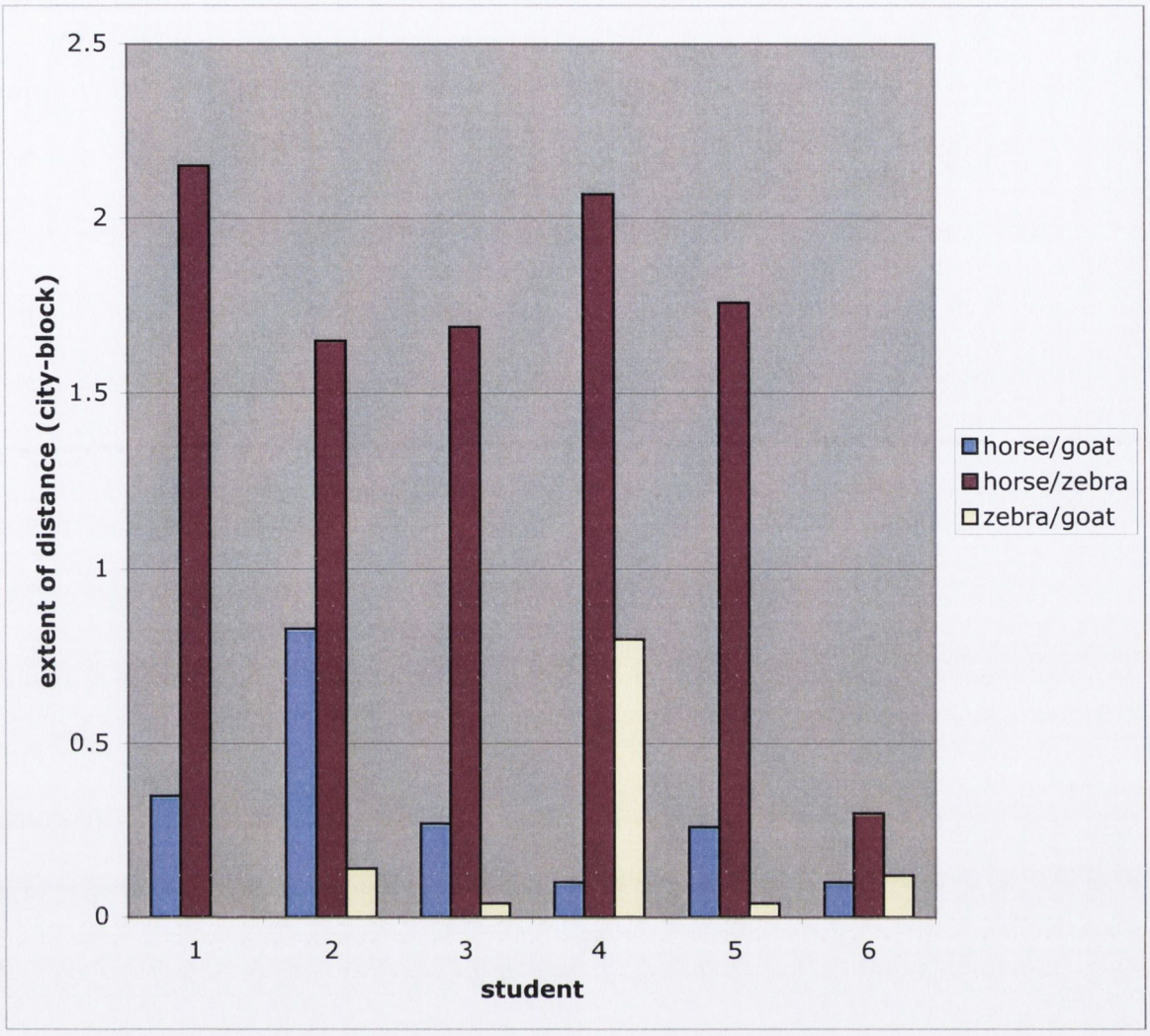

Figure 5.10 Bar-chart of three city-block distance comparisons for six students

The results in Figure 5.10 show that the students conceived of *horse* and *zebra* as being further apart mentally, *i.e.*, considering the terminology of applying Kelly's geometry of psychological space, than *horse* and *goat*. This is evidenced in Figure 5.10 by observing which bar is longest. This can also be verified by examining both the original grids and the plots of principal component loadings. It is thought that this is the result of the constraining effect of *stripes* on the perception of certain animals.

5.6 Bieri analysis

In the previous two sections, two analyses of grids were outlined from the viewpoint that they both elicited different kinds of grids and in different ways. To recap, Bannister-Fransella (BF) analysis asked the student to 'type the letter of the element that is most "*zebra*" (and likewise this is done for all the elements and the other constructs). BF analysis was important in that the practitioner could use this analysis to compare two grids, usually by the same person, to measure the consistency of the grid production. CGA concerned only constructs and asked the student to 'type the letter of the figure or construct that is, in general, most similar to: "*zebra*"'. This is interesting in that here, the living kind is assumed to be perceived as an entire entity or, having a recognisable essence so that an animal-to-animal comparison is made, without first consciously extracting features. BF analysis compared two grids using Pearson's ρ, and calculated two measures, intensity and consistency. CGA performed principal components analysis to produce scattergraphs representing the distribution in mental space of the constructs (and if desired, their features, being the so-called 'elements').

5.6.1 Methodology

The third analysis produces grids of elements against constructs of the $m \times n$ form (where m = elements, n = constructs). It is named after James Bieri, a student of George Kelly who worked intensively in the area of grid theory and practice in clinical psychology (*e.g.*, see Bieri, 1953).

Bieri analysis is a means of eliciting the structure of constructs through ranking elements against constructs. If a construct is envisaged as a line with *zebra*

being one pole and *not-zebra* at the other, "stripes" is placed on this line, the closer it is placed to the zebra end, the more significant this element is to *zebra*. The software prompts for the number of constructs and elements (six in each case in order to keep the task relatively simple for the student), the names of constructs and elements. The subjects typed "yes" to whether the data was to be entered interactively. When prompted for the principal components analysis the options given are for row components, column components, both or none; the subjects chose "both". The student is asked the following question:

'Is stripes zebra' (?)

('*i.e.*, is [element] indicative of [construct]' (?))

This demonstrates the propositional logic of RGA in whatever guise we choose to operate. Earlier, in the discussion on concept map frameworks, it was suggested that concept map frameworks are composed of simple propositional statements such as the 'IS A' type, for example. RGA seeks to elicit such propositional logic by posing simple propositional statements as interrogatives. What is different, and of greater value, is the fact that in RGA a score or rank denotes the 'strength' of the linkage between the two parts of the propositional statement.

A simple Likert scale is produced and the student must move the cursor so that it is at the desired position, and press enter. This question is repeated until each element has been paired against each construct. The program produced a matrix of six rows and six columns (Table 5.33).

Table 5.33 *Grid resulting from ranking elements (column headings) against constructs (row headings)*

	chestnut	Long face	Deep throat	General horse-like appearance	Short mane / tail	stripes
Horse	1	1	2	-1	-1	-1
Pony	-2	2	2	1	-1	-1
Goat	-2	2	2	2	2	-1
Donkey	-2	1	2	1	-2	-1
Mule	-2	2	2	1	2	-1
Zebra	-2	1	1	1	1	1

The Bieri analysis calculates a measure of the complexity of grid, which in this case was '44'. In a class setting, this is another parameter, which can have a comparative use.

5.6.2 Principal components analysis (PCA)

Principal component analysis is employed as part of the computer program Circumgrids III, and a set of co-ordinates based on first and second principal components was produced from the table of correlations (Table 5.34). However, the principal components may also be calculated from the table of covariances. Here, we shall demonstrate the type of manipulation of the original data in the calculation of principal components loadings starting from the correlation matrix (R) in Table 5.34 (which is also a covariance matrix of standardised variables).

Table 5.34 *Row Correlations (R)*

Horse	1.00	0.42	0.01	0.45	0.11	-0.31
Pony	0.42	1.00	0.77	0.96	0.75	0.62
Goat	0.01	0.77	1.00	0.62	0.98	0.76
Donkey	0.45	0.96	0.62	1.00	0.57	0.52
Mule	0.11	0.75	0.98	0.57	1.00	0.75
Zebra	-0.31	0.62	0.76	0.52	0.75	1.00

The first, second and third principal components are then determined from this matrix (R) by the program. The results for the calculation are shown in Table 5.35. Appendix 5.2 outlines the manual calculation of the first principal component.

Table 5.35 *Eigenvalues, percent value of the eigenvalues and eigenvectors*

	EIGENVALUES	3.96	1.45	0.43
	PERCENT VALUE OF THE EIGENVALUES	66.05	24.16	7.23
		EIGENVECTORS		
a.	Horse	0.11	0.78	0.31
b.	Donkey/ass	0.47	0.23	-0.24
c.	Mule	0.46	-0.19	0.39
d.	Zebra	0.43	0.31	0.54
e.	Goat	0.46	-0.15	0.55
f.	Pony	0.40	-0.43	-0.32

Again, note that the first and second eigenvalue exceeds the value of 1 and together they account for 90.21% of the total variance.

5.6.3 The Relationship between the Bieri and Bannister-Fransella analyses

Since both Bieri and BF analyses involve both the production of grids with elements and constructs, it might be reasonable to investigate whether both analyses would provide information that would lead practitioners to the same conclusions. However, just as the elicitation of elements and constructs yields different grids for the same person, and a different means of allocating scores, then one could not assume that a person carrying out both Bieri and BF analyses could produce equivalent grids. However, in chapters 6 and 7, the comparison of grids will be examined in detail. The three analyses outlined previously and the examinations of the graphical representation of grid data obtained from principal components analysis provides a firm starting point for a wider examination of biological natural kinds concepts. In Chapter 6 and following, later studies in Repertory Grid Technique relating to BNKCs will be discussed in detail.

Chapter 6. Explorations with natural kinds and repertory grids: *mammalia*.

> *There are many kinds included in the group of viviparous quadrupeds; but they are unnamed. Each constituent, we may say, has been named individually, as man has, e.g. lion, deer, horse, dog, and the rest of them in the same way, though in fact there is a single named group in the case of the 'lophoura', such as horse, ass, mule, 'ginnos' and the animals known as the half-asses in Syria – so called because they resemble mules, though actually they are not the same type, as is shown by their mating and breeding with one another. This too, is why we are obliged to take them separately and examine the nature of each individual type*
>
> Aristotle (Historia Animalium, H.A. 490 b 33ff).

6.1 The study of mammals

The first study with repertory grids analysis on conceptions of living kinds (Chapter 5) consisted of a small scale study of eleven individuals using a freeware computer program (Circumgrids III, Chambers & Grice, 1986) which showed the feasibility of having the student enter their ratings, and thus their grids, themselves. This was a time consuming process and in a single class period only two students entered their grids in the available time. Thus for the 11 students to enter their grids for one of the analysis *e.g.*, Bannister-Fransella analysis required 3 hours and forty minutes. For future work, it was decided to administer the task in the form of a questionnaire and have the students rate the elements against the constructs directly. Because this is a laborious process, the grid would have to be kept relatively small, and since the Circumgrids III program used a minimum of six elements rated against six constructs, this system was adopted for future work on 'open rating'.

Figure 6.1 represents the concept map for this chapter. In Chapter 5, students were probed for their perceptions of five equids and a goat. Three of the equids as it

happens fall within the Aristotelian group called the *lophoura*[13], *i.e.*, the "bushy-tailed animals": horse, donkey and mule. Whereas the Aristotelian school was aware of the breeding difficulties of mules or jack-asses and jinnets, they were still thought of as a biological category on a par with horse and donkey. The students of Chapter 5 demonstrated a certain sense of exclusivity about mules, locating them in 'psychological space' away from horses but sometimes between horses and donkeys or else separate altogether. A potential problem with the interpretation of the data from Chapter 5 is that the students were given the word 'mule' as opposed to a picture and some may not have genuinely known what a mule is. In this chapter, this possible difficulty is averted with the use of pictures, so that the student is using the picture as the stimulus for their perception. Further, a naming task is associated with the grid elicitation to determine whether the students do indeed 'know' the names of a wide range of mammals.

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[13] λοφούρα

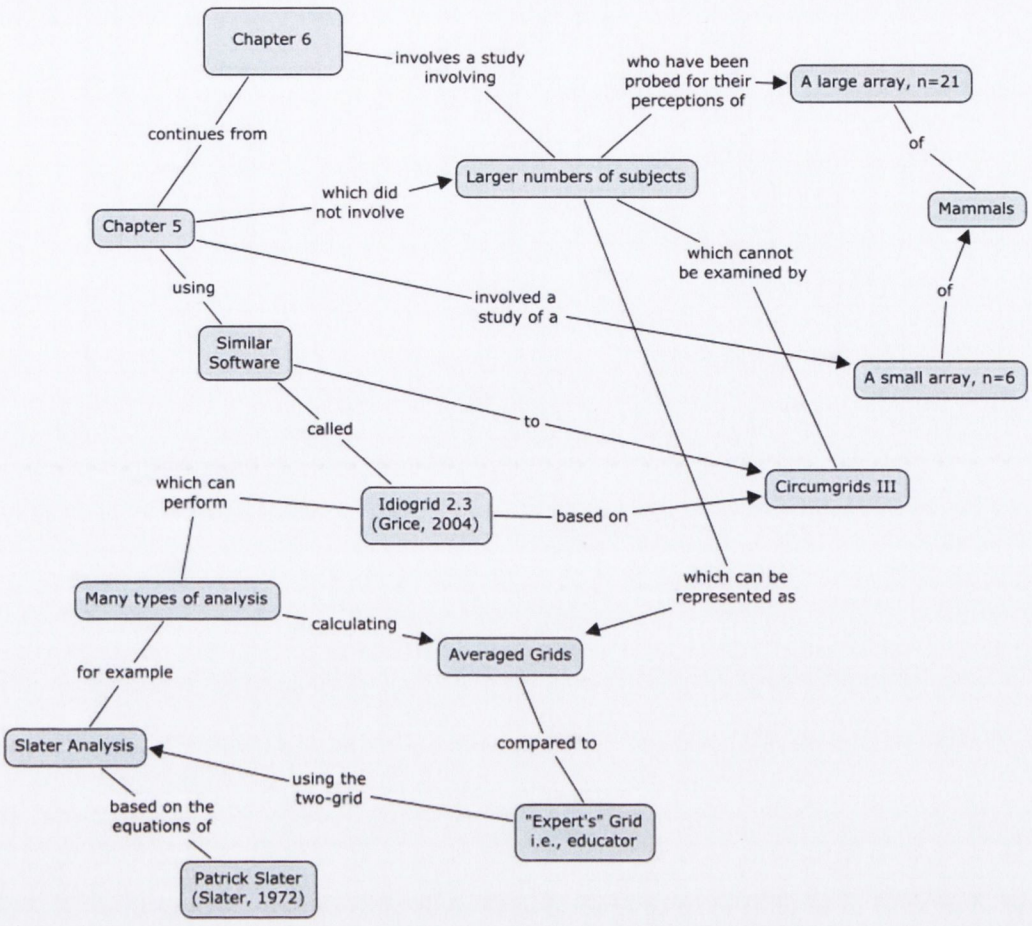

Figure 6.1 A concept map of Chapter 6 done by CMap Tools™

6.2 The purpose of studying perceptions of *mammalia.*

The *mammalia* hold a special place in human cognition due to the close association of hominids during the course of evolution with members of that group. For example, hominids and equids, *inter alia,* both evolved concomitantly in Eastern Africa over the last five million years, so that the dating of human fossils can be estimated from the associated quadruped fossil record. It can be reasonably surmised, therefore, that human cognition with respect to natural kinds has itself evolved in tandem with the evolution of the equids. According to some authors, *e.g.*, Atran (1999), *mammalia* fall into the folkbiological taxon or 'rank' (Berlin, 1992) of 'Life Form' — the second

of the absolutely distinct hierarchical levels of lay taxonomy that Atran has developed over the course of a number of years (Table 6.1).

Table 6.1 *Examples of Scott Atran's Folkbiological levels (Atran, 1999)*

Level of Premise Category / Folkbiological taxon	Example	
Folk-kingdom	Plant or animal	
Life-form[14]	Mammals, trees, birds, fish or subgroups of mammals, e.g., dogs; reptiles e.g., snakes, or birds e.g., chickens	
Generic Species or *generic-specieme*[15]	Horse	Dog
Folkspecific	Thoroughbred	Sheepdog
Varietal	Racehorse	Welsh-border

Folkbiological classification is taxonomic since it is composed of a rigid hierarchy of inclusive classes of organisms or taxa, and at each level of the hierarchy, the taxa that are mutually exclusive partition the locally perceived biota. It is a common assumption of both folk and scientific classifications that living kinds naturally fall into a 'groups within groups' structure or model (Atran, 1999). The hierarchical structure of categories (*i.e.*, a categorization) has been described as a special kind of network where the only relation allowed between category members is the so-called 'set inclusion' relation (Murphy, 2002). Set inclusion has been termed the 'IS-A' relation (Collins & Quillian, 1969) because the subordinate category 'is a' super-ordinate category in turn: *e.g.*, a dog is a carnivore, a carnivore is a placental mammal, a placental mammal is a mammal in general.

Lopez *et al.* (1997) carried out an important study comparing the taxonomies constructed by two cultural groups: an American, n = 12 rural adults, gender

[14] Μέγιστον γένος (Aristotle, *H.A.* 486 α 23)

[15] Ατομον εἶδος (Aristotle, *H.A.* 486 α 17)

balanced, taxonomy of local mammals in Michigan and an Itzaj, n = 12 adults, gender balanced, taxonomy of local mammals in Petén, Guatemala[16]. They conducted sorting tasks of the handwritten terms (which were also read aloud) for a wide range of mammals: American, n = 40; Itzaj, n = 42. The subjects had to sort the cards into piles. The first sort was according to whether the subjects 'knew' the word on the card — those that were not known were discarded. The remaining cards were placed in alphabetical order. The subjects were prompted to "*put together those mammals that go together by nature into as many different groups as you want.*" The subjects were then asked to carry out a successive grouping task by "*putting together those groups of mammals that go together by nature into as many different groups as you want*". This instruction was repeated until the subjects indicated that all the mammals would fit in the next grouping. The researcher then brought back the first sort and asked the subjects to carry out a successive dividing task by "*subdividing the subgroups as you want*". At each stage of the process the researcher had to record all the sortings. The groupings were 'translated' into a taxonomic tree by allocating groups to specific nodes on the tree. The bottom level corresponded to individuals, the top level included all mammals together, whilst the intermediate levels correspond to the groupings the participants made during the sorting. Finally, each level includes all groupings made during a given round of sorting, and the levels are rank-ordered from the last successive divided sort to the last successive group sort.

A pair-wise mammal-by-mammal 'folk-taxonomic distance' matrix was produced by calculating the distance between all possible pairs of mammals in the

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[16] Péten was once the epicenter of the classic Maya civilization and is inhabited by the last of tribe of the Maya, the Itzaj.

taxonomy. The folk-taxonomic distance was defined as the lowest level at which two given mammals go together in a folk taxonomy (López *et al.*, 1997). Subjects' mammal distance matrices were correlated producing a single pair-wise subject by subject correlation matrix: principal components factor analysis was then performed separately on the American and Itzaj correlation matrices. This approach differs from RGA in that López *et al.* (1997) correlated distance matrices rather than ranks or scores of elements against constructs. Because the data is manipulated in a further step, a comparative study of the two approaches would be useful in determining whether calculating the distance matrix and correlating such matrices would be substantively different from handling raw scores or ranks.

In the study that follows, a range of generic species was chosen to be stimuli for perception. Some were members of the placental mammals whilst others were marsupial and egg-bearing mammals. In evolutionary terms, marsupial mammals developed on large island masses separate from the placental mammals, the latter evolving into a range of habits that marsupials had already formed, *e.g.* kangaroo for deer; koala for bear, *thylacine* for wolf; possum for squirrel *inter alia*. The marsupials in turn had replaced egg-bearing mammals (although the young were fully developed in such eggs which resembled the reptile egg in shape and structure). There is a need to research conceptions of mammal *per se*, mammals as a class of organisms composed of classes and orders

One possible classification of these large groups is as follows:

Class: Mammalia - having a 'yolk' on the ventral side of the embryo
Subclass: Aplacentaria - lacking a placenta
Order: Monotremata - egg-bearing mammals
Order: Marsupialia - pouched, neonate-bearing mammals
Subclass: Placentaria - having a placenta

Order: e.g., Cetacea - whales, dolphins and porpoises

(Lurie, 2004)

Some of the *placentaria* belong to life form groups that were at one time not classified as mammals, *e.g.*, whales, dolphins and porpoises, *i.e.*, *Cetacea* (*cf.* Keil, 1996, p. 160). The *Cetacea* can only be classified as mammals if a certain degree of a theory of mammal exists, *i.e.* consisting of features such as (i) mammals give birth (they are viviparous), (ii) have functioning mammary glands/suckling offspring, (iii) the evolution of a pentadactyl limb albeit in the form of a wing, fin, arm or leg and disregarding the basic visual form of the animal as a quadruped. The Aristotelian School seem to accept that dolphins are members of *the tribe of fish*[17] , albeit a viviparous fish, in spite of the fact that the organs and process of lactation is described and compared to the *quadrupedia*[18].

The recognition of an organism as a mammal had importance first and foremost as a nutritional issue: 'can I eat it?' or a safety issue: 'will it eat me?" for humans living as hunter-gatherers. This question was best answered when previously constructed knowledge by a knowledgeable elder, sage or shaman could be drawn upon.

However, the present study, whilst bearing some of the hallmarks of a folkbiological or folktaxonomic study, is a study of how the conceptions of living kinds are structured in the minds of learners of science. Folkbiological studies (such as described earlier *e.g.*, Atran, 1999; Berlin, 1992) are similar to the studies in this thesis with respect to the use of multidimensional scaling and/or principal components

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[17] των ἰχθρύων γενος

[18] τά τετράποδα

analysis; they are, however, strongly focussed on comparing the taxonomic systems of indigenous peoples to western technological populations. The studies in this thesis examine the comparison between the taxonomic systems of science learners to certain experts (sometimes a teacher of biology); but go further in ascertaining the nature of the comparison and surveys a range of techniques of representing the mental structures of living kinds. Both types of study, ultimately shed some small light though on how the human mind has evolved to attend to living kinds especially.

6.3 Methodology

6.3.1 Production of visual stimuli

Laminated cards were produced, depicting two figures. One, the animal as a stimulus, and second, a human figure drawn to scale. If the animal had a flying habit, then it was depicted in flight and if a crawling habit, it was depicted on the ground. The images were composed from Appleworks 5.0 clipart and made into single graphic files. These were printed on A4 sheets of paper, laminated and cut out to produce the finished cards. One disadvantage of this technique was that the cards were different shapes and sizes, which may be a distracting feature. All the cards are produced below in Figure 6.2 and listed in Table 6.2 with the names used by the students in this study. 13, 14 and 15 year olds in the school *Sagrado Corazon*, a cross phase school in the suburbs of Valencia, *Communidad Valenciano*, Spain took part in this study. Their first language is *Valenciano*, a close dialect of Catalan and where Spanish *per se* is termed *Castelano*. The 13 year olds were in the final year of primary education and the 14/15 year olds in the first year of post-primary education. Table 6.1 lists also the specific rationale for each exemplar. The students were selected on the basis that they attended a cross-phase school so that doing the task at the end of primary school and

beginning of secondary school was done easily and because the school was attached to a teacher education institution that was being visited as part of an Erasmus teacher mobility grant.

6.3.2 Elicitation of the grids

A questionnaire was administered to the students entitled '*Encontrando Semejanzas entre Animales*' *i.e.*, recognising similarity between animals, headed by a number of instructions in *Castelano* (Figure 6.2):

Instrucciones
Observe con atencion los animals mostrados.
Busque las caracteristicas siguientes en cada animal e.g., da la leche, tiene cuernos, peligroso etc.,
Ponga una X en el rectangulo bajo caracteistica que el animal tiene en esa fila.
Ponga un circulo alrededor de la caracteristica mas importante y un rectangulo alrededor de la Segunda mas importante.

Instructions
Study carefully the numbered animals
Search the characteristics in each animal e.g., provides milk, has horns, dangerous etc.,
Put an X in the box below the characteristic that the animal has in each row
Put a circle around the most important characteristic and a rectangle around the second most important.

Figure 6.2 Instructions given to the students and an English translation

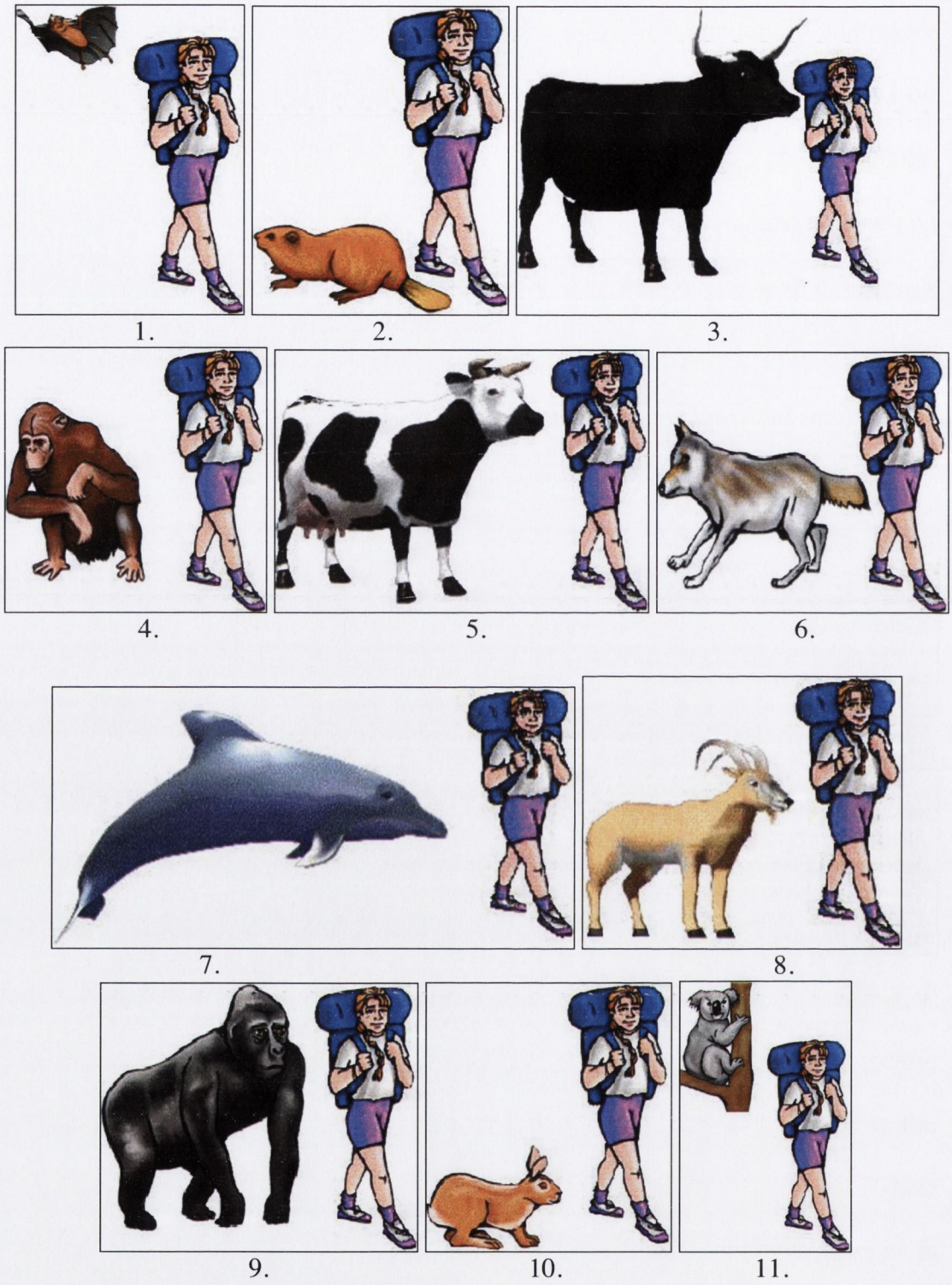

Figure 6.3 Visual stimuli used in the study on mammals

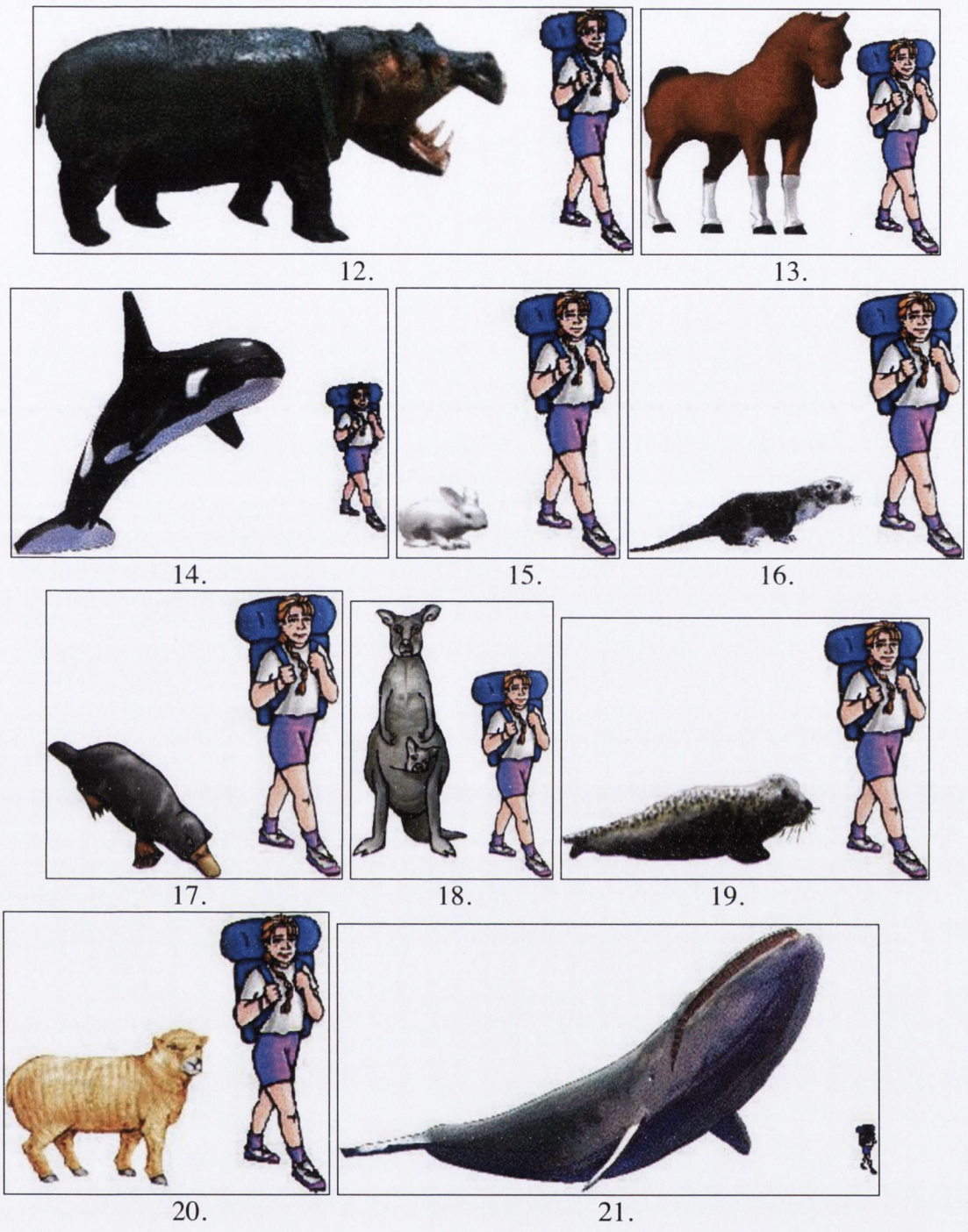

Figure 6.3 Visual stimuli used in the study on mammals

Table 6.2 *Details of the visual stimuli used in the study on mammals*

Number	English Name	Latin Name (Family: Genus species)	Spanish / Valenciano name	Rationale for inclusion
1.	Bat	Vespertilionidae	Murceliago	How does a flying mammal relate to quadrupeds
2.	Beaver	Castoridae Castor	Castor	Unknown in Valencia
3.	Bull	Bovidae Bos taurus	Toro or Vacan	Hypothesising a cultural constraint
4.	Chimp-anzee	Pongidae Pan troglodytes	Mono	How does this mammal relate to other mammals?
5.	Cow	Bovidae Bos taurus	Vaca	The relationship to other cattle
6.	Wolf	Canidae Canis lupus	Lobo	Hypothesising constraint as a dangerous animal
7.	Dolphin	Delphinidae Tursiops truncatus	Delfin	How does an aquatic mammal relate to quadrupeds
8.	Goat	Bovidae Capra hircus	Cabra	The relationship to other cattle
9.	Gorilla		Gorila	Hypothesising constraint as a dangerous animal
10.	Hare	Leporidae Lepus sp.	Liebre	Confused with a rabbit?
11.	Koala	Phalangeridae Phascolarctos cinereus	Koala	Would this marsupial be classified with others
12.	Hippo-potamus	Hippopotamidae Hippopotamus amphibius	Hipopotamo	How would a water quadruped be classified?
13.	Horse	Equidae Equus caballus	Caballo	Would there be cultural constraints with horse?
14.	Killer Whale	*Delphinidae Orcinus orca*	*Orca*	*Would this be classified closer to whale or dolphin?*
15.	Rabbit	*Leporidae Oryctolagus cuniculus*	*Coneja*	*Confused with hare?*
16.	Otter	*Mustelidae Lutra*	*Nutria*	*How would a water quadruped be classified?*
17.	Platypus	*Ornithorhynchidae Ornithorhynchus anatinus*	*Ornitorinco*	*How would a monotreme be classified?*
18.	Grey Kangaroo	*Macropodidae Macropus giganteus*	*Kanguro*	*Would this marsupial be classified with others*
19.	Seal		*Foca*	*How does an aquatic mammal relate to quadrupeds*
20.	Sheep	*Bovidae Ovis aries*	*Oveja* or *Obeja*	*The relationship to other cattle*
21.	Grey Whale	*Eschrichtidae Eschrichtius glaucus*	*Ballena*	*Constrained by size*

6.3.3 The role of language

Whereas *Castelano* is a second language to many if not all the students (excepting those who had moved into the area from another *pais* or *communidad*) their fluency in *Castelano* can be assumed to be much higher than the level of the questionnaire. To ensure the idiom of the translation was understandable to these students, the staff of EDETANIA[19], Valencia assisted in the proof reading of the questionnaire suggested changes, which were incorporated into the questionnaire.

6.4 The Slater analysis of multiple grids

Patrick Slater (1972) introduced novel methods for multiple grids with different numbers of constructs or different numbers of elements. Idiogrid 2.3[20] follows the formulae put forth by Slater and allows the user to analyse any number of grids in which the constructs, elements, or both the constructs and elements are matched. When both are matched, the user can also request an analysis for comparing each individual grid with an average grid. In this way, the user can identify typical and atypical grids in the analysis, what follows are the steps in the so-called Slater Analysis.

Within Slater Analysis, the user has a choice over a number of important routes to take. They are important because they allow the user to verify that the analysis is valid and consistent. In the section that follows, an analysis of variance (ANOVA) will be conducted on the grid data. The general correlation among grid constructs or elements was also computed. This ranges from 0 to 1, but it can yield a

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[19] EDETANIA is part of the Catholic University of Valencia and is the teacher education college responsible for the formation of primary school teachers in Valencia. The author is indebted to Aida Garcia, Teresa del Caño, and Esther Moreno for their assistance in translation.

[20] In this study, *Idiogrid 2.3* (Grice, 2004) was used as the preferred computer package. Idiogrid is an updated version of Circumgrids and has overcome the main problems experienced by the older *Circumgrids III* program while allowing the data to be exported to SPSS, EXCEL or SAS.

negative result with empirical data. It is composed as the intra-class correlation coefficient among the elements angles of the grids being computed. The first step in computing this value is to compute the element correlation matrices for the grids. These correlations are converted to angular distances in radians. An ANOVA is then conducted on these matrices of angular distances from which the intra-class correlation coefficient is finally computed.

6.4.1 Analysis of variance

The Slater Analysis conducts the ANOVA by copying all of the angular distances from the matrices into vectors. The vectors are then concatenated to form a matrix. The rows of this matrix represent the unique pairs of elements used to compute the angular distances in the grids being compared. The columns represent the grids. Rearranging the angular distances from the grids in this fashion greatly facilitates the computation of the ANOVA as well as the presentation of the formulae below[21]. The concatenated matrix of angular distances will be represented as ${}_tU_k$,

where:

t = number of unique angular distances for each grid
k = number of grids

and variation down the rows of this matrix represents within-grid variance, and variation across the columns of this matrix represents between-grid variance. The within-grid sum of squares, SS_{within}, for the element angular distances computed as follows, Equation 6.1:

$$SS_{within} = \sum_{i=1}^{t} n_i \left(U_{(i)} - U_{(..)} \right)^2 \qquad \textit{Equation 6.1}$$

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[21] The formulae can be found in Grice (2003)

where $U_{(i)}$ refers to the mean for corresponding angular distances from the grids, and $U_{(..)}$ refers to the mean of the angular distances from the grids. The within-grid degrees of freedom, df_{within}, equals $t - 1$. The within-grid mean squares, MS_{within}, is computed by dividing SS_{within} by df_{within}. The between-grid sum of squares, $SS_{between}$, is similarly computed, Equation 6.2:

$$SS_{between} = \sum_{j=1}^{t} n_j \left(U_{(j)} - U_{(..)}\right)^2 \qquad \textit{Equation 6.2}$$

where $U_{(j)}$ refers to the mean for the angular distances for the entire j grid. The degrees of freedom for the grids, $df_{between}$, equals the number of grids minus one. The between-grids mean squares, $MS_{between}$, is computed by dividing $SS_{between}$ by $df_{between}$. The residual sum of squares, SS_{resid} , is computed as follows, Equation 6.3:

$$SS_{resid} = \sum_{j=1}^{k} \sum_{i=1}^{t} \left(U_{(ij)} - U_{(i)} - U_{(j)} + U_{(..)}\right)^2 \qquad \textit{Equation 6.3}$$

where $U_{(ij)}$ refers to a given angular distance. The df_{resid} is equal to n_{total} - n_t - n_k + 1; where n_{total} equals the number of non-missing angular distances, n_t equals the number of non-missing ${}_tU_k$ and n_k equals the number of non-missing means for columns of ${}_tU_k$. The

residual mean squares, MS_{resid}, is computed by dividing SS_{resid} by df_{resid}. The total sum of squares and total degrees of freedom are computed by summing the respective within, between, and residual values. Alternatively, the total sum of squares could be computed as follows, Equation 6.4:

$$SS_{total} = \sum_{j=1}^{k} \sum_{i=1}^{t} \left(U_{(ij)} - U_{(..)}\right)^2 \qquad \textit{Equation 6.4}$$

Table 6.3, 6.4, 6.5, 6.6, 6.7, 6.8 show the ANOVA source tables for 13, 14, and 15 year old students: in the tables following ***SS*** refers to the sum of squares, ***df*** refers to

degrees of freedom, ***MS*** refers to mean squares, and ***F*** is the F value calculated. The within-grids F-value is computed by dividing MS_{within} by MS_{resid}, and the between-grid F-value is computed by dividing $MS_{between}$ by MS_{resid}. Beneath each table the correlation between grid angles are stated. The value to the researcher in conducting the ANOVAs was that, when in Chapter 5, the Circumgrids III program calculated 'consistency' and 'Bieri intensity', a similar measure or indicator of rigour was needed here. ANOVA was chosen because it is less specialised as consistency and intensity are – coming from the personal construct psychology as they do. ANOVA is a commonly carried out procedure using other computer programs. The ANOVA option in Idiogrid produces two tables – one for constructs – and one for elements. The F values were compared to the critical values, as described by Grice (2003), based on numerator df_{within} or $df_{between}$ and denominator df_{resid} and judged for statistical significance.

In all cases, the F values exceeded the critical values. In Tables 8.3 – 8.8, it is obvious that df_{resid} is so large with respect to df_{within} or $df_{between}$ that the critical values (CV) will all be very small decimal figures. For example, in Table 8.3, $F_{within} = 13.7$, its corresponding $CV_{within} = 0.036$; the $F_{between} = 12.43$, its corresponding $CV_{between} = 5.5 \times 10^{-3}$. This pattern, of a F value exceeding the CV *in extremis* was repeated in Table 6.4 – 6.8 .

Table 6.3 *ANOVA source table for between-grid comparison for 13 year old students: constructs*

	SS	df	MS	F
Within-Grids	1368565.64	209	6548.16	13.70
Between-Grids	190123.65	32	5941.36	12.43
Residual	2777622.32	5810	478.08	
Total	4336311.60	6051		

Correlation Between Grid Construct Angles: 0.93

Table 6.4 *ANOVA source table for between-grid comparison for 13 year olds: elements*

	SS	df	MS	F
Within-Grids	138440.32	35	3955.44	22.39
Between-Grids	23921.29	32	747.54	4.23
Residual	195073.41	1104	176.70	
Total	357435.01	1171		

Correlation Between Grid Element Angles: 0.96

As well as noting that, in Table 6.3 and 6.4, the F value exceeds the critical value, we should also note the differences in F values between the 'within grids' and 'between grids' situations in both constructs (Table 6.3) and elements (Table 6.4). The F value is a simple ratio and it is a measure of homogeneity in the data. In Table 6.3, both the within- and between-grids F values are very high and relatively at the same level; however, in Table 6.4, the F value for the between-grids is much lower than the F value for within-grids. This implies that in the case of elements, the 13 year olds, had much less homogeneity between each other than within their respective grids. In the case of constructs, the 13 year olds had a high degree of homogeneity. This can be explained by the fact that in the case of constructs, there is no choice as to which are chosen – there is only choice of scoring. In the case of elements, the students could choose which elements to use and then how to score them. Unscored items were assigned a 'score' of zero. This had the effect of

ensuring that all constructs and elements could be kept in all the grids as they were entered. This does however, cause a certain bias in the data, because if a number of students do not use the same elements, and hence they are scored zero, this influences the various calculations on the data. Notwithstanding this point, the system of scoring takes into account what the student rejects as relevant instead of focussing on the active scoring of chosen features only. In Table 6.5 and 6.6, a similar pattern was observed except that in Table 6.5, the F values were lower in general.

Table 6.5 *ANOVA source table for between-grid comparison for 14 year olds: constructs*

	SS	df	MS	F
Within-Grids	573184.57	209	2742.51	6.50
Between-Grids	18776.69	10	1877.67	4.45
Residual	800776.52	1897	422.13	
Total	1392737.78	2116		

Correlation Between Grid Construct Angles: 0.85

Table 6.6 *ANOVA source table for between-grid comparison for 14 year olds: elements*

	SS	df	MS	F
Within-Grids	44378.04	35	1267.94	10.77
Between-Grids	4551.64	10	455.16	3.87
Residual	39317.97	334	117.72	
Total	88247.65	379		

Correlation Between Grid Element Angles: 0.91

In Table 6.7 and 6.8, the pattern was repeated again, but the difference bewteen the F values in the elements table (Table 6.8) was less again – they appeared to be converging over the three age-groups. In other words the degree of homogeneit descreases over the three age groups. Also, the 15 year old group had the closest affinity between the F values and the CVs. Another observation is that the F value for

between grids was lower than the F valuefor within grids. This implies that the variation between individuals was greater than the variation within any particular grid.

I must provide a word of caution since the number of students involved decrease sharply over the three age groups, therefore developmental patterns based on age can only be tentative.

Table 6.7 *ANOVA Source Table for Between-Grid Comparison for 15 year olds: constructs*

	SS	df	MS	F
Within-Grids	305060.16	209	1459.62	3.39
Between-Grids	11965.63	5	2393.13	5.56
Residual	433365.74	1006	430.78	
Total	750391.53	1220		

Correlation Between Grid Construct Angles: 0.70

Table 6.8 *ANOVA source table for between-grid comparison for 15 year olds: elements*

	SS	df	MS	F
Within-Grids	31197.99	35	891.37	6.17
Between-Grids	3474.13	5	694.83	4.81
Residual	25299.43	175	144.57	
Total	59971.55	215		

Correlation Between Grid Element Angles: 0.84

6.4.2 Correlation between grid angles.

This statistic is printed below the standard ANOVA output, and is computed as follows, Equation 6.5:

$$Correlation\ Between\ Grid\ Element\ Angles = \frac{MS_{within} - MS_{resid}}{MS_{within}}$$

Equation 6.5

It is a form of intra-class correlation coefficient and is equivalent to Cronbach's alpha. The general correlation among element angles are computed for the constructs using

the same formulae, adjusted accordingly, the values are tabulated in Table 6.9 . The higher the correlations the greater the consistency of the students' scoring and the correlation for the 13 year olds appears to be particularly high (Table 6.9).

Table 6.9 *Correlations between grid angles*

	Correlation between grid construct angles	Correlation between grid element angles
13 year olds	0.93	0.96
14 year olds	0.85	0.91
15 year olds	0.70	0.84

Curiously, the correlations between the grid construct and element angles decrease slightly with age, being slightly more marked with respect to constructs.

6.4.3 Final note on ANOVA

Further notes on using Idiogrid are provided in Appendix 6.1 . Although the use of rotated grids in principal components analysis was not dealt with in this chapter – since the rotated plots did not vary significantly from the unrotated plots – the structure coefficients (for both rotated and unrotated calculations) and the plots of the rotated principal components are provided for reference in Appendix 6.2 and 6.3 respectively.

6.4.4 Averaging grids

When the constructs and elements are matched, *i.e.*, each grid contains the same elements in the same order, and each grid contains the same constructs in the same order, an average grid can be computed. Each individual grid is then compared to this average grid. Following Slater, the average grid is computed by first centering each grid by its constructs. Centering is simply a matter of subtracting the respective construct means from their grid values. Each construct will consequently be centered around a mean of zero. The centered grids are then simply averaged. The new resulting grid can then be subjected to statistical analysis, edited or saved and are presented in Table 6.3 , 6.4, and 6.5 . In this study, the average grid was subjected Principal Components Analysis, *i.e.*, PCA.

Table 6.10 *Averaged grid for 13 year old students and table of translations*

conocido	tiene cernos	da leche	pelig-roso	pelo espero	tiene pezu-nyas	nos da comida	come hierba	cuerpo grande	poco
orejo	-0.79	1.18	-0.82	0.94	0.06	0.60	0.27	-0.58	-0.85
ballena	-0.51	-0.36	1.09	-0.54	-0.54	0.19	-0.51	1.67	-0.48
lobo	-0.58	-0.19	1.90	-0.01	-0.28	-0.43	0.05	-0.13	-0.34
foca	-0.44	-0.14	0.86	-0.44	-0.44	0.44	-0.41	0.59	-0.02
canguro	-0.71	-0.25	0.26	0.05	-0.13	-0.49	0.78	0.96	-0.46
hornitorinco	-0.52	-0.40	0.54	-0.19	0.03	-0.40	0.03	-0.52	1.42
nutria	-0.47	-0.07	-0.16	-0.01	0.02	-0.23	0.14	-0.47	1.26
conejo	-0.63	-0.33	-0.57	0.07	-0.14	1.52	1.19	-0.63	-0.48
koala	-0.63	-0.27	0.12	0.25	-0.30	-0.51	0.97	-0.63	1.00
orca	-0.58	-0.37	1.51	-0.58	-0.58	-0.03	-0.58	1.42	-0.22
caballo	-0.79	-0.42	0.36	-0.36	0.36	0.76	0.27	0.58	-0.76
hipopotamo	-0.63	-0.26	1.46	-0.60	-0.05	-0.54	-0.17	1.13	-0.35
liebre	-0.56	-0.26	-0.53	0.32	0.01	1.01	0.95	-0.56	-0.38
gorila	-0.64	-0.43	1.54	0.21	-0.52	-0.61	0.15	0.85	-0.55
murcieldgo	-0.36	0.00	0.97	0.06	-0.21	0.12	-0.30	-0.36	0.06
castor	-0.55	-0.01	0.11	0.39	-0.13	-0.31	0.54	-0.55	0.51
toro	0.81	-0.82	0.85	-0.49	0.03	-0.09	0.09	0.45	-0.82
mono	-0.42	-0.15	0.18	0.88	-0.33	-0.42	0.58	0.03	-0.33
cabra	0.78	0.57	0.27	-0.46	0.12	0.03	0.12	-0.64	-0.79
vaca	0.09	0.48	0.00	-0.33	-0.18	-0.06	-0.15	0.58	-0.42
delfin	0.14	0.29	-0.04	-0.35	-0.13	-0.01	-0.10	0.56	-0.35

Elements		Constructs	
Spanish	English	Spanish	English
Tiene cernos	Has horns	Murceliago	Bat
Da leche	Gives milk	Castor	Beaver
Peligroso	Dangerous	Toro or Vacan	Bull
Pelo espero	Warm skin/pelt	Mono	Chimpanzee
Tiene pezunyas	Has hooves	Vaca	Cow
Nos da comida	Gives us food	Lobo	Wolf
Come hierba	Eats vegetation	Delfin	Dolphin
Cuerpo grande	Large body	Cabra	Goat
Poco conocido	Little known	Gorila	Gorilla
		Liebre	Hare
		Koala	Koala
		Hipopotamo	Hippopotamus
		Caballo	Horse
		Orca	Killer Whale
		Coneja	Rabbit
		Nutria	Otter
		Ornitorinco	Platypus
		Kanguro	Grey Kangaroo
		Foca	Seal
		Oveja or Obeja	Sheep
		Ballena	Grey Whale

Table 6.11 *Averaged grid for 14 year old students and page of translations*

conocido	tiene cernos	da leche	peligroso	pelo espero	tiene pezunyas	nos da comida	come hierba	cuerpo grande	poco
orejo	-0.90	1.46	-0.63	0.46	0.01	0.37	0.37	-0.26	-0.90
ballena	-0.53	-0.43	1.11	-0.53	-0.53	0.11	-0.53	1.75	-0.43
lobo	-0.59	-0.31	2.23	0.41	-0.13	-0.59	-0.40	-0.22	-0.40
foca	-0.37	-0.37	-0.10	-0.10	-0.37	0.17	-0.37	0.90	0.63
canguro	-0.68	-0.40	-0.13	-0.13	0.05	-0.40	0.96	1.05	-0.31
hornitorinco	-0.44	-0.44	-0.44	0.28	0.46	-0.44	0.65	-0.44	0.83
nutria	-0.41	-0.41	-0.41	0.13	0.59	0.22	-0.14	-0.32	0.77
conejo	-0.65	-0.46	-0.56	0.17	-0.01	0.99	1.35	-0.65	-0.19
koala	-0.58	-0.39	-0.58	0.61	-0.12	-0.58	1.70	-0.58	0.52
orca	-0.52	-0.52	1.03	-0.52	-0.52	0.03	-0.52	1.58	-0.06
caballo	-0.82	-0.64	-0.45	-0.36	0.55	0.82	0.64	1.09	-0.82
hipopotamo	-0.63	-0.63	1.65	-0.63	-0.17	-0.54	-0.35	1.46	-0.17
liebre	-0.62	-0.53	-0.62	0.20	-0.07	0.57	1.75	-0.62	-0.07
gorila	-0.76	-0.30	1.24	0.33	-0.67	-0.76	0.15	1.42	-0.67
murcieldgo	-0.31	-0.13	1.32	-0.22	-0.13	-0.31	-0.31	-0.31	0.41
castor	-0.48	-0.48	-0.21	0.52	-0.21	-0.48	1.15	-0.48	0.70
toro	1.52	-0.94	1.15	-0.76	-0.12	-0.03	-0.21	0.33	-0.94
mono	-0.51	-0.14	0.31	1.04	-0.51	-0.51	0.49	0.31	-0.51
cabra	1.21	1.12	-0.52	-0.52	-0.06	-0.42	0.12	-0.06	-0.88
vaca	0.63	0.99	-0.92	-0.65	-0.01	0.63	-0.19	0.54	-1.01
delfin	-0.22	-0.04	-0.31	-0.31	-0.22	-0.13	-0.22	1.78	-0.31

Note. The grids were centered by constructs prior to being averaged.

Elements		Constructs	
Spanish	English	Spanish	English
Tiene cernos	Has horns	Murceliago	Bat
Da leche	Gives milk	Castor	Beaver
Peligroso	Dangerous	Toro or Vacan	Bull
Pelo espero	Warm skin/pelt	Mono	Chimpanzee
Tiene pezunyas	Has hooves	Vaca	Cow
Nos da comida	Gives us food	Lobo	Wolf
Come hierba	Eats vegetation	Delfin	Dolphin
Cuerpo grande	Large body	Cabra	Goat
Poco conocido	Little known	Gorila	Gorilla
		Liebre	Hare
		Koala	Koala
		Hipopotamo	Hippopotamus
		Caballo	Horse
		Orca	Killer Whale
		Coneja	Rabbit
		Nutria	Otter
		Ornitorinco	Platypus
		Kanguro	Grey Kangaroo
		Foca	Seal
		Oveja or Obeja	Sheep
		Ballena	Grey Whale

Table 6.12 *Averaged grid for 15 year old students and table of translations*

conocido	tiene cernos	da leche	pelig-roso	pelo espero	tiene pezu-nyas	nos da comida	come hierba	cuerpo grande	poco
orejo	-0.87	1.30	-0.87	0.13	0.13	1.30	0.46	-0.70	-0.87
ballena	-0.63	-0.63	1.87	-0.63	-0.63	0.37	-0.63	1.54	-0.63
lobo	-0.57	-0.41	2.43	0.09	-0.24	-0.57	-0.24	0.09	-0.57
foca	-0.52	-0.52	0.65	-0.35	-0.52	0.98	-0.52	0.98	-0.19
canguro	-0.69	-0.69	0.15	-0.02	0.15	-0.69	1.65	0.81	-0.69
hornitorinco	-0.57	-0.57	0.43	-0.41	-0.57	-0.07	0.59	0.26	0.93
nutria	-0.57	-0.57	0.59	-0.24	-0.24	-0.07	0.43	0.09	0.59
conejo	-0.59	-0.09	-0.43	0.74	-0.26	1.07	0.74	-0.59	-0.59
koala	-0.67	-0.67	-0.17	0.83	-0.33	-0.33	1.50	-0.67	0.50
orca	-0.61	-0.61	1.72	-0.44	-0.61	0.22	-0.61	1.22	-0.28
caballo	-0.80	-0.63	-0.13	-0.30	0.70	0.54	0.70	0.54	-0.63
hipopotamo	-0.72	-0.56	1.11	-0.56	0.11	-0.72	0.61	1.11	-0.39
liebre	-0.61	-0.44	-0.44	0.22	-0.28	1.56	1.22	-0.61	-0.61
gorila	-0.80	-0.63	1.54	0.04	-0.46	-0.80	0.70	1.04	-0.63
murcieldgo	-0.39	-0.06	1.11	0.11	-0.22	0.11	-0.22	-0.39	-0.06
castor	-0.56	-0.56	0.44	0.94	-0.06	-0.56	0.94	-0.56	-0.06
toro	0.89	-0.78	1.22	-0.61	0.22	-0.44	0.06	0.39	-0.94
mono	-0.56	-0.56	0.44	0.61	-0.22	-0.56	1.11	0.11	-0.39
cabra	1.57	0.41	0.24	-0.43	0.07	-0.26	-0.09	-0.59	-0.93
vaca	0.96	0.63	-0.04	-0.70	-0.04	0.30	-0.04	-0.04	-1.04
delfin	-0.44	-0.44	-0.11	0.06	-0.44	-0.11	0.39	1.56	-0.44

Note. The grids were centered by constructs prior to being averaged.

Elements		Constructs	
Spanish	English	Spanish	English
Tiene cernos	Has horns	Murceliago	Bat
Da leche	Gives milk	Castor	Beaver
Peligroso	Dangerous	Toro or Vacan	Bull
Pelo espero	Warm skin/pelt	Mono	Chimpanzee
Tiene pezunyas	Has hooves	Vaca	Cow
Nos da comida	Gives us food	Lobo	Wolf
Come hierba	Eats vegetation	Delfin	Dolphin
Cuerpo grande	Large body	Cabra	Goat
Poco conocido	Little known	Gorila	Gorilla
		Liebre	Hare
		Koala	Koala
		Hipopotamo	Hippopotamus
		Caballo	Horse
		Orca	Killer Whale
		Coneja	Rabbit
		Nutria	Otter
		Ornitorinco	Platypus
		Kanguro	Grey Kangaroo
		Foca	Seal
		Oveja or Obeja	Sheep
		Ballena	Grey Whale

6.4.5 The general degree of correlation

The general degree of correlation ranges in value from 0 to 1. A value near 1 indicates that the particular grid is highly similar to the average grid. A value near 0 indicates that the grid is dissimilar from the average grid. The general degree of correlations are presented in Table 6.13, 6.14, and 6.15 . The formula for the general degree of correlation is as follows (Equation 6.6):

$$r_{AB} = \frac{\sum_{i=1}^{c}\sum_{j=1}^{e}\left(A_{(ij)} * B_{(ij)}\right)}{\sqrt{\sum_{i=1}^{c}\sum_{j=1}^{e}A_{(ij)}^{2}\sum_{i=1}^{c}\sum_{j=1}^{e}B_{(ij)}^{2}}} \qquad \textit{Equation 6.6}$$

where
r_{AB} is the general degree of correlation
c is the number of constructs, i
e is the number of elements, j
$A_{(ij)}$, $B_{(ij)}$ are grids composed of element and constructs, one of which is the 'average' grid

The range of lowest general degree of correlation between the respective average grid and individuals who contributed to the calculation of the average grid were similar in the three age groups. This procedure could be used to spot outliers, *i.e.,* students who do not fit within an acceptable range. For a given set of constructs and elements, a 'standard' range could be devised and students who hold widely varying construction systems could be identified and remediation undertaken by the classroom teacher. What form this would take is beyond the scope of this present work and would

depend on the topic and concepts concerned and the degree of disparity between the student's construction and that of her/his teacher.

However, it is important to remember that in order for the average grid to be calculated in the first place, all the students must have attempted the elicitation insofar that they have rated the same number of constructs against the same number of elements. Three students did not complete the elicitation in the 13 year olds group and thus were left out of the average grid calculation. These three would be a subset of outliers, but they are the extreme cases, and the analysis presented in this chapter is useful for determining the more subtle variations within a group. If a correlation between construct angles between the average grid and an individual's were below 0.55, for example, these students might need additional assistance (Table 6.13: VASC13DR – starred). As the children became older, the limit could be adjusted to take account of their age, assuming that ability in the task related to the correlation between the average grid and that of a particular student e.g., 0.65 in 14 year old students (Table 6.14 MUSC14HAT and MUSC14IMG – starred) and 0.70 in 15 year old students (Table 6.15 VASC15EMM – starred).

Table 6.13 *General degree of correlation between average grid and each 13 year old student*

MUSC13LME	0.67	MUSC13NGA	0.79
MUSC13AC	0.76	MUSC13PFR	0.75
MUSC13ACG	0.61	MUSC13TCP	0.59
MUSC13AG	0.63	VASC13AG	0.65
MUSC13ASL	0.67	VASC13BC	0.55
MUSC13BDO	0.63	VASC13BL	0.49
MUSC13CCM	0.59	VASC13CA	0.73
MUSC13CP	0.77	VASC13DR	0.50 *
MUSC13DB	0.80	VASC13DRR	0.61
MUSC13DSG	0.69	VASC13IC	0.74
MUSC13EF	0.82	VASC13JMPG	0.72
MUSC13LM	0.71	VASC13MLLB	0.56
MUSC13LME	0.67	VASC13RLR	0.58
MUSC13MAP	0.59	VASC13RV	0.72
MUSC13MBM	0.60	VASC13TG	0.68
MUSC13MG	0.80	MUSC13MTG	0.70
MUSC13MOF	0.60		

Table 6.14 *General degree of correlation between average grid and each 14 year old student*

MUSC14ANR	0.70	VASC14AMM	0.75
MUSC14BDO	0.69	VASC14GP	0.75
MUSC14HAT	0.61 *	VASC14JC	0.74
MUSC14IIB	0.77	VASC14JCS	0.75
MUSC14IMG	0.63 *	VASC14JT	0.82
VASC14AL	0.73		

Table 6.15 *General degree of correlation between average grid and each 15 year old*

VASC15ALC	0.71	VASC15EMM	0.69 *
VASC15AR	0.80	VASC15TE	0.71
VASC15EL	0.75	VASC15VCB	0.80

What follows is a description of PCA as it is performed by the *Idiogrid* program.

6.4.6 Principal components analysis of the average grids derived through Slater analysis

Principal components analysis, PCA, is a means of calculating eigenvectors from a larger dataset. The correlation matrix is the starting point for the PCA. Table 6.17 & 6.18 together constitute the correlation matrix for the 13 year old students. Table 6.19 & 6.20

together constitute the correlation matrix for the 14 year old students and Table 6.21 & 6.22 together constitute the correlation matrix for the 15 year old students. The tables have been split for the purposes of clarity.

It is important to note that there were a number of cases where the correlations were extremely low e.g., Table 6.17 row 5, column 1; row 19, column 13; and there were cases where the correlations were extremely high e.g., Table 6.17 row 13, column 8. Extremely high or low correlations can affect the analysis, there is however, no means of excluding such cases in Idiogrid except by running the program, noting such cases and removing the extreme cases from the original grid and then running the program again.

Table 6.17 *The correlation matrix for 13 year old students*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	1.00													
2.	-0.39	1.00												
3.	-0.26	0.50	1.00											
4.	-0.35	0.89	0.59	1.00										
5.	-0.04	0.56	0.38	0.28	1.00									
6.	-0.45	-0.13	0.31	0.12	-0.12	1.00								
7.	-0.15	-0.41	-0.10	-0.18	-0.22	0.89	1.00							
8.	0.51	-0.24	-0.20	-0.10	0.05	-0.19	-0.02	1.00						
9.	-0.06	-0.37	0.20	-0.22	0.18	0.75	0.80	0.19	1.00					
10.	-0.48	0.97	0.66	0.92	0.50	0.07	-0.27	-0.34	-0.22	1.00				
11.	0.09	0.59	0.29	0.54	0.53	-0.28	-0.42	0.48	-0.26	0.49	1.00			
12.	-0.47	0.87	0.75	0.76	0.64	0.12	-0.25	-0.39	-0.11	0.93	0.50	1.00		
13.	0.60	-0.34	-0.22	-0.23	0.07	-0.18	0.02	0.98	0.25	-0.44	0.42	-0.46	1.00	
14.	-0.30	0.75	0.85	0.64	0.72	0.08	-0.27	-0.26	0.07	0.82	0.41	0.88	-0.27	1.00
15.	-0.12	0.32	0.85	0.61	-0.07	0.44	0.11	-0.10	0.17	0.50	0.15	0.47	-0.13	0.55
16.	0.20	-0.44	0.25	-0.27	0.14	0.66	0.73	0.22	0.94	-0.29	-0.25	-0.17	0.32	0.08
17.	-0.59	0.51	0.41	0.35	0.26	-0.28	-0.64	-0.17	-0.40	0.50	0.35	0.54	-0.25	0.50
18.	0.00	0.37	-0.15	0.61	-0.04	-0.05	0.17	0.45	0.02	0.06	0.12	0.29	0.53	0.13
19.	0.15	-0.25	0.08	-0.20	-0.34	-0.44	-0.51	0.02	-0.39	-0.24	-0.11	-0.14	-0.03	-0.18
20.	0.06	0.57	0.00	0.36	0.31	-0.62	-0.63	-0.29	-0.65	0.46	0.22	0.42	-0.38	0.24
21.	0.07	0.61	-0.08	0.38	0.33	-0.63	-0.65	-0.26	-0.68	0.48	0.27	0.43	-0.36	0.21

Table 6.18 *The correlation matrix for 13 year old students continued*

	15	16	17	18	19	20	21
15.	1.00						
16.	0.28	1.00					
17.	0.11	-0.53	1.00				
18.	0.33	0.57	-0.05	1.00			
19.	0.04	-0.33	0.37	-0.26	1.00		
20.	-0.19	-0.66	0.25	-0.19	0.29	1.00	
21.	-0.29	-0.74	0.36	-0.27	0.24	0.98	1.00

Table 6.19 *The correlation matrix for 14 year old students*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	1.00													
2.	-0.26	1.00												
3.	-0.20	0.45	1.00											
4.	-0.37	0.62	-0.08	1.00										
5.	0.07	0.45	-0.02	0.32	1.00									
6.	-0.12	-0.53	-0.20	-0.01	0.23	1.00								
7.	-0.17	-0.40	-0.28	0.23	-0.13	0.73	1.00							
8.	0.35	-0.37	-0.30	-0.21	0.27	0.42	0.30	1.00						
9.	0.14	-0.48	-0.18	-0.17	0.43	0.82	0.30	0.65	1.00					
10.	-0.36	0.99	0.45	0.71	0.43	-0.43	-0.30	-0.39	-0.44	1.00				
11.	0.20	0.41	-0.22	0.27	0.71	-0.03	0.06	0.48	0.05	0.35	1.00			
12.	-0.40	0.91	0.65	0.49	0.46	-0.31	-0.31	-0.43	-0.34	0.93	0.25	1.00		
13.	0.28	-0.40	-0.29	-0.22	0.40	0.56	0.26	0.96	0.81	-0.40	0.41	-0.40	1.00	
14.	-0.08	0.81	0.64	0.36	0.62	-0.28	-0.51	-0.27	-0.06	0.78	0.26	0.84	-0.19	1.00
15.	-0.41	0.34	0.85	0.07	-0.20	-0.04	-0.04	-0.35	-0.17	0.41	-0.42	0.60	-0.34	0.37
16.	-0.04	-0.41	-0.03	-0.04	0.35	0.85	0.38	0.55	0.96	-0.33	-0.07	-0.22	0.72	-0.01
17.	-0.58	0.41	0.34	-0.13	-0.06	-0.55	-0.53	-0.33	-0.47	0.37	0.00	0.44	-0.33	0.25
18.	0.26	0.22	0.44	-0.01	0.50	0.08	-0.34	0.14	0.43	0.18	0.11	0.24	0.24	0.71
19.	0.30	-0.25	-0.36	-0.53	-0.18	-0.45	-0.62	-0.27	-0.24	-0.34	-0.21	-0.33	-0.23	-0.24
20.	0.46	0.02	-0.57	-0.15	-0.05	-0.61	-0.43	-0.06	-0.45	-0.09	0.29	-0.27	-0.15	-0.24
21.	-0.03	0.75	-0.16	0.67	0.63	-0.36	-0.31	-0.32	-0.31	0.72	0.56	0.55	-0.29	0.57

Table 6.20 *The correlation matrix for 14 year old students continued*

	15	16	17	18	19	20	21
15.	1.00						
16.	0.03	1.00					
17.	0.24	-0.44	1.00				
18.	0.05	0.43	-0.13	1.00			
19.	-0.42	-0.42	0.27	-0.22	1.00		
20.	-0.65	-0.65	0.12	-0.34	0.75	1.00	
21.	-0.28	-0.36	0.12	0.16	0.06	0.39	1.00

Table 6.21 *The correlation matrix for 15 year old students*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	1.00													
2.	-0.33	1.00												
3.	-0.38	0.73	1.00											
4.	-0.08	0.86	0.38	1.00										
5.	-0.09	0.22	0.24	0.03	1.00									
6.	-0.38	0.33	0.25	0.33	0.37	1.00								
7.	-0.40	0.43	0.47	0.36	0.42	0.95	1.00							
8.	0.73	-0.23	-0.20	0.04	0.18	-0.09	-0.06	1.00						
9.	0.04	-0.35	-0.02	-0.34	0.52	0.49	0.51	0.51	1.00					
10.	-0.40	0.99	0.77	0.85	0.18	0.41	0.51	-0.27	-0.29	1.00				
11.	0.28	0.27	0.03	0.36	0.67	0.15	0.25	0.40	0.18	0.20	1.00			
12.	-0.41	0.71	0.67	0.41	0.75	0.49	0.60	-0.29	0.08	0.70	0.50	1.00		
13.	0.65	-0.13	-0.21	0.16	0.27	0.10	0.11	0.93	0.48	-0.17	0.56	-0.15	1.00	
14.	-0.38	0.73	0.79	0.41	0.72	0.47	0.59	-0.12	0.22	0.74	0.35	0.92	-0.07	1.00
15.	-0.11	0.55	0.86	0.36	-0.10	0.25	0.46	0.05	0.05	0.61	-0.11	0.30	0.01	0.48
16.	-0.08	-0.12	0.37	-0.30	0.56	0.30	0.45	0.40	0.87	-0.07	0.16	0.27	0.30	0.47
17.	-0.54	0.56	0.61	0.23	0.31	-0.04	0.10	-0.40	-0.29	0.52	0.15	0.58	-0.24	0.55
18.	-0.12	0.16	0.44	-0.05	0.85	0.39	0.50	0.34	0.76	0.17	0.39	0.59	0.31	0.74
19.	-0.05	-0.16	0.02	-0.36	-0.24	-0.59	-0.58	-0.22	-0.42	-0.22	-0.36	-0.23	-0.20	-0.21
20.	0.28	0.02	-0.11	-0.04	-0.17	-0.58	-0.63	-0.06	-0.60	-0.09	-0.07	-0.15	0.02	-0.20
21.	-0.18	0.56	0.13	0.54	0.66	0.31	0.25	0.01	0.04	0.51	0.51	0.65	0.06	0.64

Table 6.22 *The correlation matrix for 15 year olds continued*

	15	16	17	18	19	20	21
15.	1.00						
16.	0.35	1.00					
17.	0.28	0.01	1.00				
18.	0.24	0.88	0.21	1.00			
19.	-0.06	-0.26	0.55	-0.27	1.00		
20.	-0.18	-0.54	0.43	-0.38	0.84	1.00	
21.	-0.21	0.03	0.20	0.45	-0.39	-0.12	1.00

In the PCAs conducted by Idiogrid, structure coefficients and component score coefficients are produced in both the unrotated PCA and the Varimax rotated PCA. These are presented in Appendix 6.2. The data on each of these can be plotted producing a Cartesian plane; however, for this chapter the author has opted to compare the unrotated Cartesian plane for the 13 year old, Figure 6.4, and the unrotated Cartesian plane for the combined 14 & 15 year olds, Figure 6.5 . The latter age groups were combined because of the small numbers in each group, they were combined by adding the grids into the dataset to create the average grid. The plots for unrotated factors are provided in Figures 6.6 to 6.8 . An important point to note is that the plots have been consistently made using the first and second components extracted. Generally, the first two principal components account for the majority of the variance, and two facts were considered in this respect: (i) the percentage variance accounted for by the compnents extracted; and (ii) the scree plot of the components extracted. These were found using the appropriate option under 'principal components' analysis' in Idiogrid producing Tables 6.23 to 6.26 . Although the first two principal components account for the 'majority' of the variance, noting the cumulative percentage of variance shows that this 'majority' may be rather slim. See Tables 6.23 – 6.26 where the cumulative percentage does not exceed 60% in any of the cases studied. However, if a sizeable proportion of the variation did remain, additional

components can be used in the analysis, *e.g.*, by plotting the 1st against the 3rd principal component. All 8 factors extracted are listed in Table 6.23 and the full scree plot provided, whereas only the first two factors are given in Tables 6.24 – 6.26 since the 'kick' appeared in the plot after factor 2.

Table 6.23 *The eigenvalues for 8 unrotated components for the 13 year old students*

	Eigenvalue	% Variance	Cumulative %	Scree
PC_ 1	7.59	36.12	36.12	|********
PC_ 2	4.97	23.68	59.80	|******
PC_ 3	3.10	14.77	74.58	|****
PC_ 4	1.72	8.21	82.78	|***
PC_ 5	1.58	7.55	90.33	|***
PC_ 6	1.14	5.43	95.77	|**
PC_ 7	0.61	2.92	98.68	|**
PC_ 8	0.28	1.32	100.00	|*

Table 6.24 *The eigenvalues for unrotated components for the 14 year old students*

	Eigenvalue	% Variance	Cumulative %	Scree
PC_ 1	7.03	33.46	33.46	|********
PC_ 2	4.84	23.04	56.50	|******

Table 6.25 *The eigenvalues for unrotated components for the 15 year old students*

	Eigenvalue	% Variance	Cumulative %	Scree
PC_ 1	7.60	36.18	36.18	|********
PC_ 2	4.74	22.56	58.75	|******

Table 6.26 *The eigenvalues for unrotated components for the 14 and 15 year old students*

	Eigenvalue	% Variance	Cumulative %	Scree
PC_ 1	6.66	31.74	31.74	|*******
PC_ 2	5.73	27.31	59.04	|******

Table 6.27 *The eigenvalues for unrotated components for the biologist*

	Eigenvalue	% Variance	Cumulative %	Scree
PC_ 1	8.56	40.76	40.76	|*********
PC_ 2	3.82	18.19	58.96	|*****

6.4.7 Interpreting the Cartesian plots of the loadings.

In the diagrams produced by Idiogrid are distinctive in that they are produced in colour, boxed by a border and the constructs written external to the box. Constructs are typically represented by vectors, which in the Idiogrid output are drawn in grey as straight lines

from the origin to the point plotted with the construct loadings. The construct label is printed at a point where the construct vector would cross the boundary of the box if it were propagated that far. The construct labels are printed in blue. The elements are printed as points and in black. The axes are labelled 'comp 1' and 'comp 2' to mean 'component 1' and 'component 2' respectively.

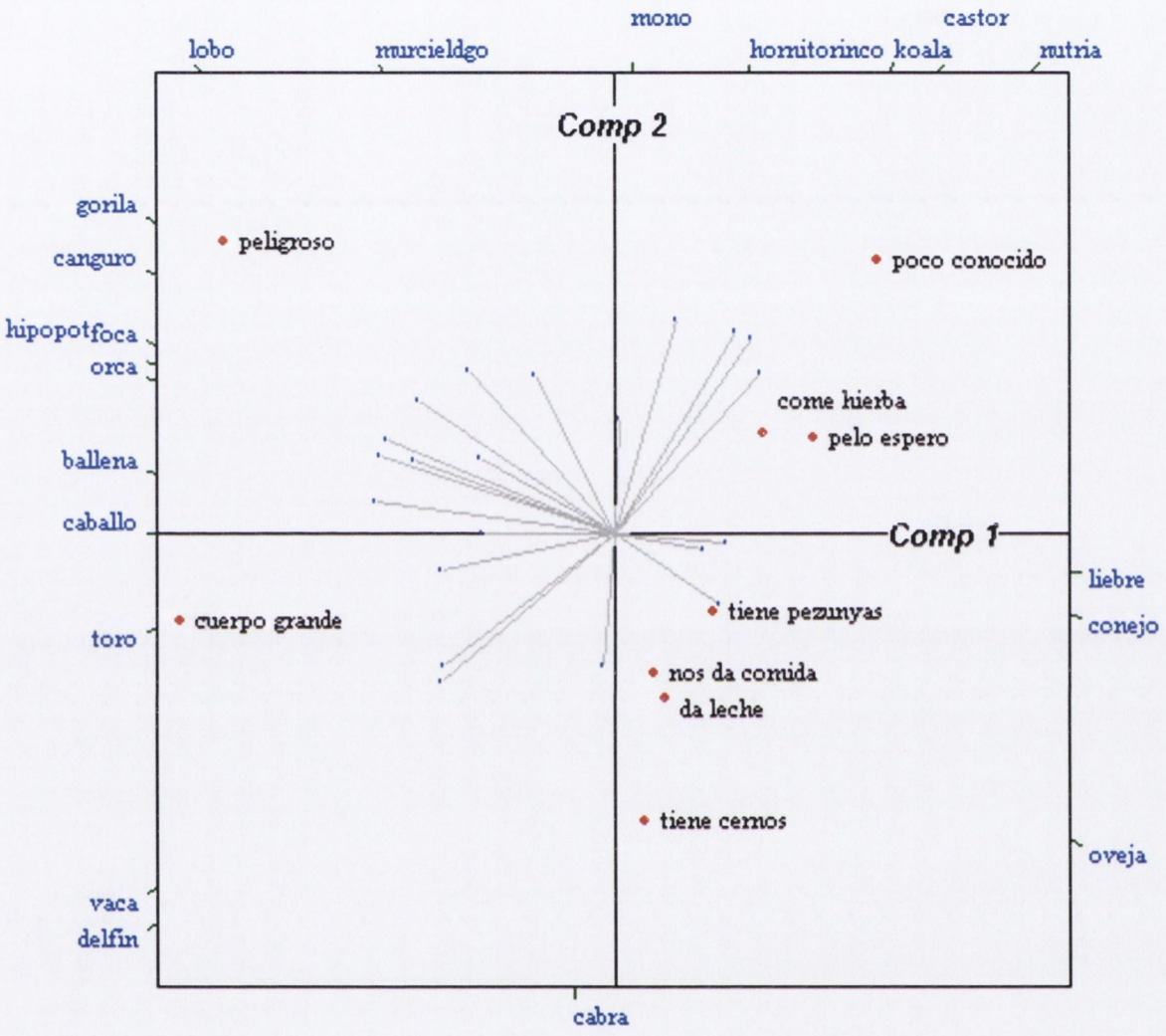

Figure 6.4. Unrotated Plot of 1st and 2nd principal components for 13 year olds with table of translations (variance accounted for: C1 = 36.12%, C2 = 23.68%)

Elements	
Spanish	English
Tiene cernos	Has horns
Da leche	Gives milk
Peligroso	Dangerous
Pelo espero	Warm skin/pelt
Tiene pezunyas	Has hooves
Nos da comida	Gives us food
Come hierba	Eats vegetation
Cuerpo grande	Large body
Poco conocido	Little known

Constructs	
Spanish	English
Murceliago	Bat
Castor	Beaver
Toro or Vacan	Bull
Mono	Chimpanzee
Vaca	Cow
Lobo	Wolf
Delfin	Dolphin
Cabra	Goat
Gorila	Gorilla
Liebre	Hare
Koala	Koala
Hipopotamo	Hippopotamus
Caballo	Horse
Orca	Killer Whale
Coneja	Rabbit
Nutria	Otter
Ornitorinco	Platypus
Kanguro	Grey Kangaroo
Foca	Seal
Oveja or Obeja	Sheep
Ballena	Grey Whale

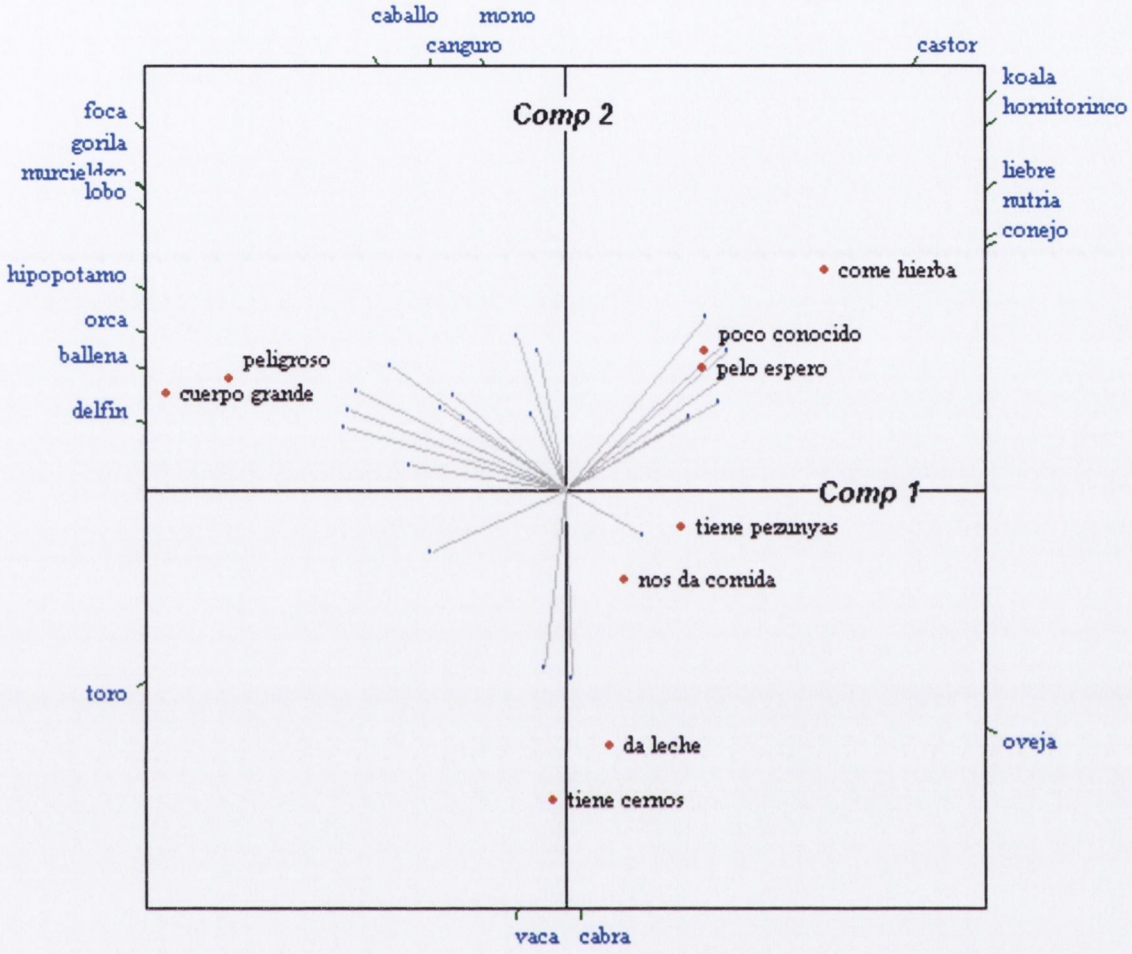

Figure 6.5. Unrotated plot of 1st and 2nd principal components for 14 year olds with table of translations (variance accounted for: C1 = 33.46%, C2 = 23.04%)

Elements	
Spanish	English
Tiene cernos	Has horns
Da leche	Gives milk
Peligroso	Dangerous
Pelo espero	Warm skin/pelt
Tiene pezunyas	Has hooves
Nos da comida	Gives us food
Come hierba	Eats vegetation
Cuerpo grande	Large body
Poco conocido	Little known

Constructs	
Spanish	English
Murceliago	Bat
Castor	Beaver
Toro or Vacan	Bull
Mono	Chimpanzee
Vaca	Cow
Lobo	Wolf
Delfin	Dolphin
Cabra	Goat
Gorila	Gorilla
Liebre	Hare
Koala	Koala
Hipopotamo	Hippopotamus
Caballo	Horse
Orca	Killer Whale
Coneja	Rabbit
Nutria	Otter
Ornitorinco	Platypus
Kanguro	Grey Kangaroo
Foca	Seal
Oveja or Obeja	Sheep
Ballena	Grey Whale

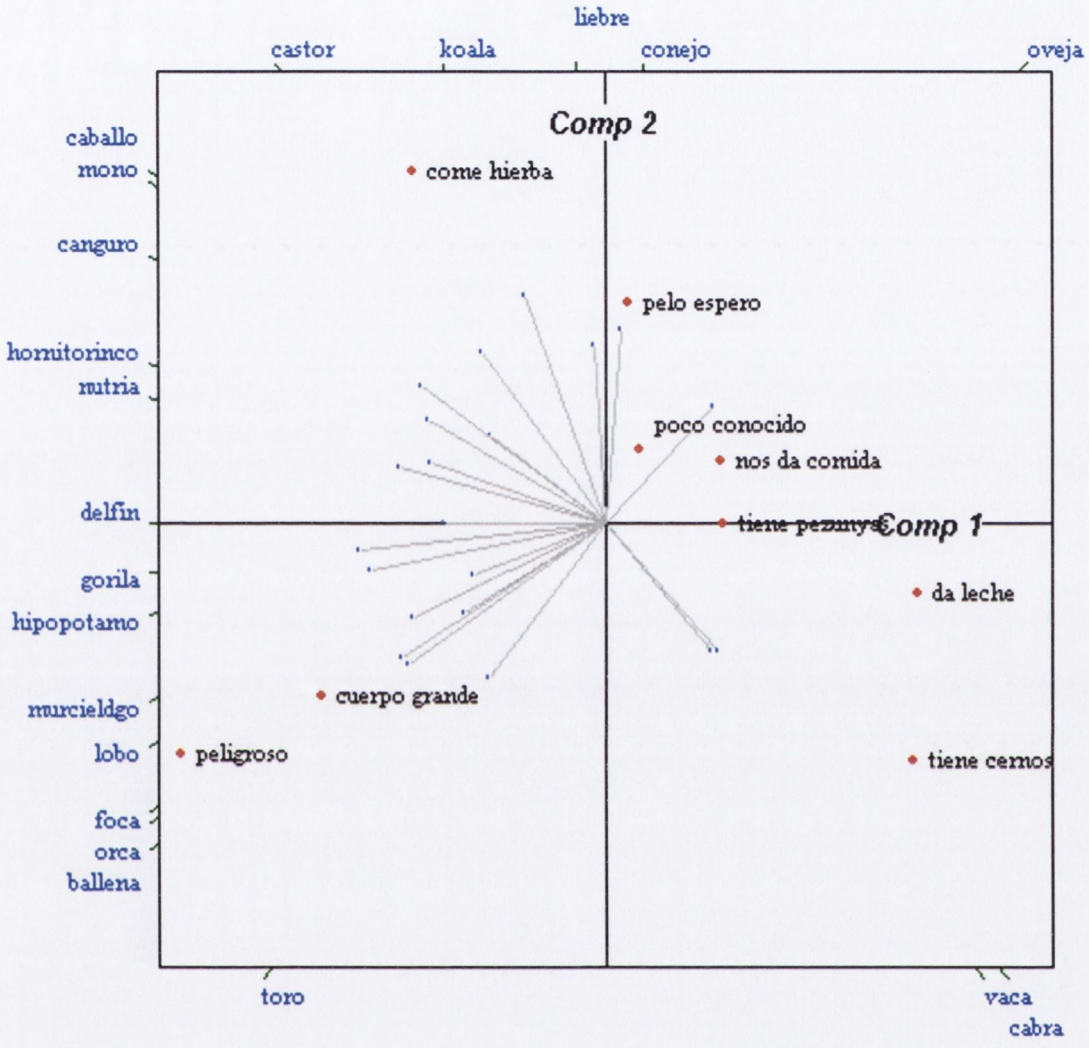

Figure 6.6. Unrotated plot of 1st and 2nd principal components for 15 year olds with table of translations (variance accounted for: C1 = 36.18%, C2 = 22.56%)

Elements	
Spanish	English
Tiene cernos	Has horns
Da leche	Gives milk
Peligroso	Dangerous
Pelo espero	Warm skin/pelt
Tiene pezunyas	Has hooves
Nos da comida	Gives us food
Come hierba	Eats vegetation
Cuerpo grande	Large body
Poco conocido	Little known

Constructs	
Spanish	English
Murceliago	Bat
Castor	Beaver
Toro or Vacan	Bull
Mono	Chimpanzee
Vaca	Cow
Lobo	Wolf
Delfin	Dolphin
Cabra	Goat
Gorila	Gorilla
Liebre	Hare
Koala	Koala
Hipopotamo	Hippopotamus
Caballo	Horse
Orca	Killer Whale
Coneja	Rabbit
Nutria	Otter
Ornitorinco	Platypus
Kanguro	Grey Kangaroo
Foca	Seal
Oveja or Obeja	Sheep
Ballena	Grey Whale

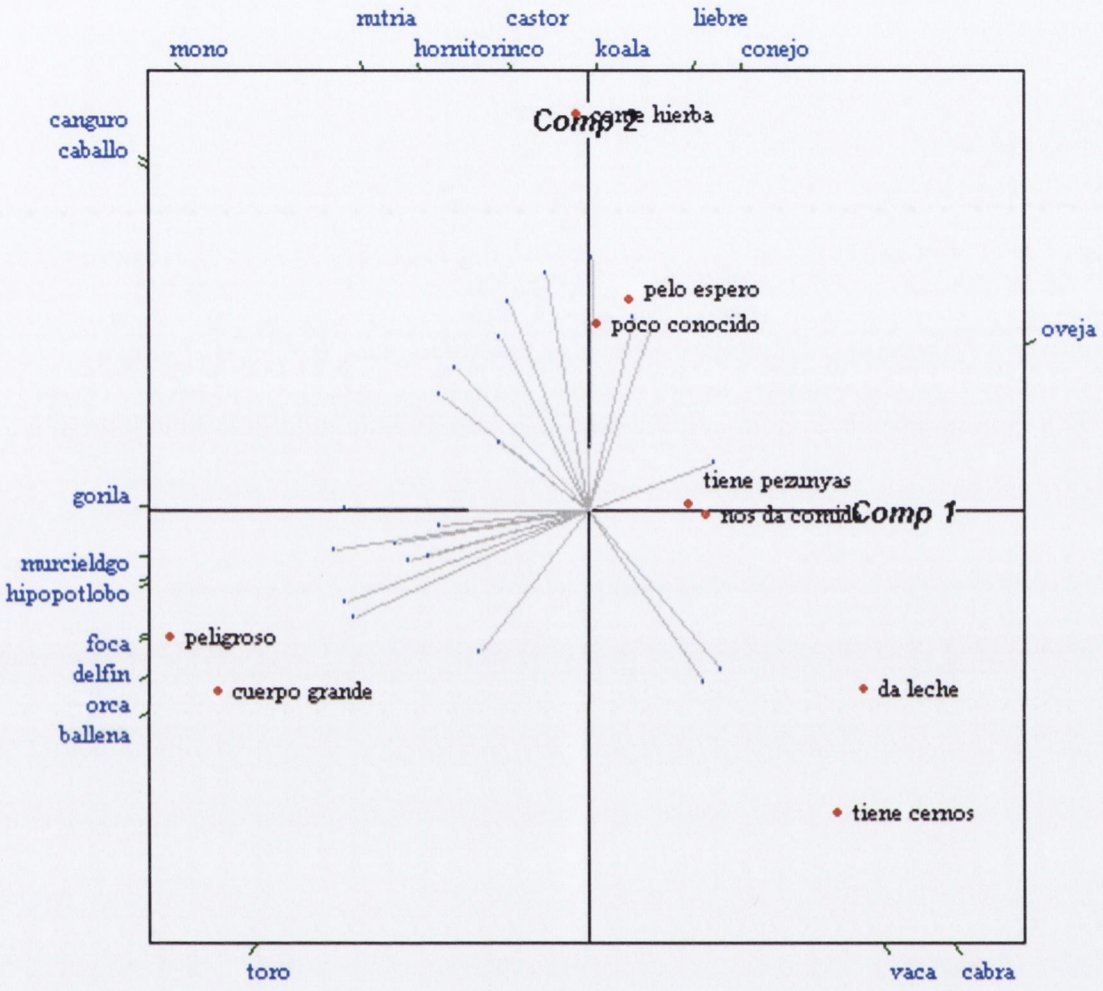

Figure 6.7. Unrotated plot of 1st and 2nd principal components for 14/15 year olds with table of translations (variance accounted for: C1 = 31.74%, C2 = 27.31%)

Elements		Constructs	
Spanish	English	Spanish	English
Tiene cernos	Has horns	*Murceliago*	Bat
Da leche	Gives milk	*Castor*	Beaver
Peligroso	Dangerous	*Toro or Vacan*	Bull
Pelo espero	Warm skin/pelt	*Mono*	Chimpanzee
Tiene pezunyas	Has hooves	*Vaca*	Cow
Nos da comida	Gives us food	*Lobo*	Wolf
Come hierba	Eats vegetation	*Delfin*	Dolphin
Cuerpo grande	Large body	*Cabra*	Goat
Poco conocido	Little known	*Gorila*	Gorilla
		Liebre	Hare
		Koala	Koala
		Hipopotamo	Hippopotamus
		Caballo	Horse
		Orca	Killer Whale
		Coneja	Rabbit
		Nutria	Otter
		Ornitorinco	Platypus
		Kanguro	Grey Kangaroo
		Foca	Seal
		Oveja or Obeja	Sheep
		Ballena	Grey Whale

In Figure 6.4 (13 year old students), and Figure 6.5 (14 year old students), Figure 6.6 (15 year old students), and Figure 6.7 (combined 14/15 year old students) several clusters of concepts are evident. *Liebre (hare), conejo (rabbit)* are found together in a place on the plots that is not governed by any clear feature and yet *liebre* and *conejo*, were ranked similarly. This is not surprising since they are difficult to distinguish for the layperson. Experience of hares tends to be somewhat counterintuitive as they appear 'over sized' rabbits, and so it is conceivable that they could have been characterized 'better' by the element *cuerpo grande (large body)* than *nos da comida (gives us food) – note that the vectors are relatively short for these constructs*. The 14 and 15 year old students (Figures 6.5 and 6.6) characterized these constructs with the elements, *pelo espero (warm pelt)* and *come hierba (eats vegetation)*, since with this logical cluster also were situated the unrelated mammals *nutria (otter), koala, castor (beaver)* and *hornitorinco (platypus)* in

Figure 6.5 and *koala* and *castor (beaver)* in Figure 6.6 . This demonstrates a feature of RGA that was met earlier with the work on Equids. The principal components are calculated from the whole grid and that the loadings plotted therefore contain relative information concerning all the constructs. Thus in Figure 6.5 *come hierba (eats vegetation)* is the most dominant element as demonstrated by the length of the vector (though plotted as a point), concerning the *otter, beaver, platypus, koala, rabbit* and *hare*, but that *pelo espero* was important ('soft furry animals'), but so too *poco conocido (little known).*

Again, in Figures 6.4 to 6.7, *cabra* and *vaca* (*goat* and *cow* respectively) are clustered. They are loosely clustered in Figure 6.4 between the features, *cuerpo grande (large body)* and *tiene cernos, (has horns)* (and near *delfin (dolphin)* due to the influence of the element of *cuerpo grande (large body)*). Nearby, are the features *da leche, (provides milk),* and *tiene pezunyas*, (has hooves) in Figure 6.5 to 6.7; and the constructs *cabra* and *vaca* (*goat* and *cow* respectively) are more tightly clustered in the older age-groups. Between this cluster and a large cluster defined by *cuerpo grande, (large body),* and *peligroso, (dangerous),* lies the cluster consisting of *caballo, delfin* and *toro, (horse, dolphin and bull). Bull* is placed between the large cluster defined by *cuerpo grande, (large body),* and *peligroso, (dangerous)* and the opposing direction defined by *tiene cernos, (has horns). Murcieldgo, (bat),* is placed between *poco conocido, (little known),* and *peligroso, (dangerous)* in Figure 6.4. In Ireland there is a spurious traditional belief that bats habitually become entangled in one's hair, thus characterising *bat* as dangerous is consistent with such a cultural constraint, so too the constraint on characterising *bull* as totally different from *cow* when only the gender differs. The overriding quality of *bull* is

large body (Figure 6.4) and *dangerous* (Figure 6.6), but more often than not, *bull* is placed between these elements.

Scientifically, all mammals are defined as animal that provide milk or suckle and this was one of the features in the repertory. Conceptions of embryonic history were not investigated in this study. However, giving milk, *da leche*, only had a role in characterising *vaca (cow)* and *cabra (goat)* in Figures 6.4 – 6.7 . Animals that were little known to both groups were *koala, castor (beaver), nutria (otter), and, hornitorinco (duck-billed platypus)*. Even though much can be said from the plots of the grids, a more clearly defined means of inducing propositions from the positions of the plots is needed.

Overall, we see that many of the rationales for including certain constructs in the array of stimuli were justified, and answers were provided to some of the questions: for example, how does does a flying mammal relate to quadrupeds? (Table 6.2). Bats were clustered with other mammals considered dangerous. Whales were constrained by size (large body), koala is little known except that it has a warm pelt. Would there be cultural constraints with horse? Horse (Figure 6.4) is located between large body and gives us food (horsemeat is eaten in Spain). Rabbits were confused with hares. Aquatic quadrupeds such as otter and beaver were clustered with others as little known as indeed they are in semi-arid Valencia.

6.4.8 Comparison of two grids: the students versus a biologist.

Idiogrid can compare two or more grids by means of creating a difference grid. This is effectively where one grid has been subtracted from another. The larger the number the greater the difference, and if a minus sign is present, the difference is in the direction of

B→A rather than A→B. Helpfully, the direction of the comparison is printed after the table.

Table 6.29 is the difference grid for the average grid for the 13 year olds and the biologist (the same biologist as the first biologist in the study on Equidae). We see that the greatest differences for the broadest group of animals lay in element 2, *da leche*, provides milk, and element 4, *pelo espero*, fur coat. These are of course the fundamental elements in terms of defining *mammalia*. Another element, gives birth to live young, was deliberately omitted as it would have made the instrument too easy. Even though the students can define *mammalia* when asked to do so as in a test, when the problem is approached from a different angle as in the RepGrid study, an underlying framework becomes apparent. The students revert to their naïve understanding of the animals in terms of dangerous or in terms of size. This demonstrates the great potential for RGA in helping to uncover such naïve understandings.

Table 6.29 *Difference Grid (Average Grid for 13 year olds - Biologist) and table of translations*

	1	2	3	4	5	6	7	8	9
orejo	-0.80	0.20	-0.83	-1.05	-0.95	-0.39	-0.73	-0.61	-0.86
ballena	-0.52	-1.36	0.14	-0.55	-0.55	-0.83	-0.52	-1.30	-0.49
lobo	-0.59	-1.19	0.94	-1.03	-0.28	-0.44	0.06	-0.13	-0.34
foca	-0.45	-1.14	0.89	-1.45	-0.45	-0.55	-0.42	-0.39	-0.02
canguro	-0.72	-1.25	-0.72	-0.97	-1.16	-2.50	-0.22	0.00	-0.47
hornitorinco	-0.53	-1.41	0.56	-1.19	0.03	-0.41	-0.97	-0.53	1.44
nutria	-0.48	-1.07	-0.16	-1.04	0.02	-0.23	-0.85	-0.48	1.27
conejo	-0.64	-1.32	-0.57	-0.95	-0.17	-0.45	0.21	-0.64	-0.48
koala	-0.65	-1.27	0.14	-0.77	-0.30	-0.52	-0.02	-0.65	1.04
orca	-0.59	-1.37	-0.47	-0.59	-0.59	-0.03	-0.59	-0.56	-0.22
caballo	-0.79	-1.42	-0.64	-1.39	-2.64	-1.23	-0.73	-0.42	-0.76
hipopotamo	-0.63	-1.26	-0.51	-0.60	-1.04	-0.54	-1.19	-1.85	-0.38
liebre	-0.57	-1.26	-0.54	-0.69	0.02	-0.94	-0.04	-0.57	-0.41
gorila	-0.65	-0.43	0.57	-1.80	-0.52	-0.61	-0.86	-2.15	-0.55
murcieldgo	-0.37	-0.99	0.98	-0.93	-0.21	0.13	-0.31	-0.37	0.07
castor	-0.56	-0.99	0.10	-1.62	-0.12	-1.31	-0.46	-0.56	0.51
toro	-0.17	-0.83	-0.14	-1.51	-0.98	-1.08	-0.92	-0.55	-0.83
mono	-0.43	-1.15	0.19	-0.12	-0.34	-0.43	-0.40	0.03	-0.34
cabra	-0.20	-0.42	-0.73	-2.48	-0.89	-0.98	-0.89	-0.64	-0.79
vaca	-0.91	-0.51	0.02	-1.35	-1.19	-3.07	-1.16	-0.41	-0.41
delfin	0.14	-0.70	-0.05	-0.36	-0.14	-0.01	-0.11	0.58	-0.36

Note. Biologist was subtracted from Average Grid.

General Degree of Correlation between the two Grids = 0.60

Elements	
Spanish	English
Tiene cernos	Has horns
Da leche	Gives milk
Peligroso	Dangerous
Pelo espero	Warm skin/pelt
Tiene pezunyas	Has hooves
Nos da comida	Gives us food
Come hierba	Eats vegetation
Cuerpo grande	Large body
Poco conocido	Little known

Constructs	
Spanish	English
Murceliago	Bat
Castor	Beaver
Toro or Vacan	Bull
Mono	Chimpanzee
Vaca	Cow
Lobo	Wolf
Delfin	Dolphin
Cabra	Goat
Gorila	Gorilla
Liebre	Hare
Koala	Koala
Hipopotamo	Hippopotamus
Caballo	Horse
Orca	Killer Whale
Coneja	Rabbit
Nutria	Otter
Ornitorinco	Platypus
Kanguro	Grey Kangaroo
Foca	Seal
Oveja or Obeja	Sheep
Ballena	Grey Whale

6.4.9 Distillation of the results

We began looking at this study with reference to Table 6.2 . In Table 6.30, Table 6.2 is repeated with respect to the names and rationale for placing the pictures in the study; however, the information obtained about these natural kinds from the PCA and original grids is summarized. It was noted that certain animals (beaver), because they are not found in Valencia, were cluster with animals not really related to them (otter, platypus) due to some superficial resemblance. Some mammals were grouped according to agricultural association (sheep, goat, cow) while others (bat, bull, killer whale) were clustered according to perceived danger or size. The cultural constraints of a bat being dangerous and of a horse as being edible was evident. The element gives milk – a key feature of mammals – was provided, but this was only deemed significant for constructs such as goat and cow. Only a very small number of students take this element and score high against all mammals in spite of being able to 'define' the word mammal without difficulty. In terms of RGA, this system of elicitation and scoring appears to assist educators document divergences from the formal scientific viewpoint concerning mammals.

6.4.10 Conclusion

We have seen that a problem with large datasets is to find an average of some sort. In this chapter, averaged grids were constructed and PCA were then performed on these new grids. This is an important step toward whole-class comparison or summarizing. In the next chapter, Chapter 7, the study takes a specific example of mammals, the horse-like

animals: the Equidae. It is anticipated that RGA will help uncover underlying naïve understandings concerning the Equidae as was found concerning the mammalia.

Table 6.30 *Details of the information gained from RGA on the visual stimuli used in the study on mammals*

English Name	Rationale for inclusion	Observations from the plots of the loadings and original grids
Bat	How does a flying mammal relate to quadrupeds	Classified as a dangerous animal and clustered with bull, killer whale etc.
Beaver	Unknown in Valencia	Classified as a herb eater and little known
Bull	Hypothesising a cultural constraint	Classified as being dangerous, having horns and a large body
Chimpanzee	How does this mammal relate to other mammals?	Vaguely, inbetween clusters
Cow	The relationship to other cattle	Cows and goats have horns and give milk
Wolf	Hypothesising constraint as a dangerous animal	As per bat
Dolphin	How does an aquatic mammal relate to quadrupeds	Firstly it is classified in a cluster with whale and orca: dangerous and big body
Goat	The relationship to other cattle	As per cow
Gorilla	Hypothesising constraint as a dangerous animal	As per bat
Hare	Confused with a rabbit?	Close to rabbit
Koala	Would this marsupial be classified with others	As beaver
Hippopotamus	How would a water quadruped be classified?	Classified between the whales and dolphins and bat, wolf, gorilla group
Horse	Would there be cultural constraints with horse?	In the grids many children described horses as animals that provided meat
Killer Whale	Would this be classified closer to whale or dolphin?	Closer to whale
Rabbit	Confused with hare?	Classified closely with hare
Otter	How would a water quadruped be classified?	As beaver
Platypus	How would a monotreme be classified?	As beaver
Grey Kangaroo	Would this marsupial be classified with others	As horse
Seal	How does an aquatic mammal relate to quadrupeds	As per bat
Sheep	The relationship to other cattle	Between cow/goat and the beaver group
Grey Whale	Constrained by size	Large body is the main characteristic and dangerous is second

Chapter 7 Explorations with natural kinds and repertory grids: *Equidae*

> *"As all the species of the same genus are supposed to be descended from a common progenitor, it might be expected that they occasionally vary in an analogous manner; so that the varieties of two or more species would resemble each other, or that a variety of one species would resemble in certain characters another and distinct species, – this other species being according to our view, only a well-marked and permanent variety.* [...] *It might further be expected that the species of the same genus would occasionally exhibit reversions to long lost characters."*
>
> Darwin (1876, p. 126 – 128)

Figure 7.1 is the concept map for this chapter. The Equidae[22] hold a special place in the evolution of human cognition since they have themselves evolved concurrently with the Hominidae[23] and it is thought that there was interaction between these two groups of animals. Images of equids have appeared in neolithic cave paintings and the finds of Equid and Hominid fossils and bones have pointed to a general coexistence in terms of time and space[24]. Equids hold a special place in the social and religious history of humans, many mythical creatures assumed the form of an equid or an equid transformed into another kind; *e.g.*, Centaur[25], Pegasus[26], Unicorn[27], or the recently invented "Hippogriff" from J.K. Rowling's 'Harry Potter' series of books. Other animals, though not obviously Equids have had Equid attributes ascribed to them *e.g.*, the hippopotamus

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[22] i.e., the horse-like animals
[23] i.e., the human-like animals
[24] Johanson & Edey (1981, p. 180) discuss the role equine teeth fossils take in dating early hominid fossils
[25] For a graphic, see http://blogs.warwick.ac.uk/images/victoriagalloway/2005/04/29/p4280002.jpg
[26] For a graphic, see http://www.library.yale.edu/MapColl/pegasus.GIF
[27] For a graphic, see http://www.tchevalier.com/unicorn/img/croppedsight3.jpg

from the Greek[28] for 'river horse'. It also appears that humans hold fairly definite views of what a horse should look like, despite the previous example. For example, Keil (1996) chose the example of *horse/zebra* pair in testing notions concerning transformations from one kind to another because of the definite notions children hold for these two categories.

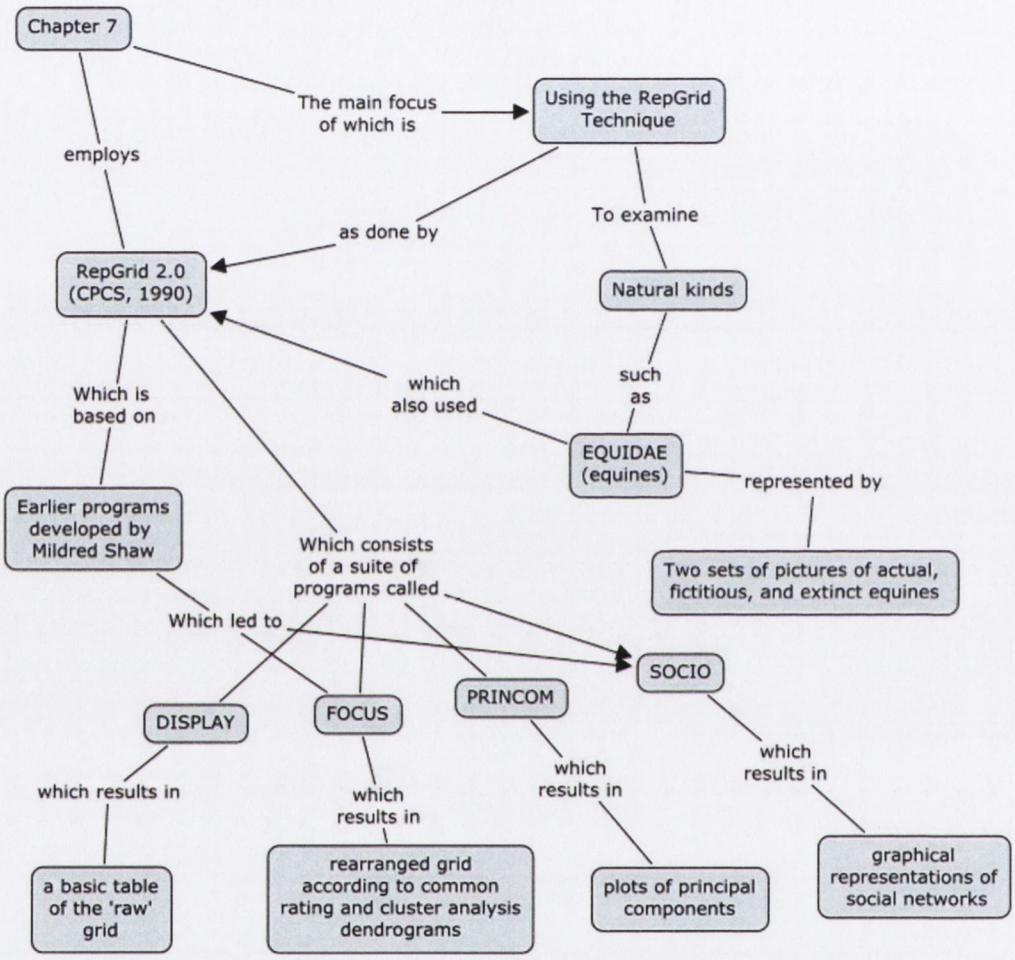

Figure 7.1 A concept map of Chapter 7 as drawn in Cmap Tools

Darwin, writing in the 19th century, collected a great deal of anecdotal evidence of instances which appeared to support the idea of a common ancestry among a disparate group of animals. Usually, the examples he chose gave indications of "reversion to long

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[28] ἱππο-πότᾶμος

lost characters" or features. The example used in *Origin of the Species* was that of the equids, which he describes as a "*curious and complex case": "the ass sometimes has very distinct transverse bars on its legs, like those on the legs of the zebra*" (Darwin, 1876, p. 126). Darwin also cited examples concerning an unfamiliar array, to western eyes, of equids such as koulan, hemionus, and kiang. What interested him was the observation[29] that leg stripes and shoulder stripes "*appear in a range of horses of different breeds in various countries from Britain to Eastern China; and from Norway in the north to the Malay Archipelago in the south*" (Darwin, 1876, pp. 128 – 129). Aside from the obvious counter-intuitive experience of observing a horse with stripes on its legs, would such an experience distract the observer from the 'normal' cogniscizing of a horse? As Darwin points out, such features "*would probably be of an unimportant nature, for the preservation of all functionally important characters will have been determined through natural selection*" (Darwin, 1876, p. 126 – 127). Furthermore, as we shall see, zebra are typically characterised as having stripes. However, suppose a zebra is placed among an array of animals all possessing stripes of one type or another, or zebra who have had their stripes removed or altered in some way; how will a student distinguish and classify such an array?

Keil (1996, p. 197ff.) investigated whether a descriptive transformation from horse to zebra[30] would be accepted by three age groups of children, *i.e.*, 5:6, 7:7 and 9:8 years, from elementary schools in the Ithaca area of New York. Using a score of 1 to signify acceptance that a change of type had taken place; a score of 2 to denote some uncertainty,

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[29] The author has observed leg stripes in donkeys in his former role as a trained farrier of donkeys

[30] Keil (1996) presented the students with a before and after photograph and read a text describing the transformation

and a score of 3 to signify that a change of type had not taken place, Keil (1996, p. 200) reported an mean score of 1.79, 1.92 and 2.87 for the three age groups respectively. Thus, as the children got older, they became more certain that the horse had not changed into a zebra. In another study, the horse-to-zebra transformation was represented in three photographs, *i.e.*, a 'before', 'after' and an 'intermediate' half zebra-half horse. Such a transformation was conceptualised as a change in permanent surface parts, as the children got older they were more resistant to the idea that the horse transformed into a zebra[31].

In the study that follows, two arrays of equids were presented to older children than Keil (1996) used in his studies. Two sets were produced originally because it was the authors experience in using the software in Chapter 6, that six was the minimum number of constructs permitted, and it was felt that the array of stimuli should be kept to a minimum in each elicitation. Acording to Keil (1996) they should be resistant to transformations between natural kinds. For this reason, the author has chosen equids to be the subjects of the following study, to determine what insights may be gained from applying RGA to biological natural kinds such as equids.

7.1 Distinguishing equids

Two sets of six equid images were presented to secondary school students (n = 110 of which 95 completed the task) over five years (out of six) in a large community school[32] in Ireland. The examples of equids chosen were a mixture (in two sets) of conventionally familiar (in that a lay person should be reasonably able to identify the images) and less

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[31] A different set of groups were used for this second study

[32] A community school is an inclusive non-denominational and mixed gender school. Secondary schooling in Ireland is from 12 until 18 years.

familiar (*e.g.*, extinct and fictitious taxa). They were *quagga, zebra, horse*, the *appaloosa* breed of horse, the *melanic zebra* and the *speckled zebra* in the first set; and *mountain zebra, dartmoor* breed of horse, *plains zebra, Mesohippus, quagga*, and *Eohippus* in the second set, see Table 7.1 .

Table 7.1 *Descriptions of the images in the equid study*

Set	English Name	Latin Binomial	Graphic Style	Rationale for inclusion
First	Horse	*Equus caballus*	bitmap	this is a stereotype of an equid, a basic example but with stripes on its leg
First & Second	Melanic zebra	*Equus burchelli*	bitmap & cartoon	a rare form of plains zebra resulting from a genetic state which caused a large deposition of melanin in the coat of this individual.
First	Speckled zebra	*not applicable*	bitmap	an imaginary equid
First	Plains zebra	*Equus burchelli*	bitmap	this is a stereotype zebra, the common image of a zebra
First & Second	Quagga	*Equus burchelli quagga*	bitmap & cartoon	a subspecies of the plains zebra. It is extinct at present but attempts are being made to 'resurrect' this subspecies.
First	Appoloosa	*Equus caballus*	bitmap	this is a north American breed or horse with distinctive coat markings that appears counter intuitive to Europeans
Second	Dartmoor	*Equus caballus*	cartoon	an ancient breed of horse of a shape and habit that humans would have been more accustomed to than 'modern' thoroughbred types
Second	Mountain zebra	*Equus zebra*	cartoon	a zebra that appears to the untrained eye to have extra stripes
Second	Eohippus	*Hyracotherium*	cartoon	extinct, a small horse like animal with multiple toes about the size of a large dog
Second	not appliable	*Mesohippus*	cartoon	extinct, a relatively small horse but with cloven feet

For the images that are described in Table 7.1, shape, size and 'habit' (*i.e.*, poise) were factors that were kept constant, in fact all of the equids were an edited bitmap of the left-most zebra shown in Figure 7.2 . Each student (n=110), in five year groups, was given the following items that are listed in Table 7.2:

Table 7.2 *The items given to all the students*

Item	Location in this thesis
Information sheet and examples of completed grids	Appendix 7.1
Pictures of the equids, i.e., the constructs (note that the actual graphics are provided in Appendix 7.2)	Figure 7.3; Figure 7.4
List of features to choose elements from	Table 7.3

A list of 30 features, Table 7.3, and a worksheet, Appendix 7.1, was presented to secondary level students in Autumn together with Table 7.1 and they had to choose a feature that best described the first animal; another feature that best described the second and so on. They then had to rank each feature in turn with each animal thus again producing a matrix of six columns by six rows. Thus each student was given two empty test grids, two pages of images, a worksheet and a list of features to choose from, Table 7.2. The images in Figure 7.3 were made by deleting the pixels around the zebra and altering the coat pattern or body shape. This was done using Microsoft Paint in Windows '95. The images in Figure 7.4 were made by tracing through tracing paper an outline of the zebra in Figure in 7.2, copying the trace image, and altering the trace image to produce the various equids. Note that both 7.3 and 7.4 represent thumbnails of the actual images given to the students, which were also of a higher quality.

Figure 7.2 The core graphic from which the stimulus pictures were derived, Obtained from http://www.africa.upenn.edu/Wildlife_GIFS/Zebras_Striped_13286.gif last accessed 15th June 2006.

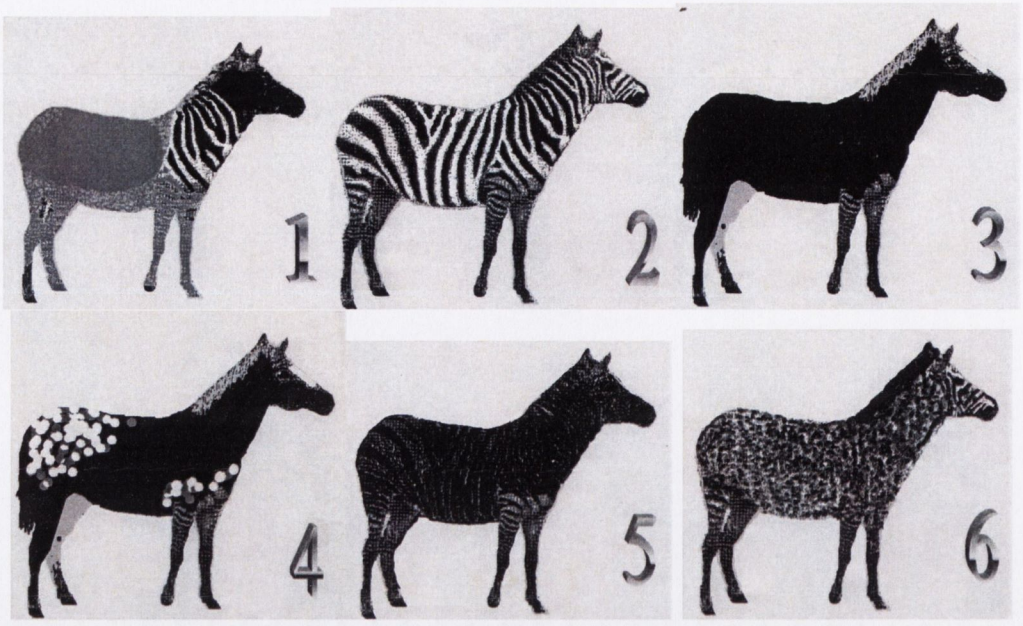

Figure 7.3 The first set of equids

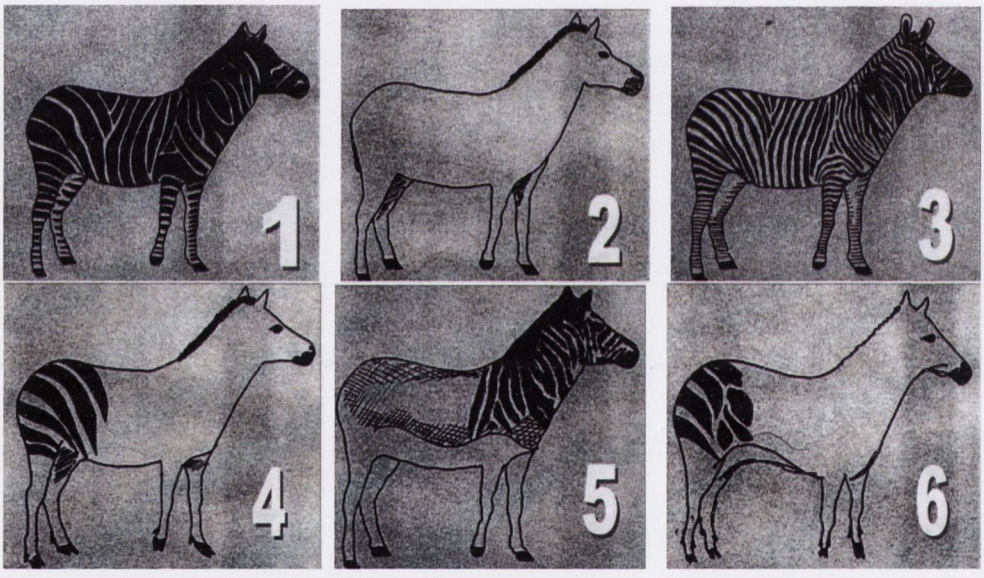

Figure 7.4 The second set of equids

Table 7.3 *List of features for the students to choose from*

Category of feature	Feature for the student to choose from
Features pertaining to stripes	Having stripes regardless of number
	Having a specific number of stripes
	Having stripes in a specific place on the body
	Having a specific colour of stripes or body
Features pertaining to the mane of an equid	Having a tall erect mane
	Having a fallen mane
	Not having a mane at all
Features pertaining to the tail of an equid	Having a tail covered in long hair
	Having a tail which has long hair only at the tip
Features pertaining to the feet of an equid	Having a hoof (single toe)
	Having a cloven foot (less than five but more than one toe)
	Having a 'chestnut' (vestigial toe-nail high on the inside leg)
Other features pertaining to an equid	Having a white belly
	Having large rounded ears with long hair on the inside
	Having a prominent (i.e., visible) jawbone
	Having a 'drop' of skin between the head and front legs obscuring the jawbone, i.e., a thick neck
	Having a horizontal body with rounded rear end and vertically arranged legs
	Having long legs raising the trunk about half the trunk's length off the ground

In Table 7.3, the features or, elements, may be grouped into five distinct categories of characteristic feature: (i) stripes; (ii) mane; (iii) tail; (iv) feet; and (v) other features. These features as with those used in the previous studies in Chapter 5 were elicited from the students by asking them first to define a horse and a zebra and then through a process of questioning to expand the students' key terms to produce subcategories. For example, the students typified a *zebra* as *having stripes*. The author asked the students whether it was important to know how many stripes a *zebra* has and where. The students felt that it was important, that in fact only two or three stripes did not constitute a *zebra* but some hitherto unknown animal; something in fact like a *quagga*, which the students had not yet been exposed to. It would be important to ascertain which features, in RGA called the 'elements', formed the most consistent strategy in differentiating this group of biological natural kinds concepts. It is critical that the elements relate to the task and are not

irrelevant to the constructs being elicited, in other words, elements should not be supplied as distractors in the sense of objective reasoning tests. Implied in Kelly's 'Range Corollary', elements should be within the range of convenience of the constructs used (Fransella *et al.*, 2004, p. 18) and Kelly's third assumption of the 'RepTest' is that elements should be representative of the area being investigated Kelly (1991, p. 161 and cited in Fransella *et al.*, 2004, p. 18).

7.1.1 Computer elicitation

The resulting matrices were entered manually by the author into the computer program RepGrid 2.1, a task requiring the input of some several hundred data items, Appendix 7.3, and see Appendix 7.4 . The four main stages of Repertory Grid technique are stated in the opening tile: (i) defining the purpose of the study (done by the researcher, which is to determine the viability of repertory grid analysis in representing the mental structuralisations of scientific concepts such as biological natural kinds concepts); (ii) eliciting relevant elements (done by the students prior to data being entered on a computer); (iii) distinguishing relevant constructs (done by the students prior to data being entered on a computer); and (iv) deriving the cognitive structures of the learners' concepts (done by the computer carrying out principal components analysis on the original grids producing graphical representations of the cognitive structures).

7.1.2 Data entry – elements

To begin entering the collected data, a new grid must be made. In this thesis, the 'starter' grid was begun by adding the elements first followed by the constructs. This process was repeated for as many elements as exist for the first grid to be entered (subsequent grids

will be an editted version of this first grid), until all the elements are shown in the grids window.

7.1.3 Data entry – constructs

Entering constructs was done using a new window showing the construct as a vector (drawn as a black vertical bar) and the elements list to the left of the vector. The explicit construct *e.g., horse*, is typed in the appropriate box; on clicking return, the 'opposite description' is highlighted and the implicit construct is entered in the blue box *e.g., not horse*, (meaning not horselike).

7.1.4 Rating / ranking the elements to the constructs

The elements were connected to the contruct vector so that the ranking used on the original grid is maintained. This is done by dragging each individual element to the vector at a point which represents the rank of the element. The vector was drawn with as many hotspots to attach elements as were ranks specified in the range in the elicit window

Once all the elements have been added, the grid has been fully entered. For subsequent grids, it is a matter of editting the first grid and renaming it to generate the grids for the other subjects. This involves changing the element titles if required and the position of the attachment on the construct vector. Some grids vary in both ways whereas others change in only one and rarely some grids are identical, requiring only to be saved under a different name.

7.2 Results from the studies on equids

The raw grids are provided in Appendix 7.3 . In the sections that follow, the results concerning the first set of equids stimuli is presented separately from those from the

second set. They will be compared to the grids of two 'experts': one a general biologist with experience of large animals, and the other (CJB), a specialist in fish parasitology. It will be seen that the grids belonging to the former display a model close to the formal scientifc model. CJB tends to do as the students do and focus on one or more key superficial traits, such as the presence of stripes.

7.2.1 Displaying a grid

The software displays the original grid according to parameters specified by the user, Figure 7.5 . Throughout this thesis, the parameters are those indicated in Figure 7.5, namely, a graphical display (as opposed to a text file) showing the title, and indicating patterns in the grid.

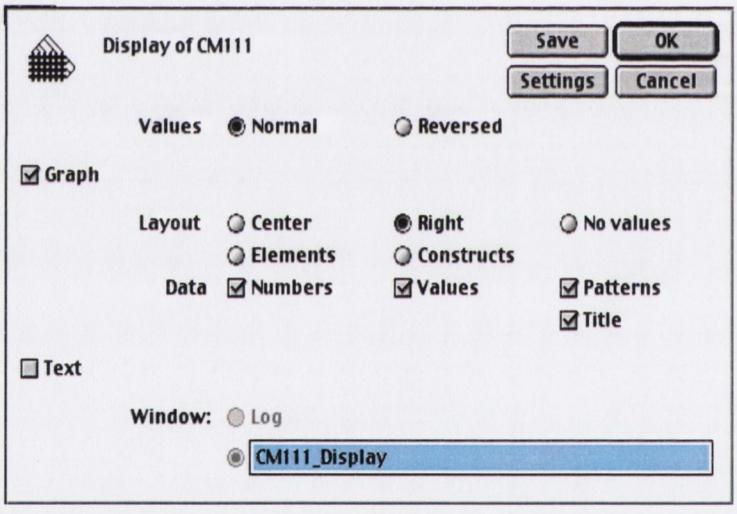

Figure 7.5 Parameters of DISPLAY

Display: PK111
Elements: 6, Constructs: 6, Range: 1 to 6, Context: equines

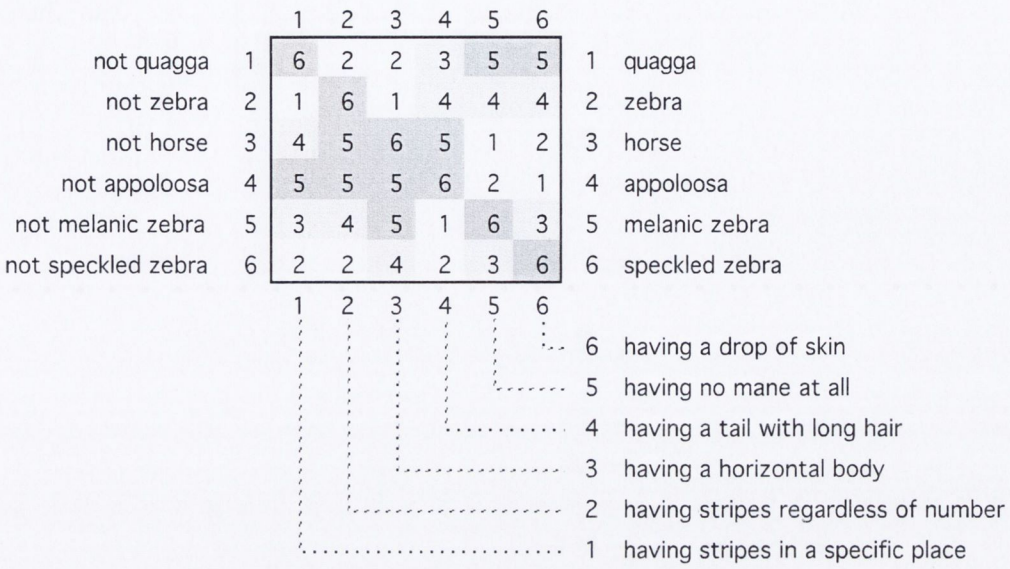

Figure 7.6 Output of DISPLAY FOR PK111

Figure 7.6 is presented as an example of the grid produced in this type of RGA. PK111 characterises *quagga* mostly as *having stripes in a specific place* and a *zebra* as *having stripes regardless of number*. These are obvious visual descriptions, however, it becomes difficult to separate the *horse* and *appoloosa*, which is a breed of *horse*. Notice the score of 6 and 5 for *having a horizontal body* and *having a tail with long hair* for *horse* Then because the *appoloosa* cannot be distinguished easily using the available features, PK111 gives a respective score of 5 and 6 to these features. For PK111 these equids are almost the same. *Melanic zebra* and *speckled zebra* are given features that might be construed as vague – four of the features for *speckled zebra* were given the near median ranking of 3 whilst three of *melanic zebra's* ranks were 4's. Ranks considered to be unambiguous would be 1's or 6's. Another degree of ambiguity arises from the choice of a superficial non-diagnostic feature such as the mane. The shading in the grids allows the user to observe quickly where the higher value integers are dispersed.

7.2.2 Grids of the first set of equid images

Figures 7.7 to 7.11 are the output graphics of the grids for one of each of 1st, 2nd, 3rd, 4th and 5th year student. These were chosen from the whole cohort as representative of the year groups, however the basis of the choice will be explained later in greater detail as it extends beyond the scope of this section.

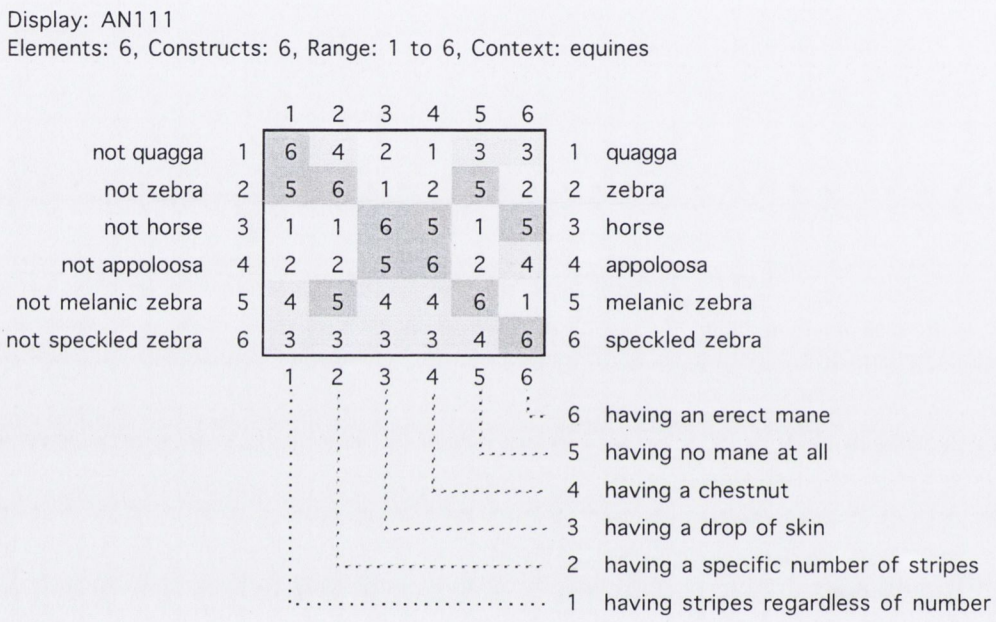

Figure 7.7 A representative grid from first year

As with Figure 7.6, AN111, Figure 7.7, characterised *quagga* and *zebra* strongly with features relating to *stripes*. *Horse* and *appoloosa* were characterised by *having a drop of skin* and *having a chestnut* respectively. Thus a box appears at the intersection of *horse* and *appoloosa*. *Melanic zebra* and *speckled zebra* were again characterised somewhat ambiguously as described in the previous section. The features chosen to best characterise *horse* and *appoloosa* were *having a chestnut* and *having a drop of skin*:

having a drop of skin was scored 6 against horse and 5 against appoloosa – then having a chestnut was scored 5 against horse and 6 against appoloosa. This may seem a somewhat arbitrary arrangement of scores, however individual elements are not all-important. Rather, in this type of task, how the constructs are represented to relate to each other is important. This is one model of categorization that differs from those presented in Chapter 3. In Chapter 3, a computational model was presented where similarity depends on the features chosen. Here too, features are chosen, however the learner has an underlying sense of similarity and yet difference and it is a source of cognitive conflict to use the feature list given to the students. The model alluded to above appears to operate in the 3rd, 4th and 5th years, Figure 7.9; Figure 7.10 and Figure 7.11 respectively. ABr211 is different. This student did not adhere to the rules of the task: she/he chose an element twice and omitted a construct.

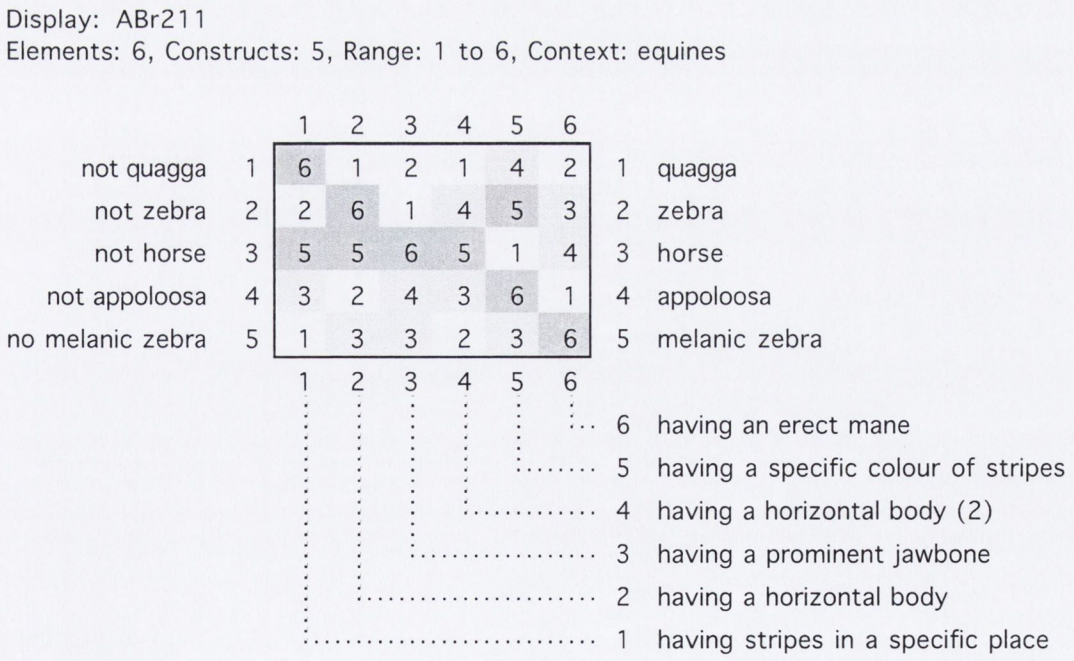

Figure 7.8 A representative grid from second year

Display: LL311+
Elements: 6, Constructs: 6, Range: 1 to 6, Context: equines

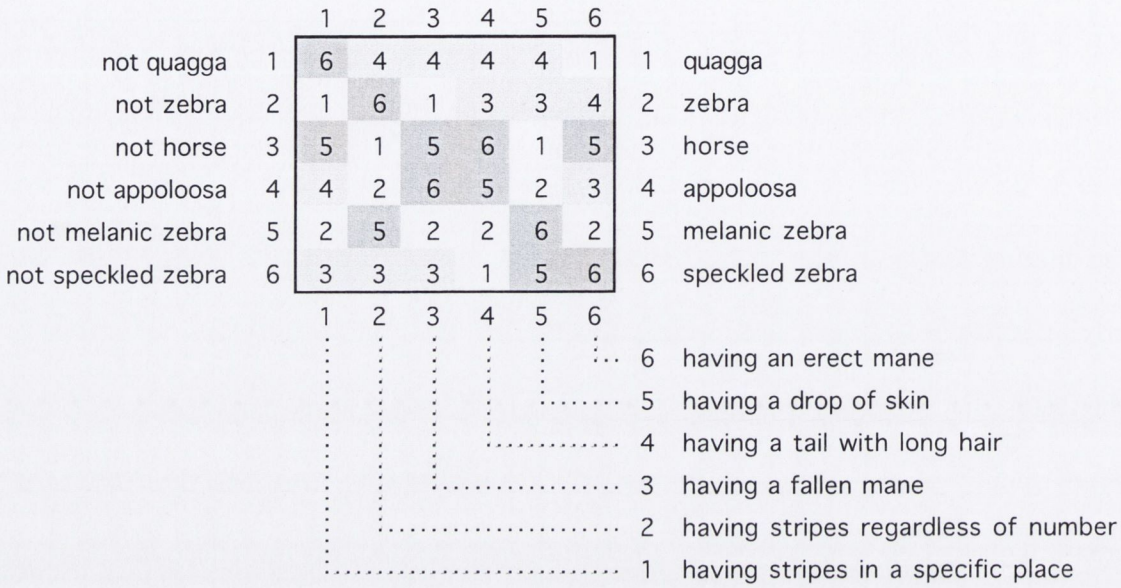

Figure 7.9 A representative grid from third year

Display: KM411
Elements: 6, Constructs: 6, Range: 1 to 6, Context: equines

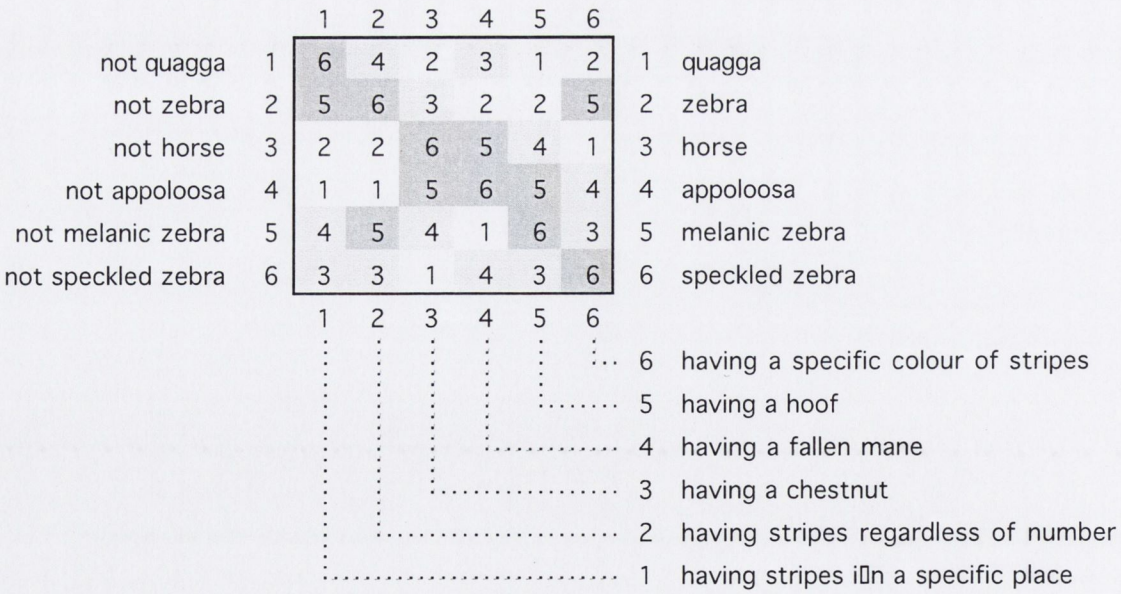

Figure 7.10 A representative grid from fourth year

Display: JM511++
Elements: 6, Constructs: 6, Range: 1 to 6, Context: equines

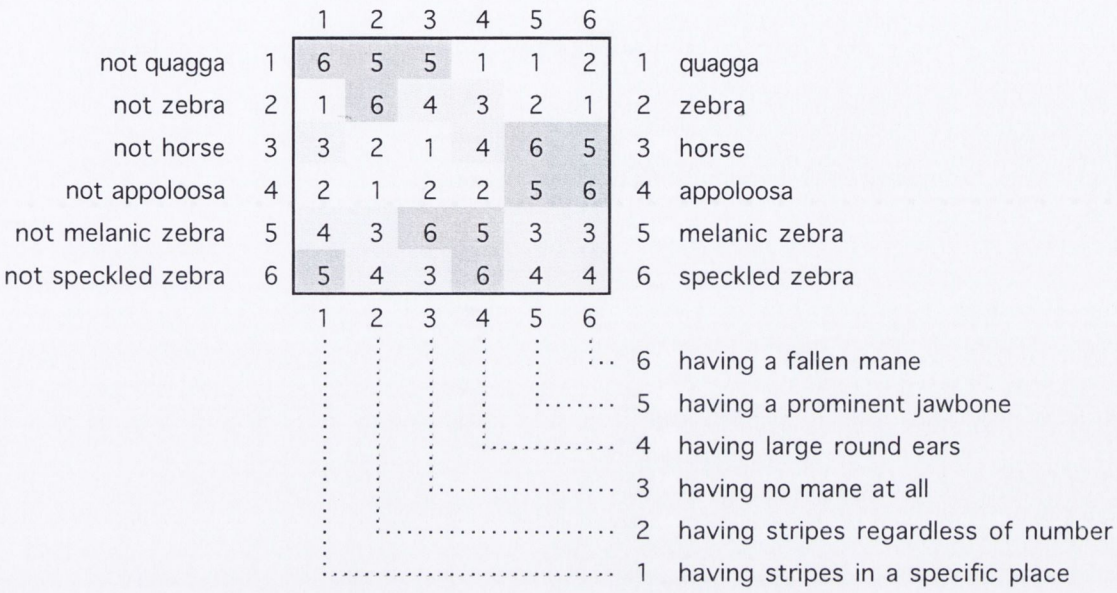

Figure 7.11 A representative grid from fifth year

Display: expert1
Elements: 6, Constructs: 6, Range: 1 to 6, Context: equines

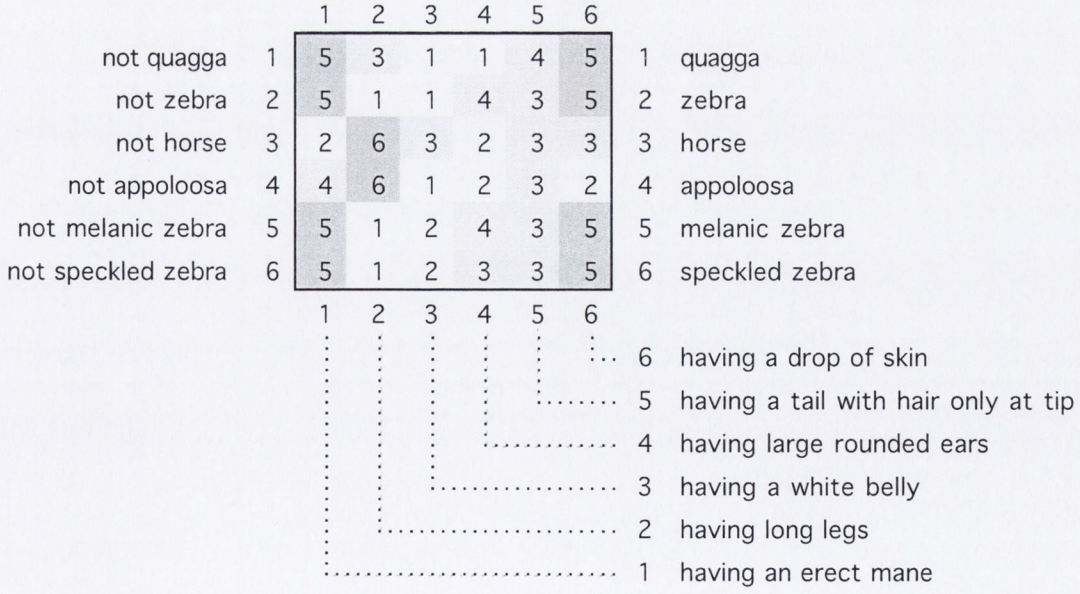

Figure 7.12 A grid from one expert

The first expert (general biologist with experience of large animals) arranged the equids in two groups: the zebra-like animals and the horse-like animals (Figure 7.12). The second expert has focussed on the presence of stripes as a diagnostic feature (Figure 7.13).

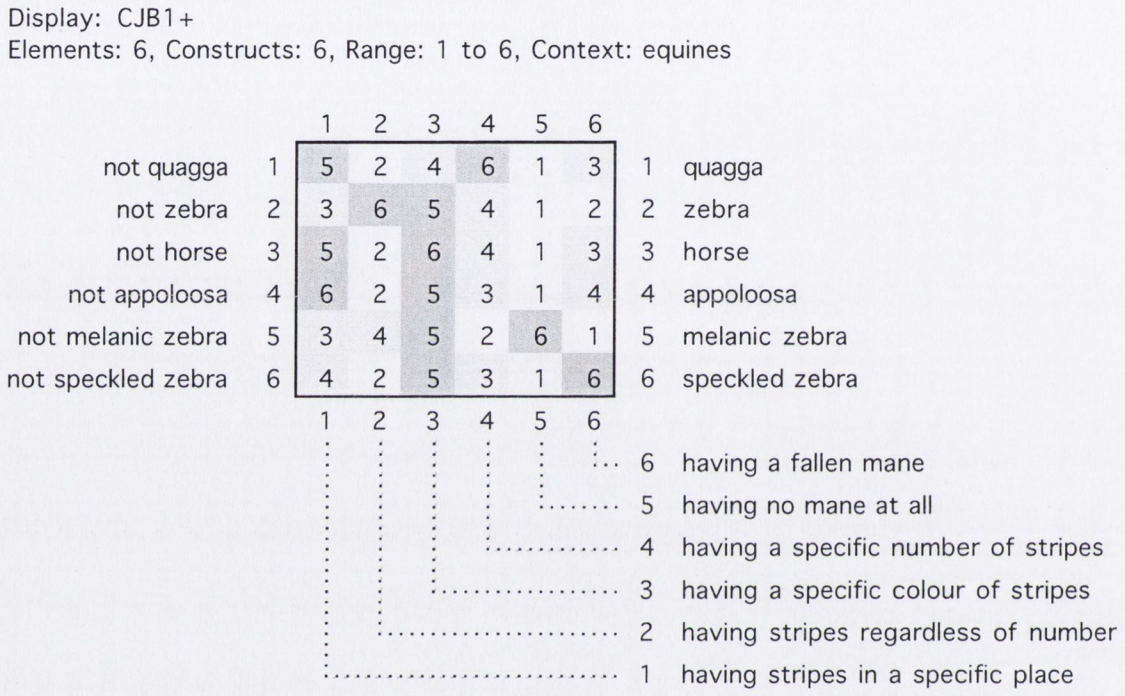

Figure 7.13 A grid from a second expert

Notwithstanding the assertions that can be made about the grids of the students, a more powerful method needs to be applied to grid data to assist in the interpretation of grid data. There are a number of avenues the research can take. Since the research relating to this thesis includes an examination of the classificatory frameworks of learners, the next step is obvious: to examine how the learners classified the six equids, and this will be dealt with in the section 7.2.4.

7.2.3 Grids of the second set of equid images

Figures 7.14 to 7.20 show representative grids from first, second, third, fourth, fifth years and the two experts respectively. The choice of elements for the second set of equids, Figure 7.4, was different from the first set, Figure 7.3, the students choosing elements that related directly to individual stimuli in the second set. Thus, having a cloven foot for Eohippus and secondarily for Mesohippus or having a hoof was dominant, as was having a white belly for quagga, and having large rounded ears for plains zebra. This demonstrated that it is possible to design a 'test' of perceptions of natural kinds by using stimuli and lists of features that relate to the stimuli. However, for such a 'test' to be viable, it is necessary to be able to predict how students rate some elements against certain constructs.

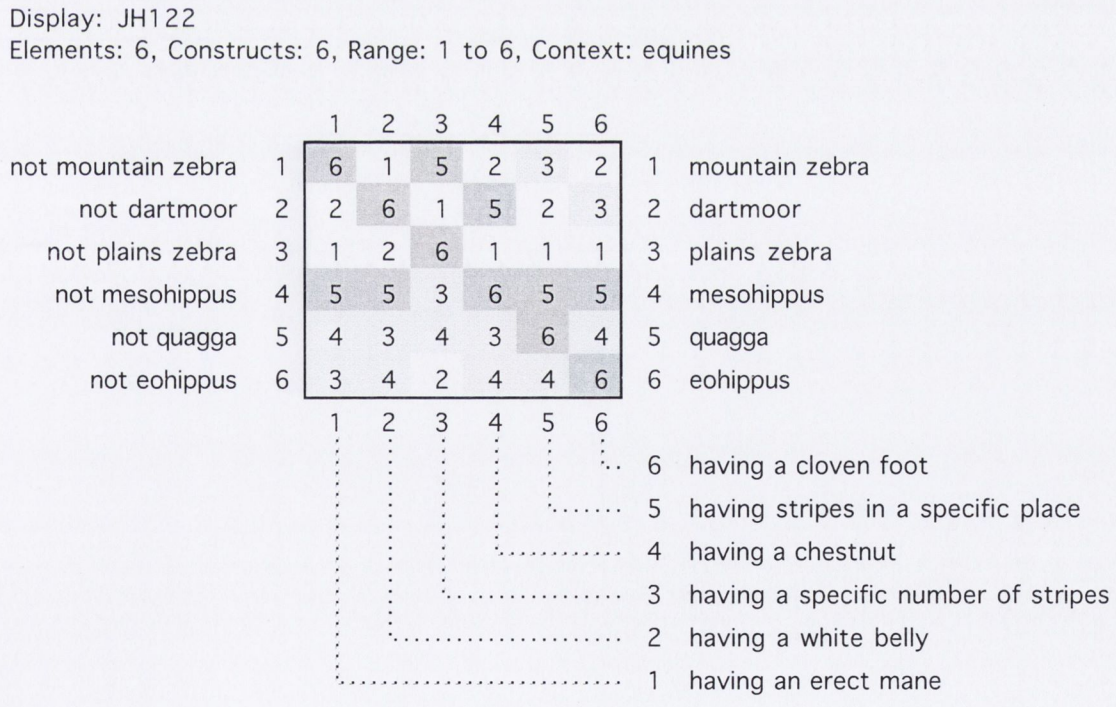

Figure 7.14 A representative grid from first year

In Figure 7.14, JH122 differentiated *Eohippus* and *Mesohippus* as having cloven foot, 6 and 5 respectively; whereas KN222, Figure 7.15, avoided the use of having a cloven foot perhaps because they were unfamiliar of the term, relying instead on elements from the stripes category and differentiating *Eohippus* as vaguely *having a horizontal body*.

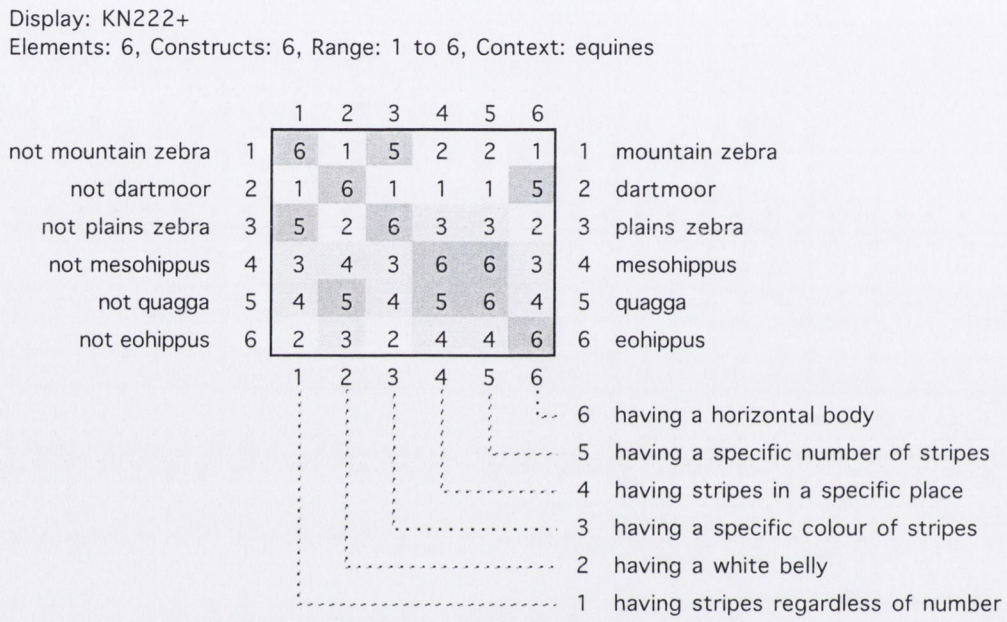

Figure 7.15 A representative grid from second year

Display: DL321
Elements: 6, Constructs: 6, Range: 1 to 6, Context: equines

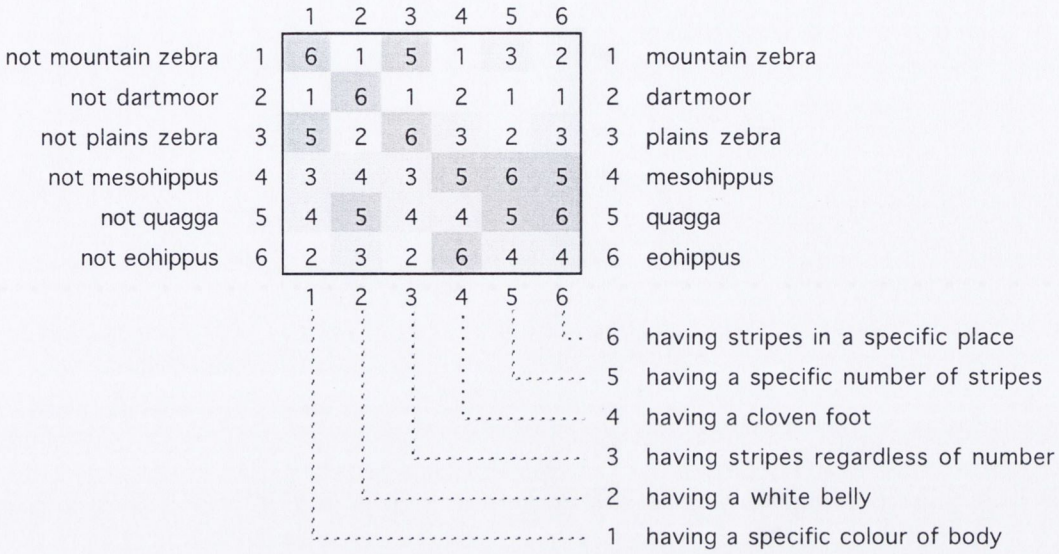

Figure 7.16 A representative grid from third year

Display: CF422
Elements: 6, Constructs: 6, Range: 1 to 6, Context: equines2

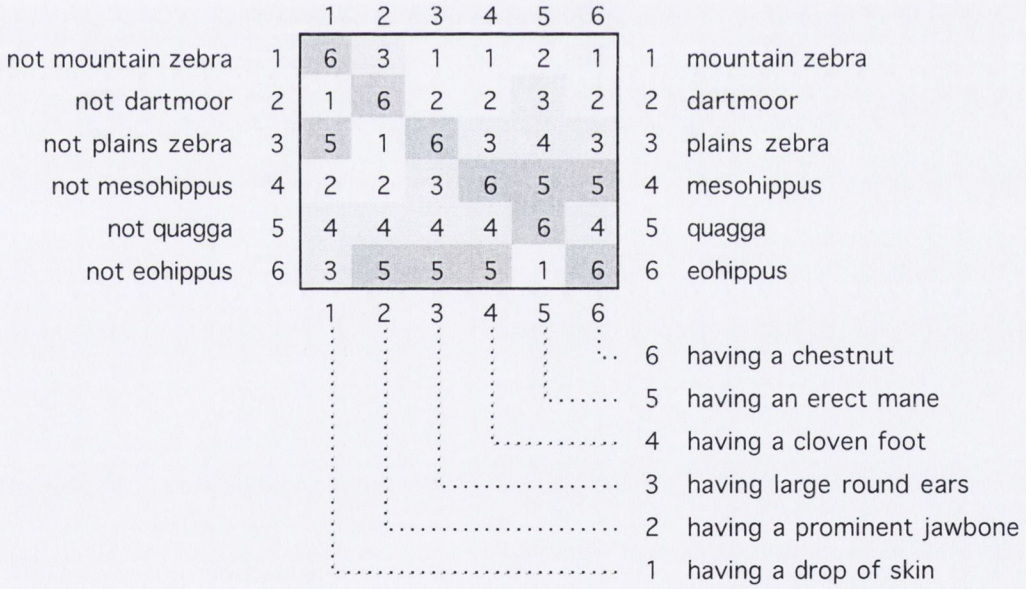

Figure 7.17 A representative grid from fourth year

Display: SH521
Elements: 6, Constructs: 6, Range: 1 to 6, Context: equines

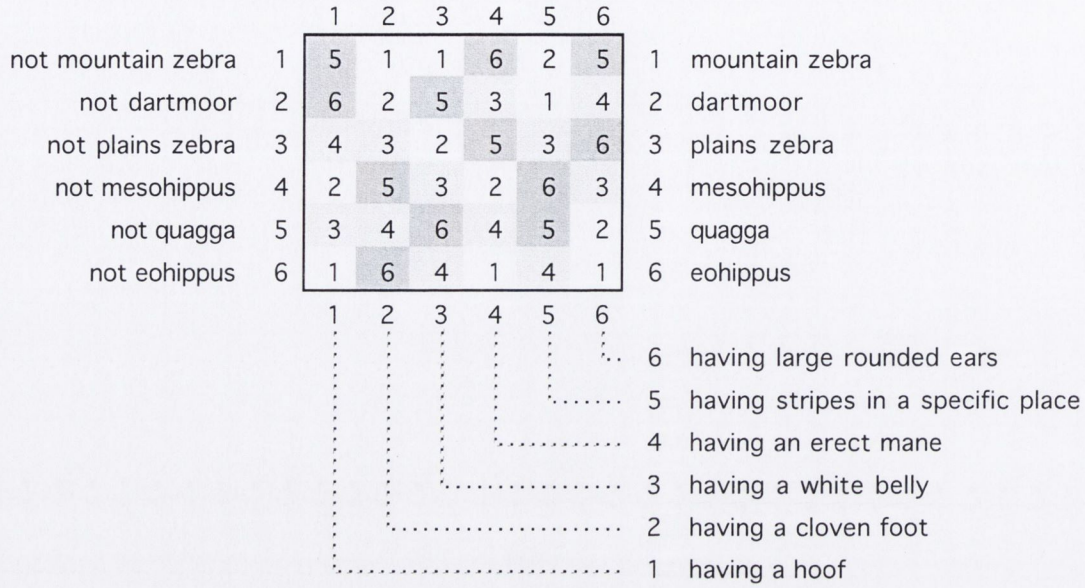

Figure 7.18 A representative grid from fifth year

Display: expert2
Elements: 6, Constructs: 6, Range: 1 to 6, Context: equines

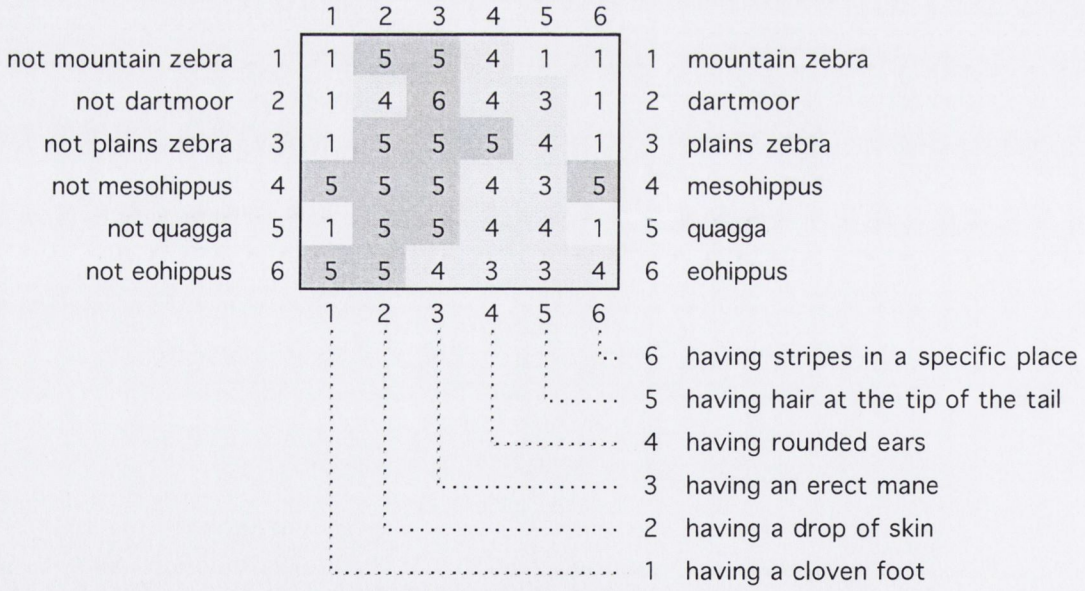

Figure 7.19 A grid from one expert

Display: CJB2+
Elements: 6, Constructs: 6, Range: 1 to 6, Context: equines

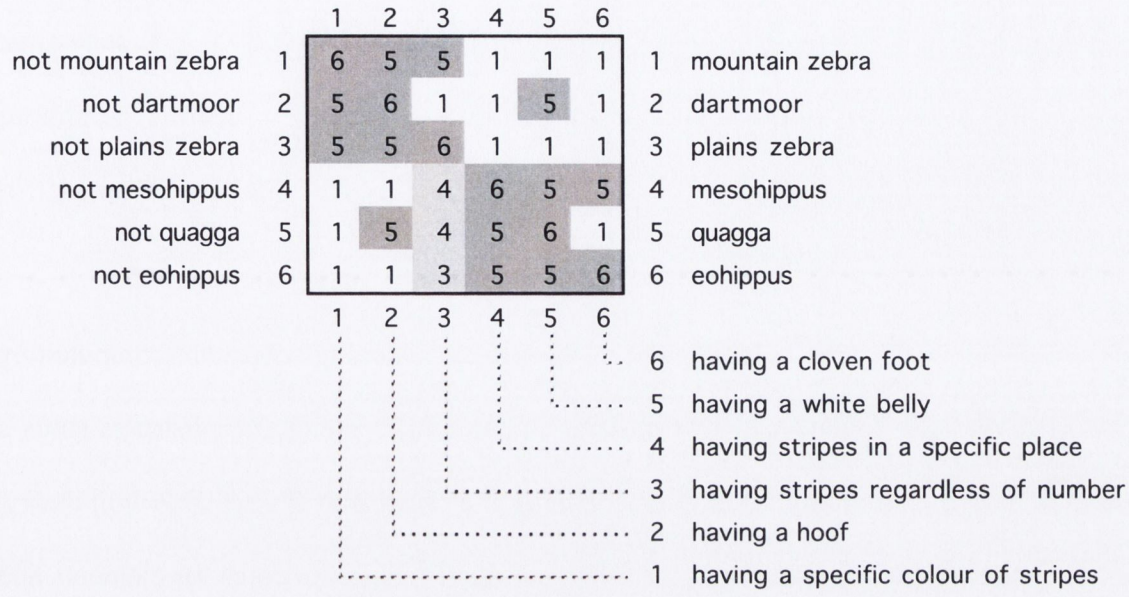

Figure 7.20 A grid from another expert

7.2.4 FOCUS and cluster analysis

Shaw (1980 p. 32) points out that the production of a grid is not so much the end of the eliciter-elicitee interaction but rather the start. The second stage beyond grid elicitation is the analysis of the grid and to make use of the results. In RGA, this is typically some form of cluster analysis. Fielding (2007, p. 46) defines cluster analysis as a method that finds structure in data by identifying groupings, called clusters, in the data. Earlier, Kaufman and Rousseeuw (1990) referred to cluster analysis as the "art of finding groups".

The first method used to cluster analyse a repertory grid was by L. Thomas and E. Mendoza in the 1970s using the hierarchical[33] method of McQuitty (1960). This was then superseded by Shaw's (1980 p. 160) focussing technique. Shaw (1980 p. 34) states that although the algorithm is most similar to the single linkage or nearest neighbour hierarchical method than partitioning, clumping or density (as described by Everitt, 1974) it is not in the strictest sense a hierarchical method.

In FOCUS (Figure 7.21), element and construct matching scores are computed by subtracting the rating values in each position of the two elements or constructs (thus a difference metric), summing them, then mapping the result into 0% to 100% similarity. This results in two matrices being formed, one matrix of matching scores for elements and another for constructs. Clusters are then computed by selecting the highest numbers from these matrices until all the constructs and elements are incorporated.

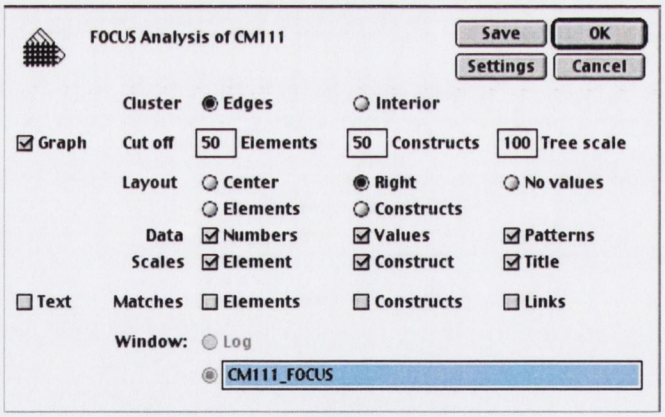

Figure 7.21 Parameters of FOCUS

[33] Whereas hierarchical is one of the general classes of clustering techniques, Grabmeier and Rudolph (2002) describe a large number of techniques, subdividing hierarchical into 'divisive' and 'agglomerative'; and divisive being further divided into 'monothetic' and 'polythetic' techniques.

7.2.5 Calculating distance

The concept of distance is central to cluster analysis because when we view similarity as the distance between instances, then we can conclude that instances within the same cluster have less distance between them; thus, there must be some means of measuring distance (Fielding, 2007, p. 48). There are, however, a huge range of distance metrics to choose from, Fielding (2007) tabulates nine, for example. In general, any system which represents information in a matrix *e.g.,* genetic (nucleic or protenomic) data, various means are employed to compare such blocks of information and one of the most reliable is the method of least mean squares. In terms of repertory grid analysis, this approach is explored to varying degrees by Slater (1977, p. 94ff); Shaw (1980, p. 160ff) and Jankowicz (2004, p. 93ff). Jankowicz (2004) points to the conventions of using repertory grid analysis that in comparing elements or constructs within grids or comparing full grids, one first calculates the per cent sum of differences and subsequently the per cent similarity.

The cluster algorithm in FOCUS hierarchically clusters the elements and constructs in a repertory grid and shows it in a graphical or text form. The algorithm is an extension of the FOCUS analysis described in Shaw (1980 p160ff); it is a distance-based hierarchical cluster analysis technique that sorts the constructs and elements into a linear order such that constructs and elements closest together in the space are also closest together in the order. The type of distance calculated is the so-called 'city block' or 'Manhatten' distance as opposed to the Euclidian distance. Fielding (2007, p. 51) states that the city block metric is less affected by 'outliers' than Euclidian or squared Euclidian metrics. Slater (1977 p. 94ff) also outlines the use of the city-block metric. It is important

to note that later, when spatial representations are produced in the PrinCom analysis as shall be seen, the city-block distance is the preferred means for visualising the two-dimensional relationship between constructs and elements on the drawn Cartesian planes (Jankowicz, 1994). The city-block distance, Equation 7.1, is also known as the 'least-mean-square' distance (L.M.S.) and it is closely related to the Euclidian distance measure.

$$d_{ij} = \sum_{k=1}^{n} |a_{ik} - a_{jk}| \qquad \textit{Equation 7.1}$$

The sum of the distances d_{ij} between elements or constructs i and j calculated from the city block metric is a function of the number of constructs, elements and the rating scale used.

The percentage construct matching score is derived from the mapping, Equation 7.2:

$$d_{ij} \rightarrow \frac{-200 d_{ij}}{(n-1)e} + 100 \qquad \textit{Equation 7.2}$$

where n is the maximum value of the rating scale, and e is the number of elements. Thus a perfect match will have a value of 100%; and 0 for no similarity; through to -100% for perfect negative or 'crossed' match. For the percentage element matching score, Equation 7.2 is adapted slightly to produce Equation 7.3:

$$d_{ij} \rightarrow \frac{-200 d_{ij}}{(n-1)c} + 100 \qquad \textit{Equation 7.3}$$

In this case there is a shorter range because elements do not exhibit bipolarity, so that the range is from 100% for a perfect match to 0 for no similarity. c is the number of

constructs. In practical terms the mapping in Equation 7.3 is equivalent to the following equality (Equation 7.4):

$$\%SD = \frac{SD}{(LR-1)\bullet C} \times 100 \qquad \textit{Equation 7.4}$$

Where *SD* is the sum of differences, i.e., the entity that is central to the calculation of the similarity. The largest difference on any single construct is the largest rating (*LR*) that is possible on the scale minus 1. This is multiplied by the number of constructs, *C*. Since the figure produced is in reality a comparison based on the difference between the two entities and it is easier to understand in terms of similarity (*%SIM* is the percent similarity) the quantity produced is subtracted from 100 (Equation 7.5):

$$\%SIM = 100 - \frac{SD}{(LR-1)\bullet C} \times 100 \qquad \textit{Equation 7.5}$$

Performing the calculation represented in Equation 7.5 on a grid such as AN111 produces a series of percent similarities for each pair of entities and these are tabulated in a matrix. In the next section, the percent similarities are used to construct classification diagrams.

7.2.6 Calculating clusters

Since Charles Darwin's *Origin of Species* was published, which contained a hypothetical and highly diagrammatic tree illustrating a divergence of species, scientists have striven to find the 'real' tree of life. In such a tree, an ancestral group yields 1, 2 or more groups which in turn do the same. At some point the scientist, specifically a systematist, given an array of examples of the species, decides when species A is separate from species B and C, and species B is separate from C on the basis of some measure of similarity; in other

words he or she decides where to make the cut. Given the following matrix, Table 7.4, of element matching scores, a diagram that arranges the constructs so that they appear closest to each other can be produced. The appearance of such a diagram is of the roots of a tree; in fact, it is often called a 'tree' but more commonly by the Greek term: *dendrogram*[34]. In examining such a matrix, one must first ignore the diagonal descending from top left to bottom right. Second, each row must be examined in turn.

---

[34] δένδρον, *tree*; γράμμα, *that which is drawn*

Table 7.4 *A matrix of element matching scores for PK111*

	E1	E2	E3	E4	E5	E6
E1	100	63	67	67	53	53
E2	63	100	70	77	50	43
E3	67	70	100	60	47	40
E4	67	77	60	100	47	47
E5	53	50	47	47	100	73
E6	53	43	40	47	73	100

In the first row, the highest match is E1 with E3 or E4 at 67%; columns E1 and E3/E4 are marked, this match listed, and the procedure repeated excluding this value. The highest match is now E1 with E2 at 63%. Again columns E1 and E2 are marked, the value listed and the procedure repeated. The next match is E1 and E5 and E6 at 53%; again E1 and E5/E6 are marked, E1 now being totally excluded as it is now matched on both sides, the value listed and the procedure repeated. The next match is E2 and E4 at 77%, then E2 and E3 at 70%, and so on until all the original elements have been incorporated. The ordering of the elements is done by selecting the highest match for each element. The list of values (calculated values in brackets) is therefore: E1 and E3/E4 at 67% (66.7%); E2 and E4 at 77% (76.7%); E3 and E2 at 70% (70.0%); E4 and E3 at 77% (76.7%); E5 and E6 at 73% (73.3%); and E6 and E5 at 73% (73.3%). If one attempts to draw this tree free-hand, one will observe that two large groups emerge with no apparent link. Also the linkage of E5 and E6 is reciprocal and does not need to be written twice. Thus we must return to the matrix of matching scores and look for a match that links seemingly unrelated

elements. E1 links with E3 and E4 at 66.7%, E2 links with E3 at 70.0%, and E2 links with E4 at 76.7%. E5 and E6 have no linkage at this level thus they constitute anothr branch linking only with E1 at 53.3%. This becomes the final likage. The final list of values therefore is: E2 linked to E4 at 76.7; E5 linked to E6 at 73.3; E2 linked to E3 at 70.0; E1 linked to E3 at 66.7; and E1 linked to E5 at 53.3. The ordering produced is therefore E6, E5, E1, E3, E2, E4 and the tree has the following pattern which is a dendrogram, Figure 7.18 . The points on the dendrogram where the lines meet relate to the per cent distance between the elements: having a drop of skin is 73.3% similar to having no mane at all and both these elements are 53.3% similar to all the other elements.

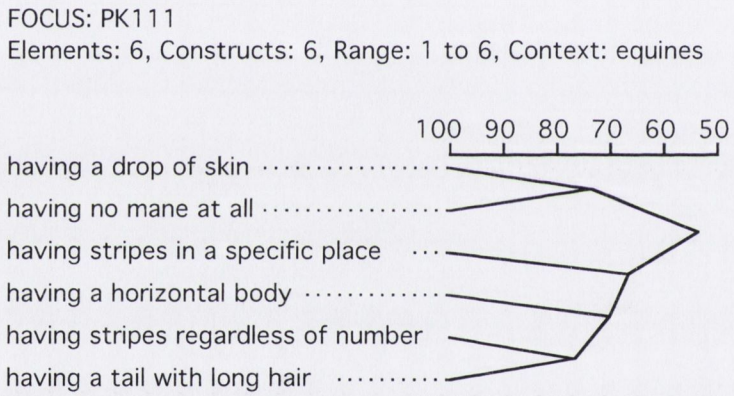

Figure 7.22 Part of the output of FOCUS possessing a dendrogram for the elements

Dendrograms are produced and they are drawn on the re-sorted original grid data, Figure 7.22 . The dendrograms produced in FOCUS in RepGrid 2.1 are analogous to the dendrograms produced in dedicated cladistic software packages, such as MacClade, some of which use the LMS method of phylogenetic inference among an array of other of other methods. Thus RGA can be used to uncover ethnobiological data regarding learners' and other individuals' perceptions and ideas, or even naive theories, concerning biological natural kinds concepts; see for example Atran (1999).

The FOCUS program examines both elements and constructs simultaneously, Figure 7.22 . CPSC (1999) state that FOCUS has the advantage of presenting the original data in a simple sorting based on the similarity of the constructs and elements. In Figure 7.23 the dendrograms for both constructs and elements are shown beside a rearranged grid with areas of commonality shaded to the same degree. PK111 classifies the constructs as follows: the *horse* and *appoloosa* are closely related, next to these is the *speckled zebra*, which might appear to be a strange breed of horse (note, the students did not have the names of the animals to work on); next to this is the *quagga* which may have been conceptualised as half *horse*/half *zebra* lying bewteen the *horse/appoloosa* group and *zebra per se*. Lastly, the *melanic zebra* exists as an outlier not apparently exhibiting the key characteristic of a *zebra*, *i.e.*, monochromatic stripes. Furthermore, to this person's mind, the *melanic zebra* is not like any of the other animals.

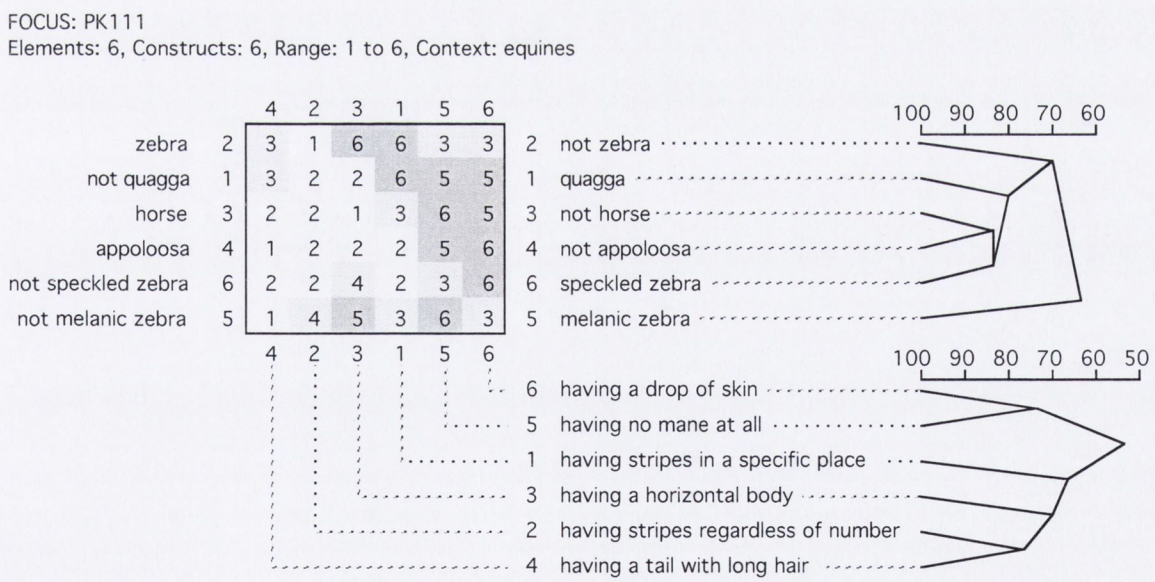

Figure 7.23 Output of FOCUS for PK111

Figures 7.24 to 7.30 display diagrammatically the dendrograms for the representative 1st, 2nd, 3rd, 4th, 5th year students and the two experts respectively. The 1st; 2nd and 4th year students typified the *horse* and *zebra* closely together

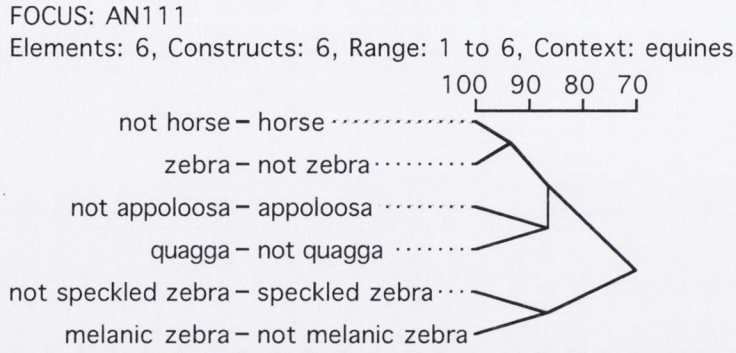

Figure 7.24 Dendrogram for the constructs of AN111

In Figure 7.24, AN111 has classified the *horse* and *zebra* most closely together; these are the species types for this person and *appoloosa* and *quagga* were seen as variants of horse and zebra respectively.

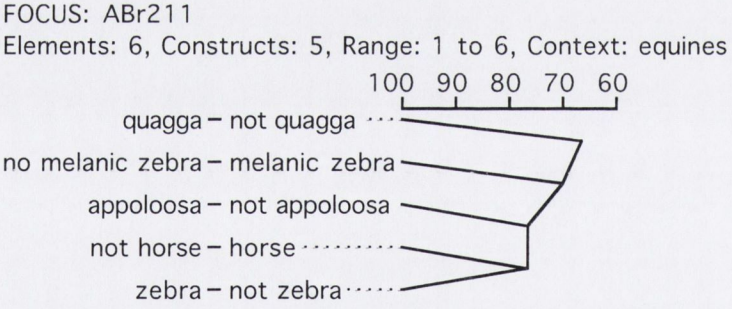

Figure 7.25 Dendrogram for the constructs of ABr211

In Figure 7.25, which only has five constructs represented, *quagga* has been singled out as a outlier, but *horse* and *zebra* are grouped again.

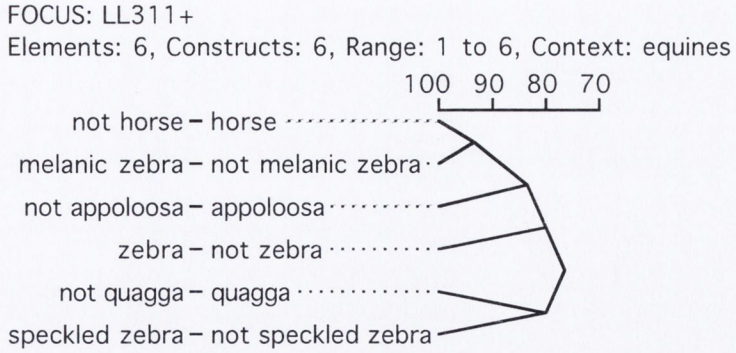

Figure 7.26 Dendrogram for the constructs of LL311

LL311 produced a grid very different from the others in the sense of which constructs were grouped. However, all the constructs are within the 75% similarity and so are relatively closely related.

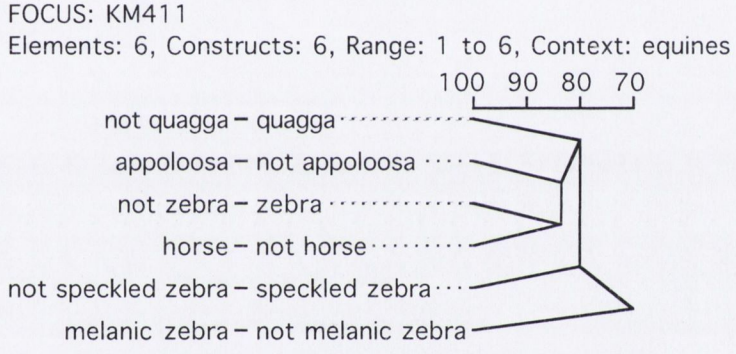

Figure 7.27 Dendrogram for the constructs of KM411

In Figure 7.27, KM411 clustered *quagga, appoloosa, zebra* and *horse* within 80% similarity and excluded the *speckled zebra* and *melanic zebra* constructs.

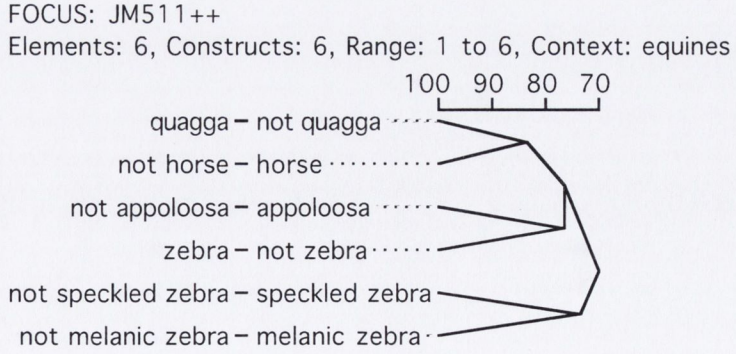

Figure 7.28 Dendrogram for the constructs of JM511

In Figure 7.28, it is worth pointing out that JM511 grouped *quagga* and *horse* as the most similar stimuli. These are two species as is *zebra*, but these were grouped with *appoloosa* with a lower similarity. Further, a third grouping with less similarity within the group and between other groups was the *speckled zebra* and *melanic zebra* demonstrating how these 'aberrant' forms, an invention and a mutation, proved difficult to classify. That they were difficult to classify is probably due to their 'ambiguous' appearance since it is felt that the students are relying on the gross appearance of the specimen to assist in their classifications when confronted with a new type of equid.

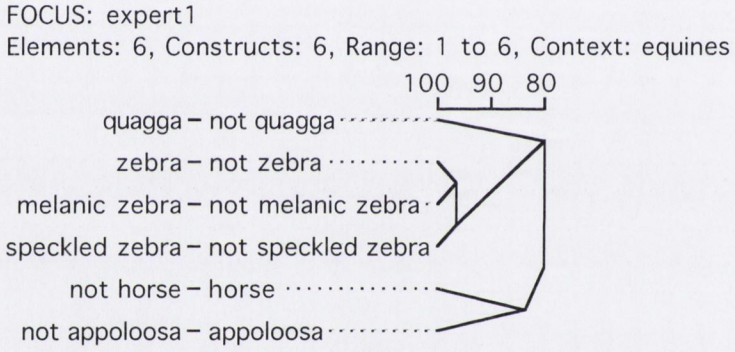

Figure 7.29 Dendrogram for the constructs of one expert

In Figure 7.29, the expert placed the three zebroids closest together as a cluster, with the *quagga* close-by. *Horse* and *appaloosa* also formed a cluster. These clusters reflect the classification of formal biology: except of course the position of the fictitious construct (*speckled zebra*). In this system where the constructs are provided to the participants, there is a 'forcing' of the constructs into fitting into the classificatory structure when it might be the case that the participant would rather leave certain constructs out.

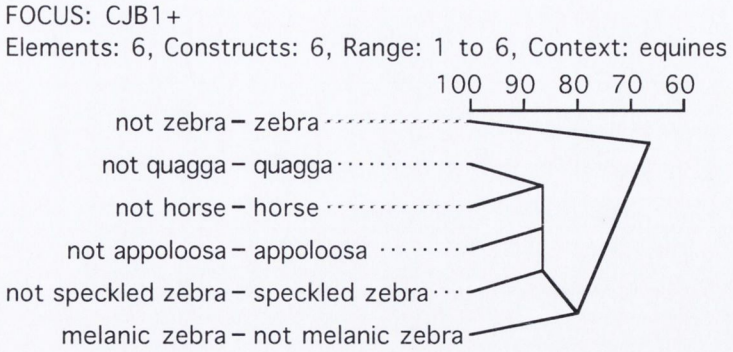

Figure 7.30 Dendrogram for the constructs of another expert

It is difficult to analyse Figure 7.30 . Zebra has been placed as an outlier although its closest 'relative' is the melanic zebra which is correct, but the quagga has been placed closest to horse, rather than the appoloosa. This expert, CJB, admitted to being an expert on fish and parasites and his expertise in classifying living things appeared to constrained in those domains.

7.2.7 Dendrograms for the second set of equids

Regarding the second set of equids, dendrograms were also produced (see Figures 7.31 to 7.37). In the second set, the array of stimuli were drawn from a range of examples with a lesser degree of biological relatedness. According to formal biological classifications, the *plains zebra* and *mountain zebra* should be closely related followed by the *quagga*, in turn followed by *dartmoor*, a varietal form of horse. This is seen in the first expert's grid and dendrogram (Figure 7.36). The *Mesohippus* and *Eohippus* should have appeared as outliers as not closely related to modern equids at all (again, the first expert shows this). They are extinct forms, and the *Mesohippus* does have the overall appearance of an equid, in fact drawn similar to the dartmoor with the exception of the toe arrangement. *Eohippus*, now renamed *Hipparion*, was only superficially similar to modern equids, the indicators for its relationship are structural.

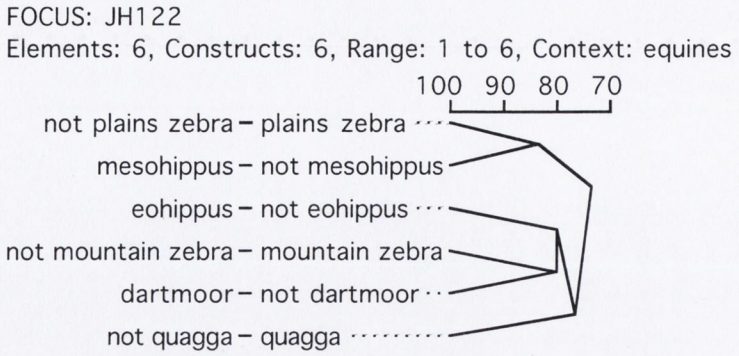

Figure 7.31 Dendrogram for the constructs of JH122

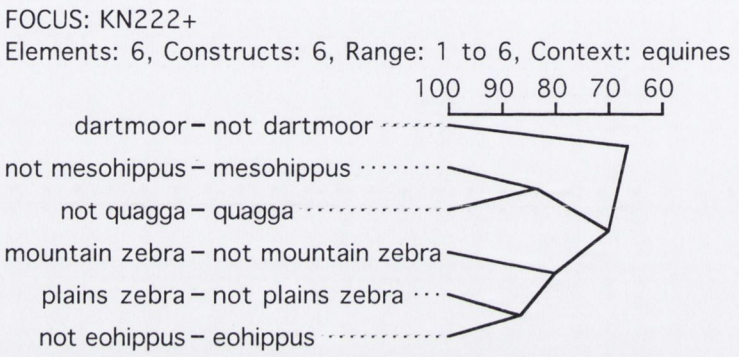

Figure 7.32 Dendrogram for the constructs of KN222

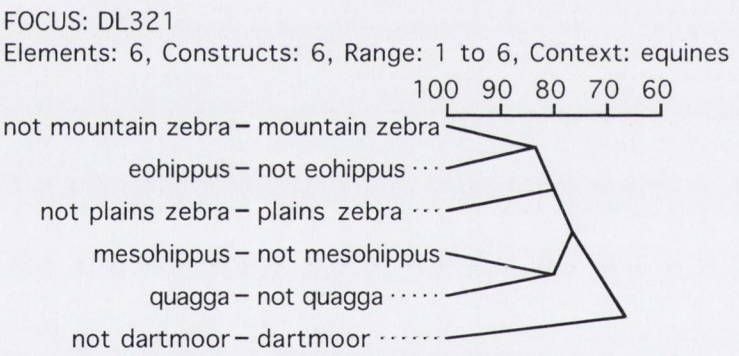

Figure 7.33 Dendrogram for the constructs of DL321

These dendrograms (Figures 7.31 – 7.37) illustrate the way that RGA uses the negative pole alignment as a basis of negative similarity. For example, in Figure 7.32, *Eohippus* is closest to *'not' plains zebra, i.e.*, the negative pole of *plains zebra*. In Figure 7.33, a similar situation exists, but instead of *'not' plains zebra*, it is *'not' mountain zebra* which is closest to *Eohippus*. In Figure 7.34, *Mesohippus* is aligned with *'not' mountain zebra*. Both the experts (Figure 7.36 and 7.37 recognised *Eohippus* and *Mesohippus* belonged to a category of themselves on the basis of their foot structures; though Expert2

(Figure 7.36) correctly placed *quagga* with *plains zebra*. This series of dendrograms also illustrate how the students and experts both struggled to include *Eohippus* in their classification systems, and the differences between the dendrograms is accounted for on the basis of whether the participants used elements concerning foot structure or coat markings of both to differentiate the living things.

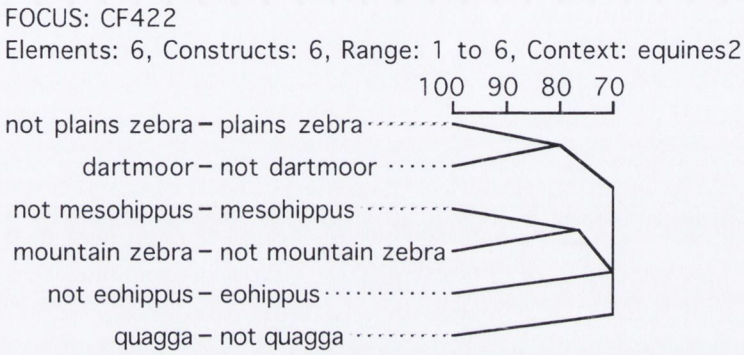

Figure 7.34 Dendrogram for the constructs of CF422

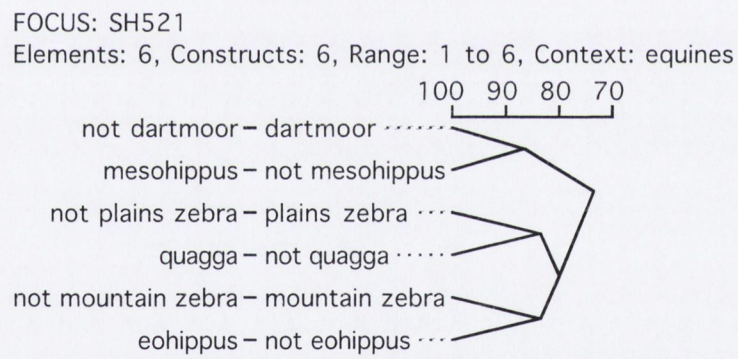

Figure 7.35 Dendrogram for the constructs of SH521

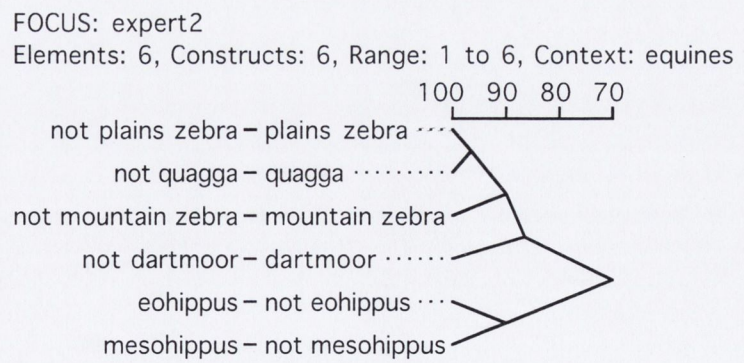

Figure 7.36 Dendrogram for the constructs of one expert

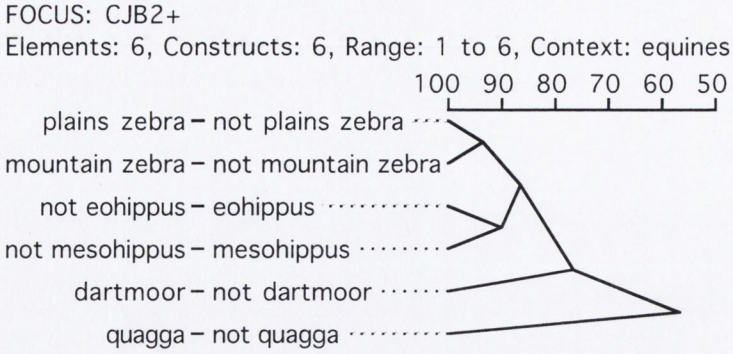

Figure 7.37 Dendrogram for the constructs of another expert

Having examined a number of exemplary grids and the dendrograms of the constructs calculated, there remains an incomplete picture of the structure of the constructs, in fact the grids and dendrograms cannot generate extensive information about the constructs and their relationship with the elements. Because of the limitations of presenting the raw grids, their FOCUSsed forms and calculated dendrograms, principal components analysis was carried out on the grids.

7.2.8 Principal Components Analysis (PrinCom)

Principal Components Analysis was discussed at length in Chapter 2. A example of a principal components plot is displayed in Figure 7.38 and those for each age-group displayed in Figures 7.39 to 7.47 for representative first, second, third, fourth, fifth year students and the two experts respectively. In each diagram, the horizontal axis represents the first principal component factor and the vertical axis represents the second principal component factor. The first and second components were selected as these had the highest percentage of the variance accounted for in them.

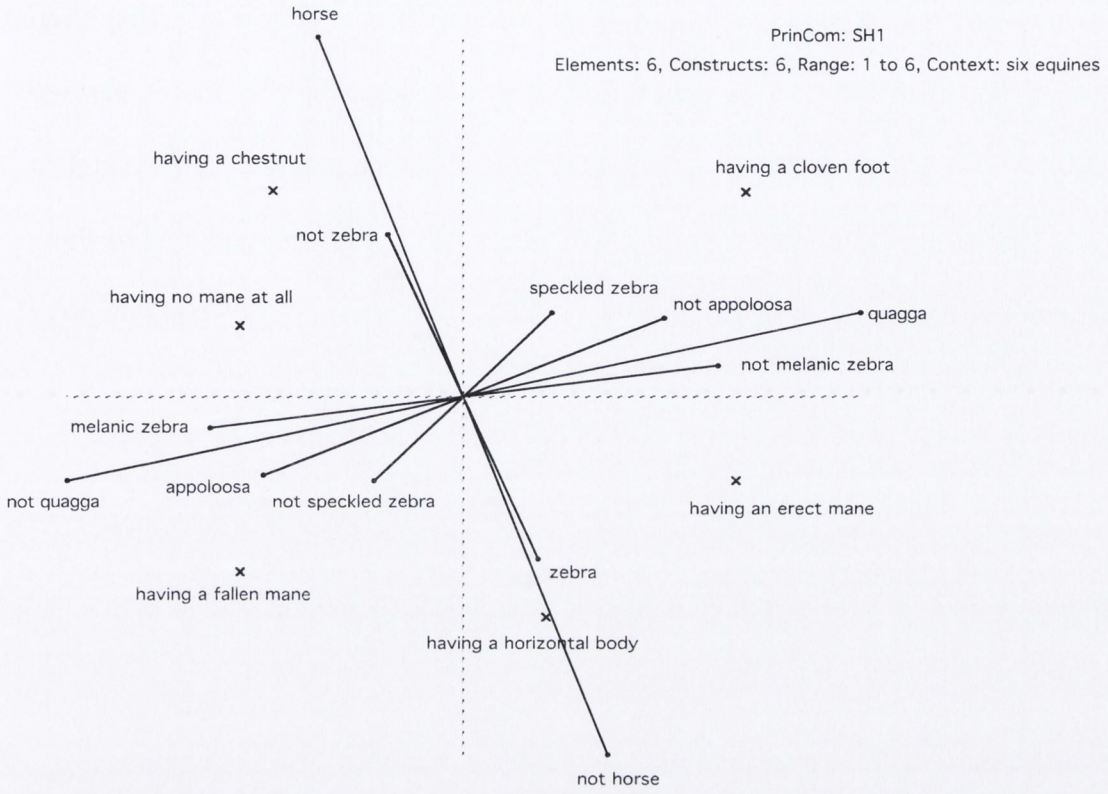

Figure 7.38 Plot of first and second principal components for elements marked with an 'x' and constructs (polar vectors) (variance accounted for: C1 = 44.62%, C2 = 31.36%)

In Figure 7.38, and the figures following, the angle between any two construct lines reflects the extent to which the ratings of elements are correlated: the smaller the angle, the more similar the ratings, thus the *horse/not-horse* and *not-zebra/zebra* vectors are very closely related. Given that polarity of the vectors is significant, from now on, only one pole shall be referred to: *horse* and *not-zebra*. Furthermore, the angle between a construct vector and the line representing the components reflects the extent to which the component can be taken to represent the construct in question: the smaller the angle, the greater the extent: thus *having a horizontal body* is important in characterising *zebra* and *not horse*.

The position of each element with respect to each component is exactly like the position of a point on a graph. Jankowicz (2004 p. 130) points out that this fact is

enormously useful in studying the relationships between elements. The distance between any two elements reflects the ratings each element received on all the constructs. Any two elements which are close together in the graph received similar ratings, *e.g.*, *having no mane at all* and *having a chestnut*, any of which are printed far apart would tend to show rather different ratings in the original grid, *e.g.*, *having a fallen mane* and *having an erect mane*.

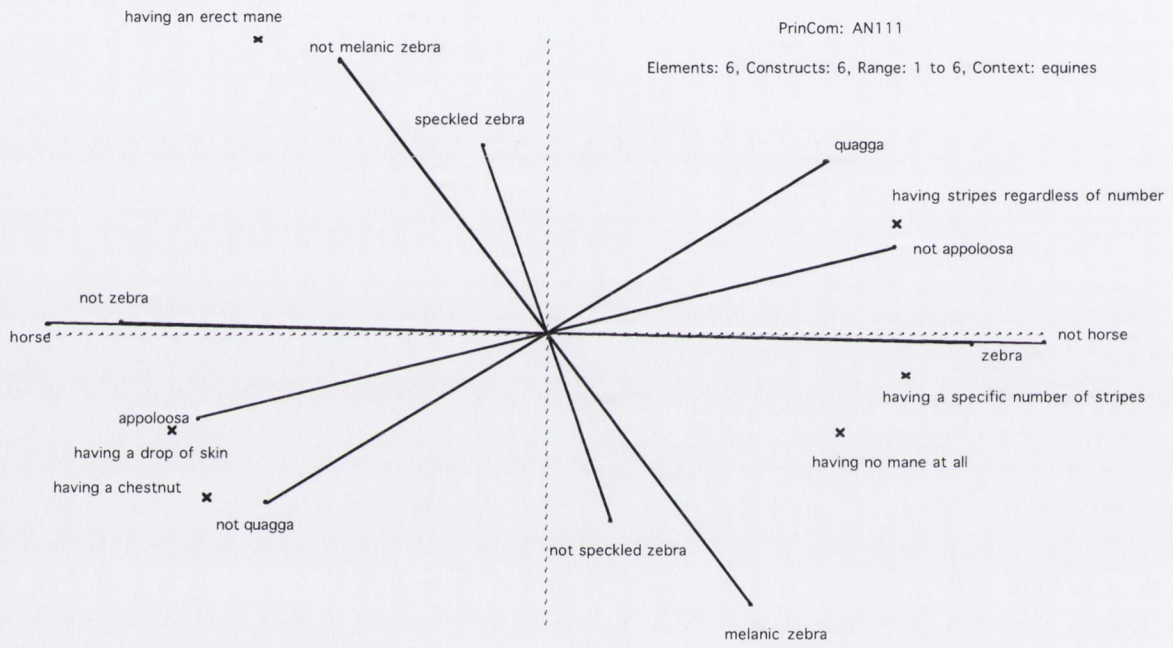

Figure 7.39 Plot of first and second principal components for AN111, the representative first year (variance accounted for: C1 = 75.74%, C2 = 16.82%)

AN111's plot (Figure 7.39) is significant because it demonstrates how RGA takes into account the negative aspect of perception. For example, *horse* and *zebra* have vectors which appear to occupy the same space, they appear to overlap. However, the vector for *zebra* is reversed with respect to *horse* and the elements relevant to *horse*. Yet because the vectors lie very close together, the focussed grid, Figure 7.7, shows *horse/zebra* to be in a cluster separate from *quagga/appoloosa* – though here too, one of the vectors is reversed with respect to the other. Interestingly, *horse/zebra* are clustered as the species-types and

quagga/appoloosa are perceived variants of *zebra/horse* respectively, but by not clustering the *appoloosa* with *horse* AN111 does not consider it to be a 'real' horse; in other words, the *appoloosa*, like the *quagga,* appear as counter intuitive entities, Table 7.1.

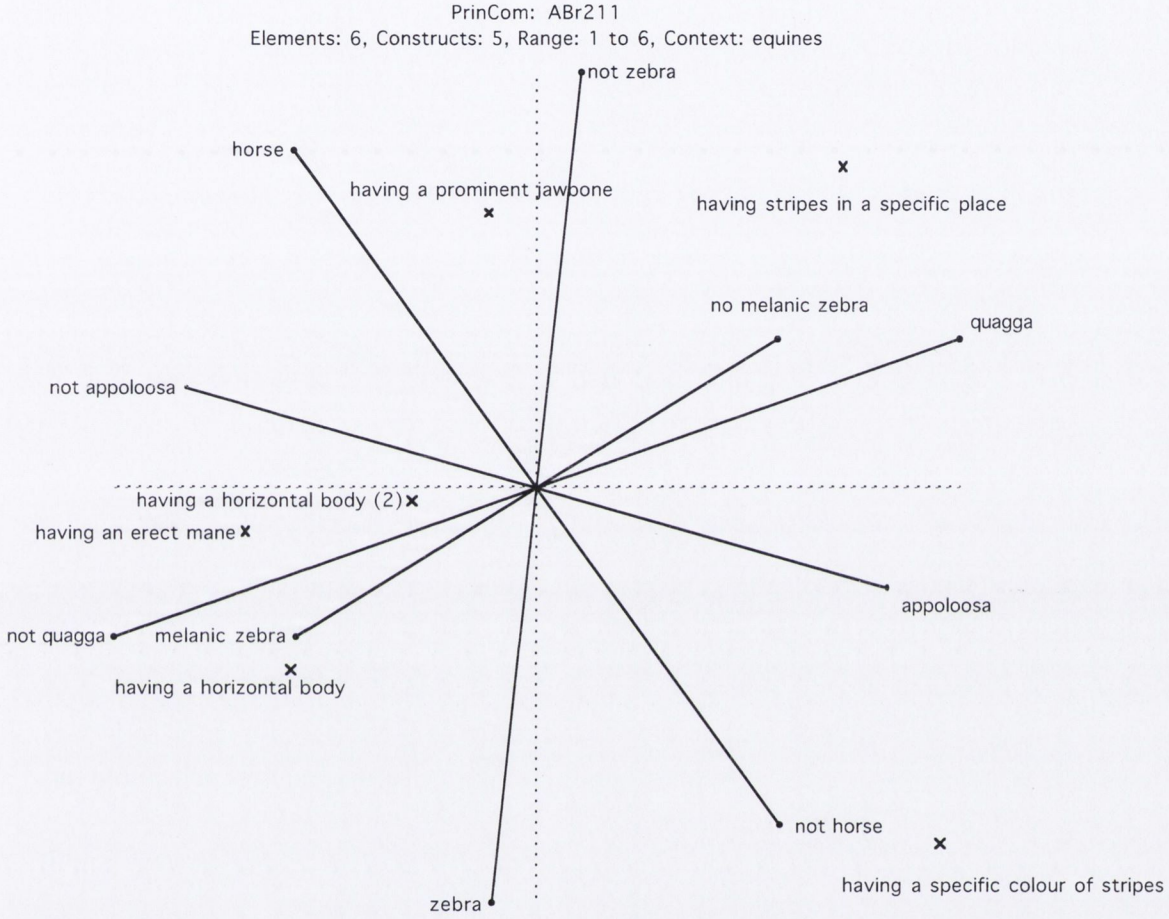

Figure 7.40 Plot of first and second principal components for ABr211, the representative second year (variance accounted for: C1 = 39.82%, C2 = 32.88%)

In Figure 7.40, we see that the vectors for horse and appoloosa are oppositely directed as in Figure 7.25. However, in the principal components plot we also see a great deal more detail than the dendrograms show, which is as it should be. The concept, or construct, *horse* is most characterised by *having a prominent jawbone* and negatively, *having a specific colour of stripes*. As might be expected, *quagga* is most characterised by *having stripes in a specific place* – a feature that negatively characterises *melanic zebra*.

Therefore, the principal components' plots provide a type of map of mental space of equids, in this case. There are locations for concepts and their features and a means to show the relationships between them.

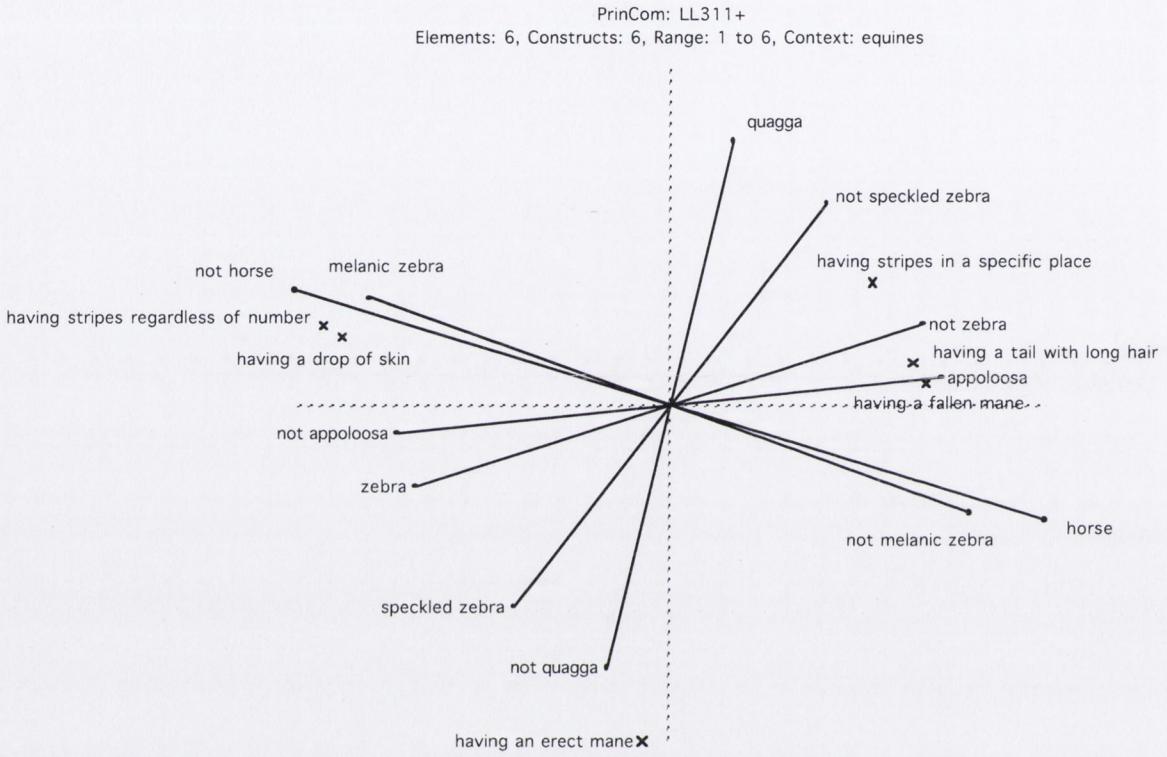

Figure 7.41 Plot of first and second principal components for LL311, the representative third year (variance accounted for: C1 = 61.09%, C2 = 22.47%)

In Figure 7.41, the angle between the horse and melanic zebra is very small, though directed oppositely – the elements having stripes regardless of number and having a drop of skin are very close. These two construct vector run orthogonally to speckled zebra and quagga with a third cluster (pair) between: appoloosa and zebra. Each of the clusters were distinguished by a positive pole and a negative pole.

In Figure 7.42, a similar pairwise arrangement of the constructs is evident but the pairs are different. The vector for quagga is paired with that for appoloosa. Again, the pairs have a positive and a negative pole near to any specific element. Although, we have

noted single specific elements that best characterise the constructs, it is important to remember that the construct vectors are positioned according to loadings that are derived from a calculation carried out on the whole original grid.

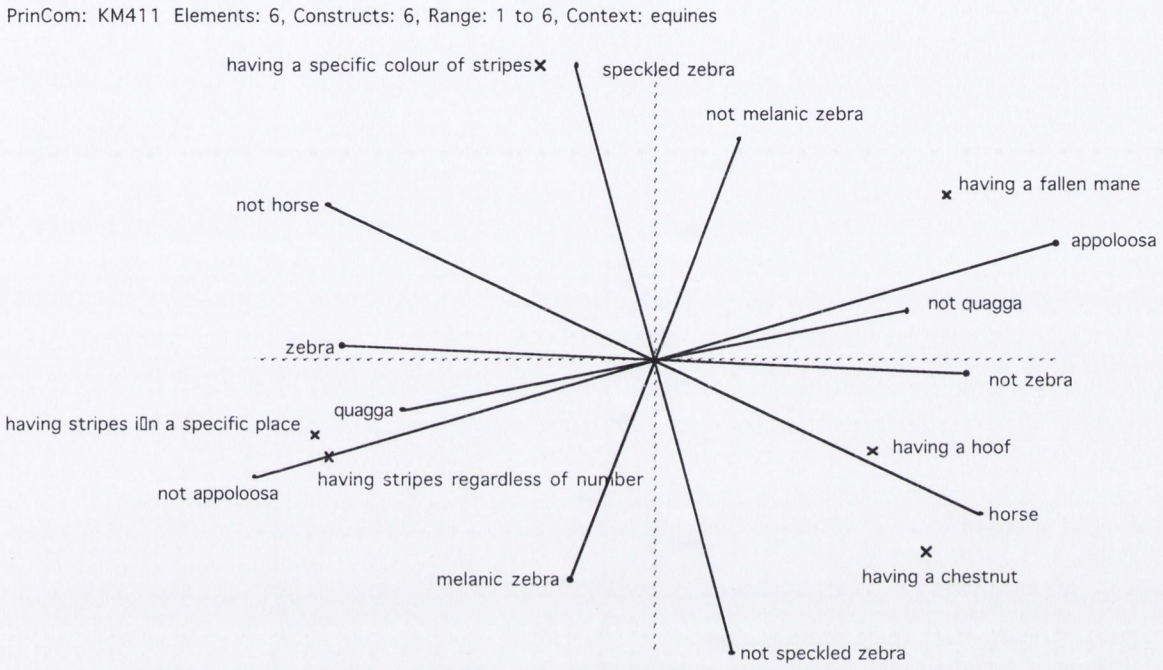

Figure 7.42 Plot of first and second principal components for KM411, the representative fourth year (variance accounted for: C1 = 57.99%, C2 = 23.39%)

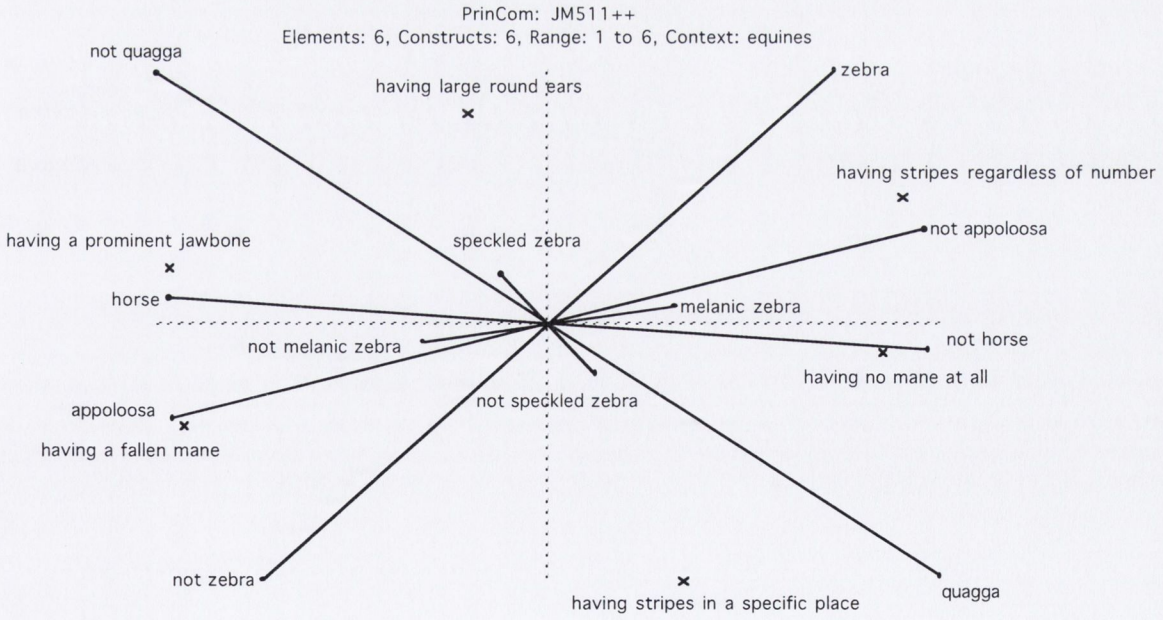

Figure 7.43 Plot of first and second principal components for JM511, the representative fifth year (variance accounted for: C1 = 64.49%, C2 = 16.71%)

In Figure 7.43, the ambiguity experienced by JM511 regarding the *speckled zebra* and *melanic zebra* is well demonstrated by the short length of the vectors. *Horse* is best characterised by *having a prominent jawbone* and *appoloosa* by *having a fallen mane*. *Quagga* is influenced most by *having stripes in a specific place* and *having no mane at all*, whilst *zebra* is influenced most by *having stripes regardless of number* and *having large round ears*. Figure 7.11, the original grid for JM511 shows a pairing pattern in the scoring and this is shown more precisely in Figure 7.19, the focussed grid for JM511 where three clusters appear: *horse/appoloosa*, *quagga/zebra* and *speckled zebra/melanic zebra* in order of respective similarity.

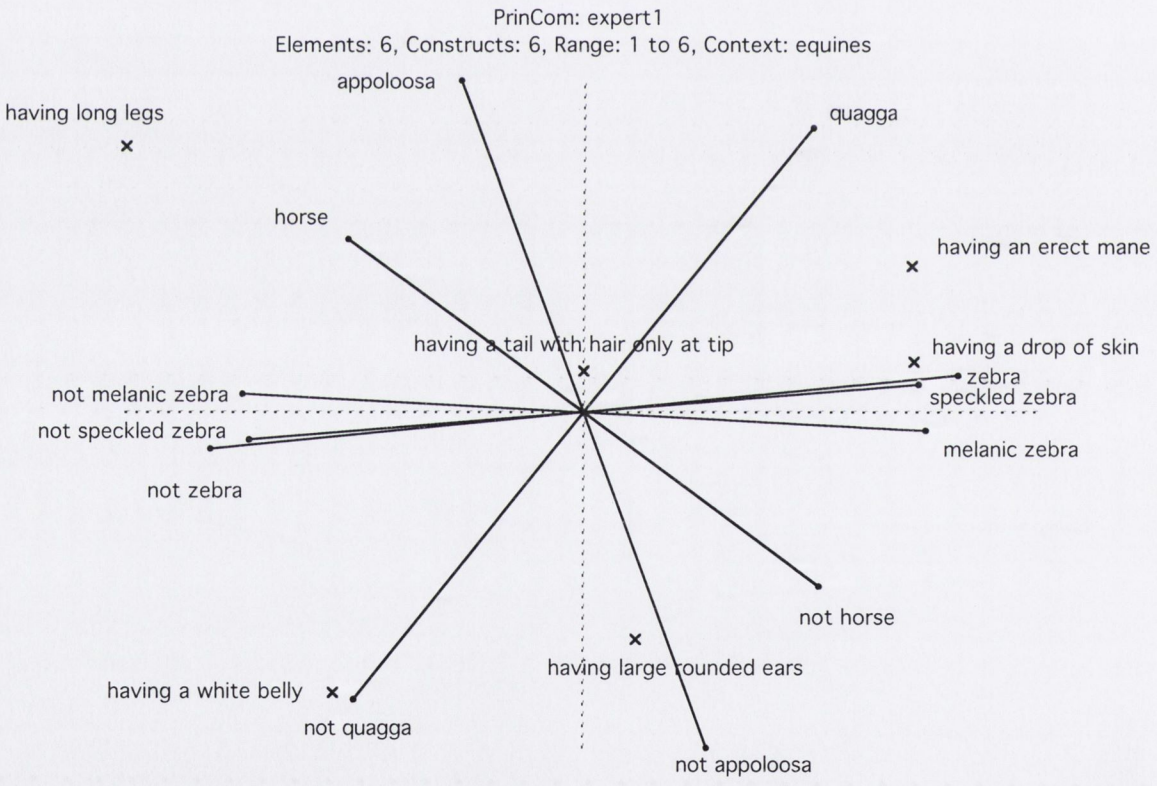

Figure 7.44 Plot of first and second principal components for one expert (variance accounted for: C1 = 63.85%, C2 = 29.38%)

In Figure 7.44, the general biology expert has clustered the zebroids including the *speckled zebra,* with the *quagga* outlying in this cluster. *Horse* and *appoloosa* form another cluster which is scientifically correct. We see that the experts though find difficulty in placing the *speckled zebra* in a credible classification. This expert did not use elements concerning *stripes* to cluster the zebroids. Instead he used the mane, neck, belly, tail, legs and ears as the distinguishing features. This choice of structurally determined features is important as the scientific expert must move beyond the perceptually shallow features of say, *stripes*.

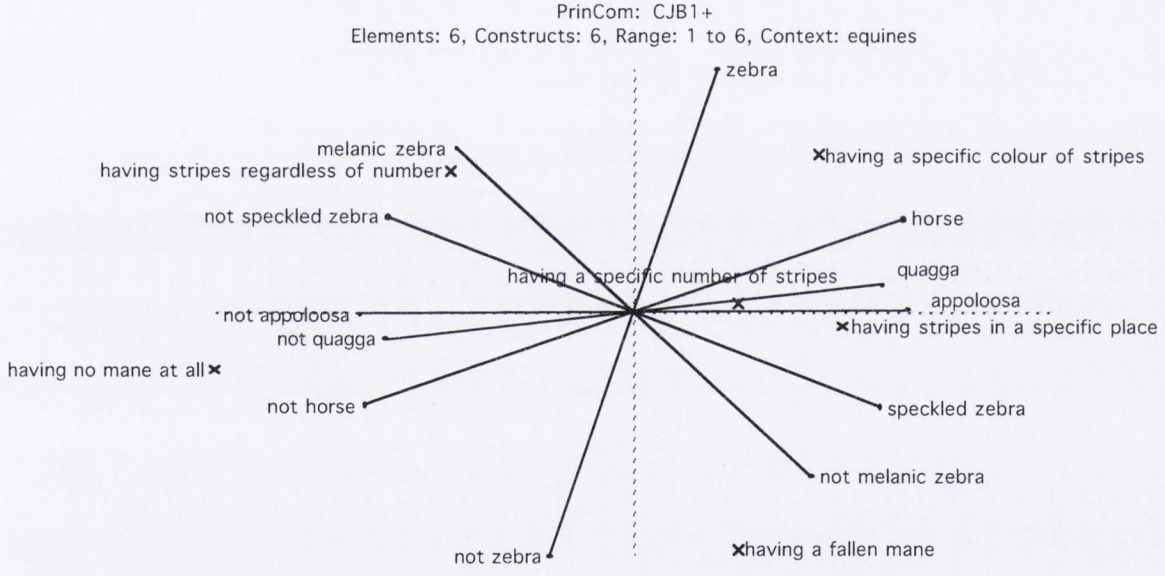

Figure 7.45 Plot of first and second principal components for another expert (variance accounted for: C1 = 57.57%; C2 = 19.70%)

In Figure 7.45, CJB, an expert in fish and their parasites has produced a plot very similar to a students in that some of the features relate to a folk classification rather than a formal scientific. *Melanic zebra* is placed close to *speckled zebra* which is not correct and *horse, appoloosa* and *quagga* form another cluster – *quagga* should be closer to *zebra*. However, we notice here, as with the students, CJB used *stripes* as a characteristic feature.

7.2.9 Principal components plots of the second set of equids

The grids of the second set of equids were also subjected to principal components analysis using the PrinCom program in RepGrid 2.0 . Figures 7.46 to 7.52 display the principal components plots for the representative 1st, 2nd, 3rd, 4th, 5th year students and the experts respectively.

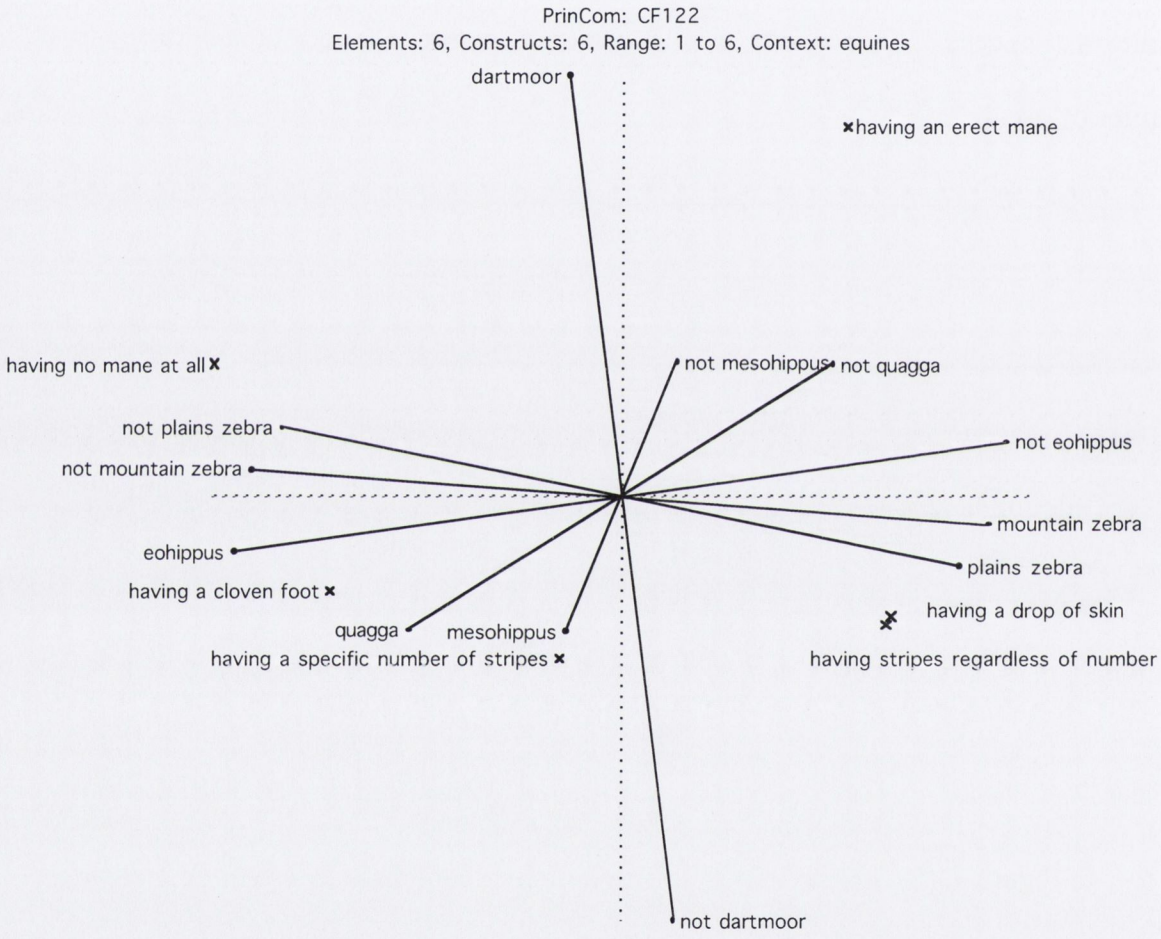

Figure 7.46 Plot of first and second principal components for CF122, the representative first year (variance accounted for: C1 = 55.10%, C2 = 27.90%)

In Figure 7.46, the *dartmoor* pony is plotted as the outlier construct from the set by virtue of its long vector line, however in terms of angle to other vector, the *Mesohippus* is plotted as its closest relative. This is interesting because it was drawn to look very like the *dartmoor* excepting the feet and the stripes on its rump. Thus the *Mesohippus* is located

close to the element: *having a specific number of stripes*. *Quagga* is located near here too – its location being constrained more by the presence of stripes – in spite of the close proximity of *having a cloven foot*, bringing *Eohippus* and *Mesohippus* close together. We see also that the *mountain zebra* and *plains zebra* are located close together as one would expect.

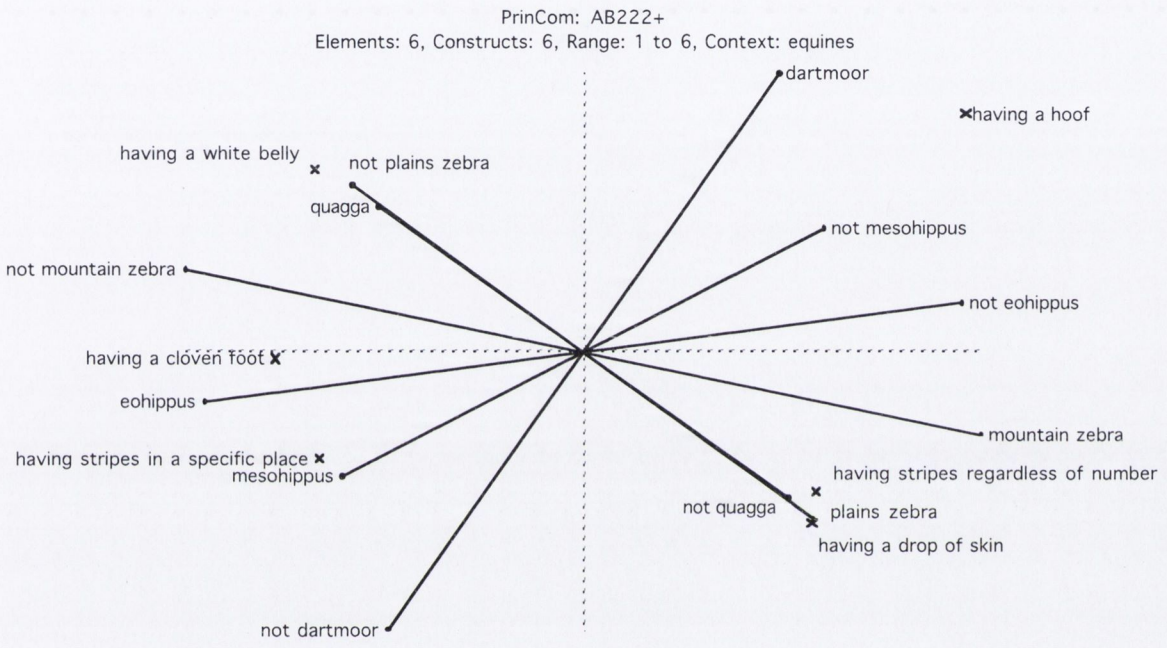

Figure 7.47 Plot of first and second principal components for AB222, the representative second year (variance accounted for: C1 = 64.50%, C2 = 20.24%)

Figure 7.47 does present as clear as picture as the previous example. The location of the *quagga* vector confuses the picture slightly and it is not clear what the student is doing here – and it is likely that they find the *quagga* construct difficult to fit into this array of equids. The two types of *zebra* are clustered near *having stripes regardless of number*; and the *Eohippus* and *Mesohippus* are clustered near *having a cloven foot* and *having stripes in a specific place*. The *dartmoor* is once again an outlier.

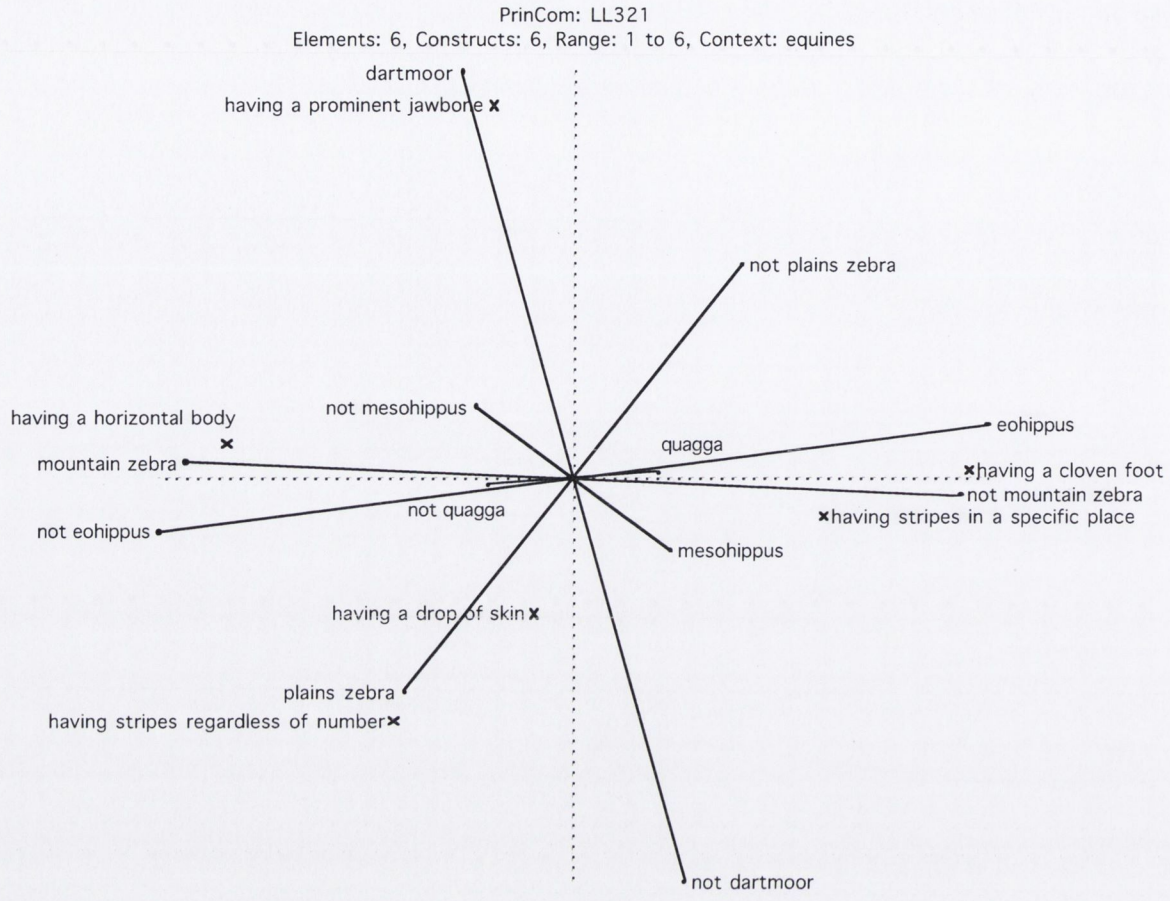

Figure 7.48 Plot of first and second principal components for LL321, the representative third year (variance accounted for: C1 = 47.29%, C2 = 27.56%)

Figure 7.48 presents a similar picture to those previously (Figures 7.46 – 7.47) whereby *quagga* is located in the 'ambiguous zone'. The angles between the *Eohippus* and *Mesohippus* indicate that the subject is considering the influence of other elements than merely *having a cloven foot*. The angle between the two *zebra* vectors is also larger than in previous examples.

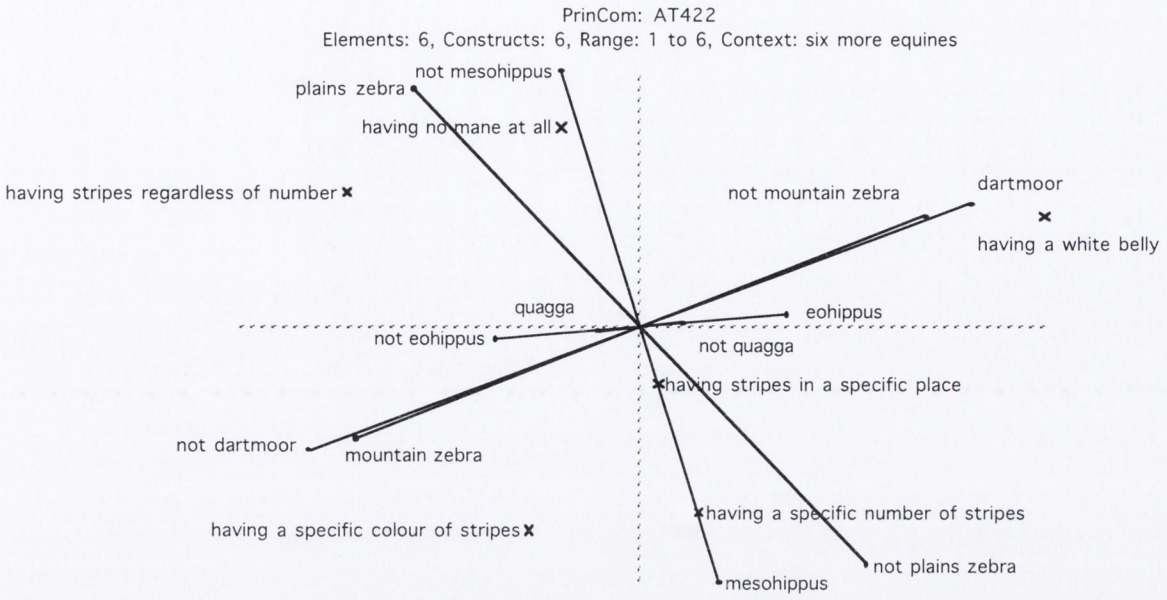

Figure 7.49 Plot of first and second principal components for AT422, the representative fourth year (variance accounted for: C1 = 46.92%, C2 = 26.01%)

In Figure 7.49, although it first appears that the six constructs have been frmed into three pairs of oppositely directed vectors, the vectors of quagga and Eohippus are most worthy of note. These are both superimposed and they are very short. The length of the vectors is important as it reflects a perceived ambiguity of the student concerning these constructs and represents the situation whereby the student gave high scores for most of the elements. Thus, by 'perceived ambiguity' I mean that the student has not fixed on any particular element as distinctive for the constructs concerned. The situation might have been different had the student chosen a key diagnostic feature for *Eohippus* – such as a feature to do with foot structure.

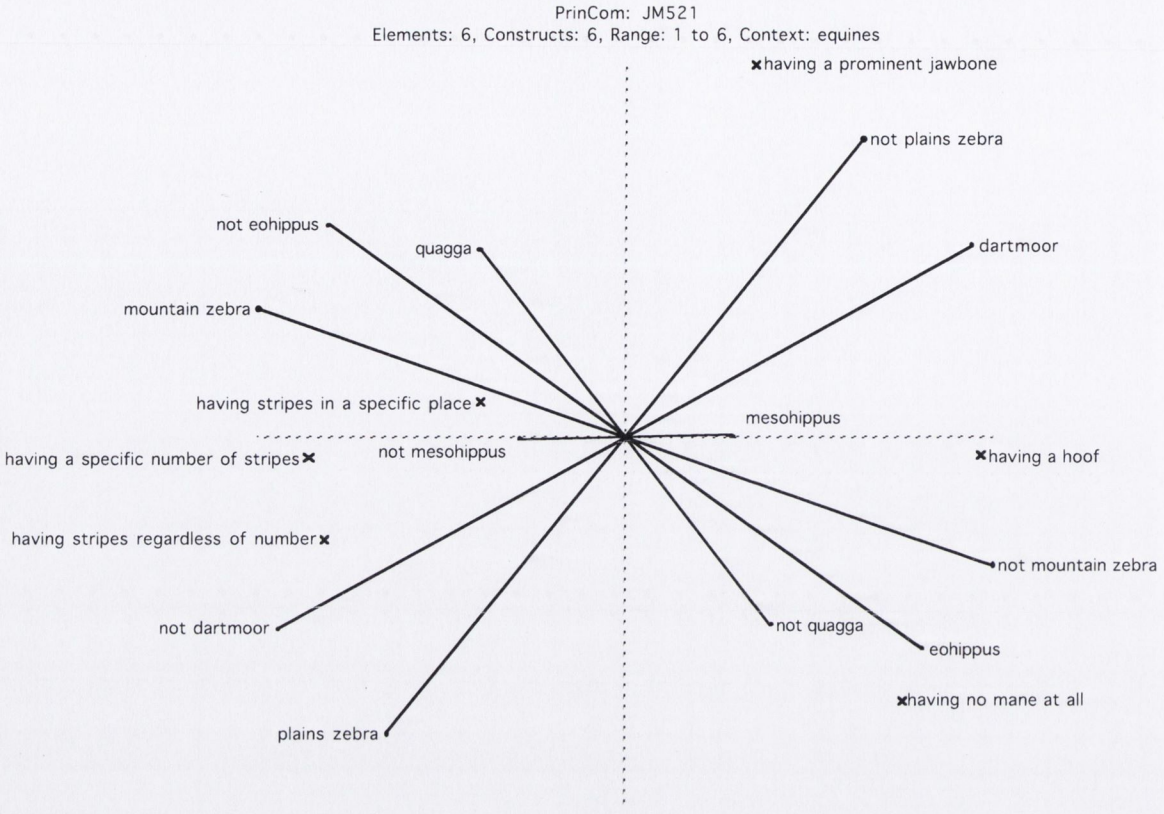

Figure 7.50 Plot of first and second principal components for JM521, the representative fifth year (variance accounted for: C1 = 54.50%, C2 = 28.23%)

In Figure 7.50, JM521, we have the same situation for *Mesohippus* as for *Eohippus* in Figure 7.49, although in this plot, *Mesohippus* is position on its own. The cause of the ambiguity in this plot is that the element having a hoof is placed near the positive pole for the mesohippus which is incongruous. In the original grid, JM521 gave the construct to element link a score of 2, rather than 1 which would have been expected. Perhaps they felt that the foot of the *Mesohippus* was on the way to having a hoof.

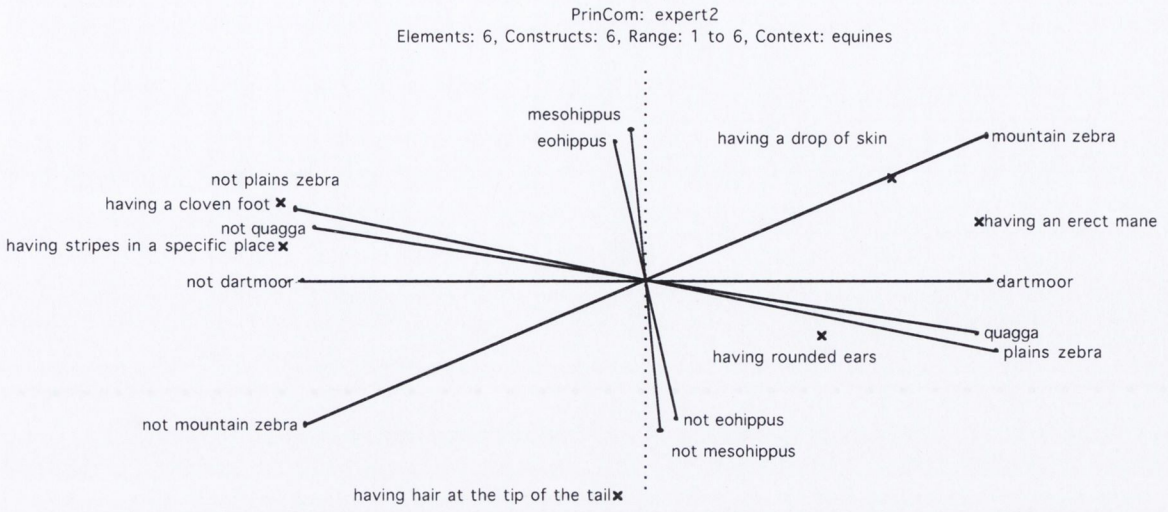

Figure 7.51 Plot of first and second principal components for one expert (variance accounted for: C1 = 83.22%, C2 = 12.61%)

Whereas the variance accounted for in the loadings calculated from grids elicited by students in the first set of equids was typically higher than in the second set of equids, the first expert, a general biologist, was an exception (Figure 7.51). However, notwithstanding the first expert's avoidance of using stripes as a distinguishing feature in the first set of equids, the same person used stripes as a distinguishing feature in the second set. It is not clear why he should have changed his mind in this matter. Perhaps, it was because the second set of equids were in general more difficult to deal with, and the features that could be chosen to separate, say, *Eohippus* and *Mesohippus* were limited.

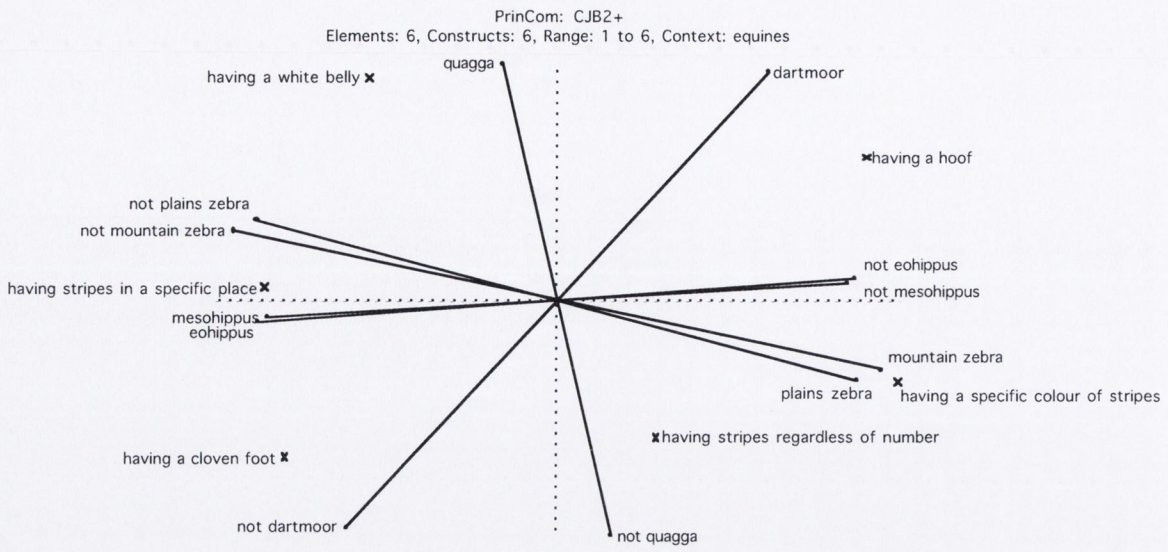

Figure 7.52 Plot of first and second principal components for another expert (variance accounted for: C1 = 67.83%, C2 = 19.81%)

In Figure 7.52, the expert in fish and their parasites has produced a plot that does not have any ambiguity nor lack clarity. The two zebra are closely aligned however the quagga is seen as more distinct – because of the influence of the element: having a white belly. Eohippus and Mesohippus are aligned tightly together, and finally dartmoor is the outlier. This is reasonably close to the formal scientific arrangement based on the elements involved and it is a natural place to leave these plots as we have have encounteres a range of shapes and types over the various age-groups.

In conclusion to this section, it must be noted that whereas the original grid, focussed grid and cluster analysis and principal components analysis each provide some information about an individual and how he or she constructs knowledge concerning natural kinds, comparison across groups has not been done. The next section attempts to remedy this. Principal components plots are conceptual maps in the literal sense sense

they 'map' using coordinates the concepts (as vectors) and their features (as points). Concerning individuals, they can be used to compare an expert with a novice, and such things as the angle between vectors, closeness to elements, and which constructs lie close to each other provide rich information about the subjects construction of the knowledge concerned. It was particularly noticeable that the second expert represented the equid constructs in much the same way as the students: focussing (or constrained by) a single feature such as the existence or number of stripes. It is striking that this can lead to relationships being constructed between living things which have no close biological relationship, *e.g.*, bongo antelope, tigers and zebra or at best distant relationships *e.g.*, tapirs. In biology, such groupings are the result of an analogous feature, whereas in equids, the key feature is the hoof, described in biology as a homologous feature. The difficulty for the students was to differentiate a group of creatures who all possessed the homologous feature. The first expert used the mane form and tail form (even though not clear in the diagrams) as diagnostic features. Clearly, a theory is at work in the mind of the first expert. The question now is: how many of the students share this theory? A record of commonality is required, and for that a social network framework is necessary. The next section deals with such frameworks.

7.3 SOCIO

So far, in dealing with the applications of RGA, attention has been on the conceptual structures of individuals. However, a practitioner would presumably wish to gain an impression of the whole class understanding of a concept. RepGrid 2.1 permits the user to calculate the similarity between any two grids.

According to Mildred Shaw (1980), one of the progenitors of the RepGrid package, Kelly's position was that both elements and constructs should be elicited from the individual, but when neither elements nor constructs are in common, measures of overlap are difficult to arrive at (Shaw, 1980 p. 88). Elements are more easily shared than constructs, since they are, in the words of Shaw "*representatives of the universe of discourse*". If they are physical entities (which is important in this thesis) or shared experience, participants should be able to construe them with little difficulty. Shaw states that the problem is to find a stable but sensitive measure of the degree of shared meaning.

Shaw (1980, p. 88) discusses how several crude measures were initially used:

(i) the number of times two adjacent elements were from different grids;

(ii) the ratio of the number of clusters contain elements from both grids to the total number of clusters formed, at an arbitrary cut-off point of seventy percent;

(iii) the sum over all pairs of adjacent elements from different grids of the levels of match at which they were brought together.

However each of these methods was finally rejected in favour of the one currently used in RepGrid and its on-line version WebGrid: this involves computation of the

'construct matching scores matrix' for the whole group of individuals selected to analyse. This is the same procedure of the calculation of clusters in the FOCUS programe. Kelly's (1992) commonality corollary states that "*to the extent that one person employs a construction of experience which is similar to that employed by another, his process are psychologically similar to those of the other person*". This is not implying that the similarity is necessarily the totality of psychological processing, but as was discussed in Chapter 1, judgements of similarity is a central process in one's mental life.

A sequence of sociometric diagrams called *socionets* in the part of RepGrid 2.0 called SOCIO is produced from the matrix of similarity measures between pairs of individual grids. Whereas in FOCUS similarity was calculated between the rows or coloumns of a single matrix. The highest related pair is picked out initially as a sub-group, followed by the sub-groups defined by the rank ordering of all similarity measures. The early development of SOCIO is described by Thomas, McKnight and Shaw (1976)[35].

In RepGrid 2.0 any individual grid can be DISPLAYed, FOCUSsed or have principal components derived (PrinCom). A number of choices must be made with SOCIO, not least whether the user wishes to view the output of the comparison in a textual or graphical format. In the textual format, a number of criteria for the comparison can be checked, and in this thesis, the author consistently checked the boxes, 'grids' and 'links' .

Once the required grids are opened and have been selected, similarity can be calculated between any two grids at a specifiable level of match. For much of the example described later, a match level of 80% was chosen, *i.e.*, the percentage of the total

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[35] Cited in Shaw (1980 p. 88)

maximum match was 80% . This value was chosen because experience showed that at lower levels, the number of links proliferated *ad absurdium*. The user has a choice of whether to have the output represented in a graphical (socionet) form or a text format. There are a number of options in the text based format: checking the 'grids' option leads to the output which is in effect a list of the input data.

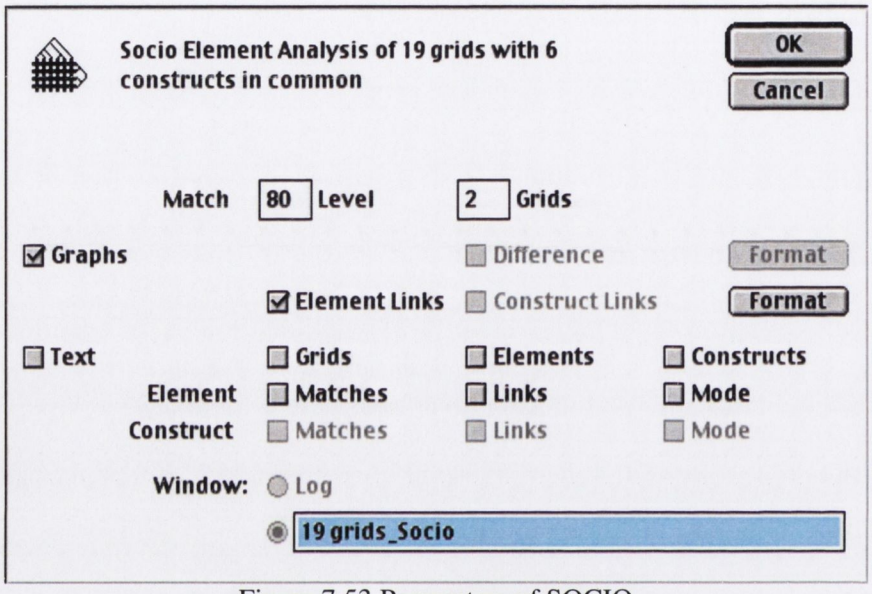

Figure 7.53 Parameters of SOCIO

Checking the box in Figure 7.53 for 'matches' provides an output similar to that shown in Table 7.5 . Table 7.5 shows the socio exchange output where the highest match from the second of any pair of grids with a closest match to each one in the first grid is shown, and *vice versa*. This occurs when, as in this case, only the constructs are in common. Two numbers appear in each comparison; one, a percentage, is a statement that that percentage of the matches have at least reached the desired 'level' – which is the second figure: a decimal figure denoting the level at which the match is calculated.

In general, the higher the level figure, the more restrictive the parameters for allowing a match. The 'level' serves to exclude some of the data from a purely pragmatic

point of view since an open comparison would be time consuming, cause issues concerning computer random access memory and processor speed. As it stands, the output in this section is, by all regards, huge and reading it, let alone analysing it, time consuming. Table 7.5 shows only one pair of grids (G1 and G2) being compared, which in the end exhibits a low similarity (16.7% overall at a match level of 80). A match level is a percent value of the maximum match possible between the two entities, thus 16.7% at a match level 80 is much less than 16.7% at level 90. Level 90 is a more restrictive matching and creates fewer matches or links in a network. Six matches are listed for each of the constructs for G1 starting from construct 4 (C4) in both grids scoring a similarity of 16.7% (low) at a relatively high match level of 86.7; to G1C6 and G2C4 scoring 100% (high) at a low match level of 66.7.

Table 7.5 *Socio Element Analysis of 2 grids in the first year cohort: element correspondence*

```
G1<:G2 16.7% over 80.0 (HM111 Element-correspondence-from GF111)
1:   16.7% ≥ 86.7      G1C4: having a fallen mane /
                              G2C4: having a fallen mane
2:              ≥ 73.3 G1C3: having a tail with long hair /
                              G2C3: having a tail with long hair
3:   50.0% ≥ 73.3      G1C5: having a tail with long hair /
                              G2C3: having a tail with long hair
4:   66.7% ≥ 70.0      G1C1: having a prominent jawbone /
                              G2C5: having a prominent jawbone
5:         ≥ 66.7      G1C2: having stripes regardless of number /
       G2C2: having stripes regardless of number
6:  100.0% ≥ 66.7      G1C6: having a fallen mane /
                              G2C4: having a fallen mane
```

Each pair of grids is compared in turn, construct by construct. For example one pair is G1 and G2; the comparison is not merely checking the occurrence of elements chosen in each grid but rather the ranks of each grid for this element. Construct 6 in each grid (*speckled zebra*) shows a very low similarity at 16.7% at a level of 93.3 because they do not have the same elements except two (*having a horizontal body* and *having no mane*

at all) but with the same rank with the first element. In the G1C4 (*appoloosa*) to G2C2 (*zebra*) comparison, different constructs have the same element but it has been ranked '2' in the *appoloosa* and '1' in the *zebra*, thus this gains a similarity score of 50% at level 73.3. In the G1C1 to G2C1 (both of which are *quagga*) comparison, they have two elements the same, one with the same rank which 'earns' 100% similarity at a relatively low level of 66.7 . The program calculates an overall similarity at the specified level (80) which in this case was 33.3%.

7.3.1 Socionets

The information from the comparisons can be represented in a graphical form known as a *Socionet*. This demonstrates in a simple way where the links between constructs exist by plotting the subjects as equidistant points in a polygon (where the number of apices equals the number of grids) and drawing a vector between the grids represented as points where a link exists at a specified level. The user selects this option on the SOCIO parameter window (Figure 7.37) by checking the graph rather than text option. If the level chosen is too high, there will not be many links made, and the converse is therefore true, too low a level and so many links are made to make the graphic unreadable. A range of miscellaneous socionets are provided in Appendix 7.4 .

7.3.2 First years

Figure 7.54 and Figure 7.55 show the socionets for the first year group for the first and second set of equids respectively. AN111 and PK111 have the most links with others, some reciprocal, some not. The people with no links are isolates. In Figure 7.54, the relatively high percentage linkage at a high level partitioned students who had no links with any other students and others who had a range of links to AN111 who had 9 links

with other students, 8 of which were unidirectional towards AN111. AN111 appears to have functioned as a stereotype; however notwithstanding such an observation, the links demonstrate that 9 students had grids of 70% commonality with AN111 and AN111 in turn had 70% commonality with CM111.

In the second set of stimuli (Figure 7.55), a much denser socionet is produced showing much shared perception if not understanding of the items in the stimulation; this is all the more marked given that the level was lowered to 70.0 to attempt to see if a more open structure emerged, however, it did not until an even lower level was used, so low in fact that the percentage similarity was in effect a poor match level. The second set of pictures were certainly processed by the students differently than the first set.

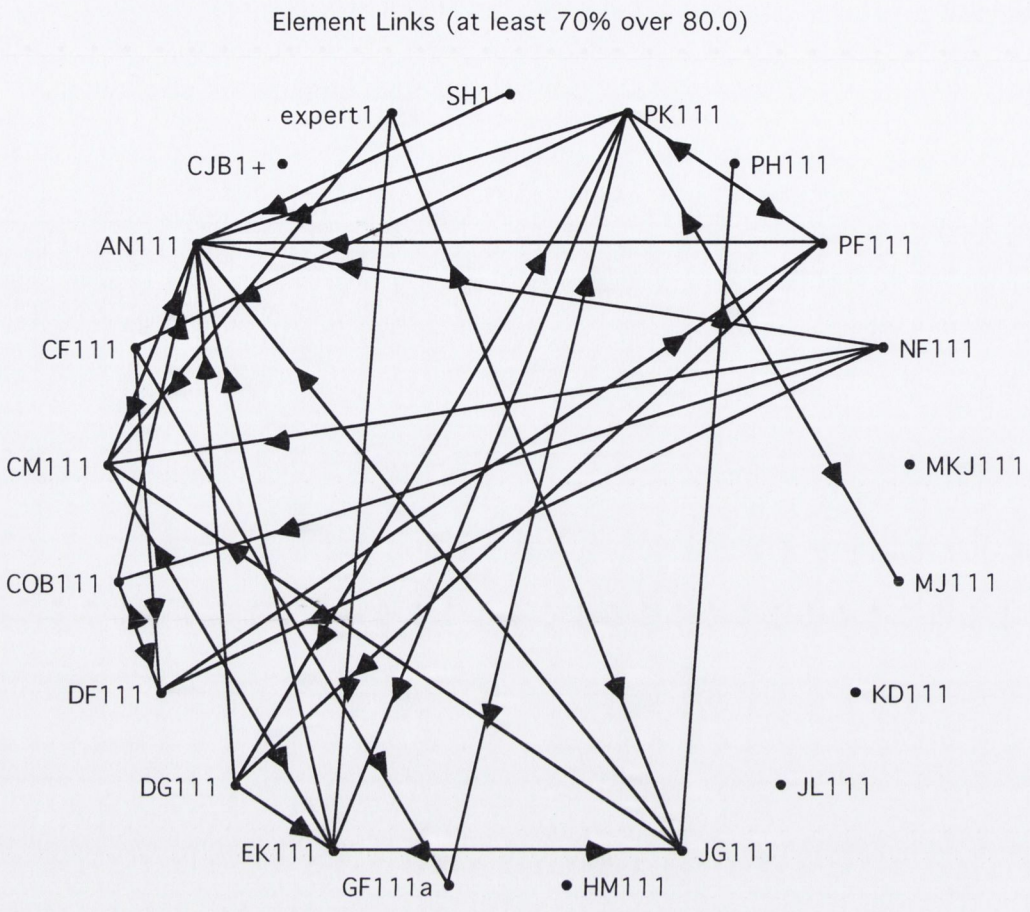

Figure 7.54 Socionets for the first years: first set

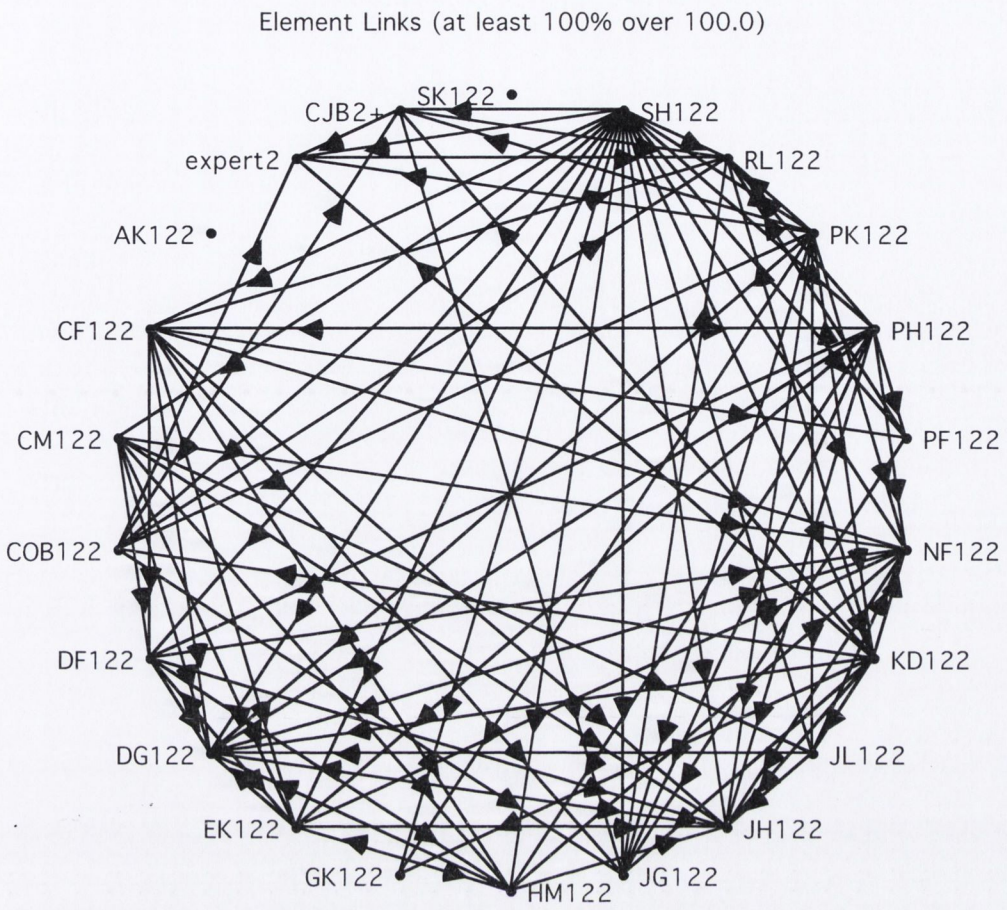

Figure 7.55 Socionets produced by the first years: second set

7.3.3 The second years

The second year results (Figures 7.56 and 7.57) showed a high degree of consensus. In the 60% at level 90 socionet, a number of individuals had no connections with anyone else. ABr211 for some reason omitted one of the constructs, and used one of the elements twice. Thus, ABr211 may not have understood the task set, and EA211 had only two connections. ED211 and AM211 (both arrowed) appear to be the stereotype for this group, because they have the greatest number of links (n=9). Note that both experts ('CJB' and 'expert1') are isolates.

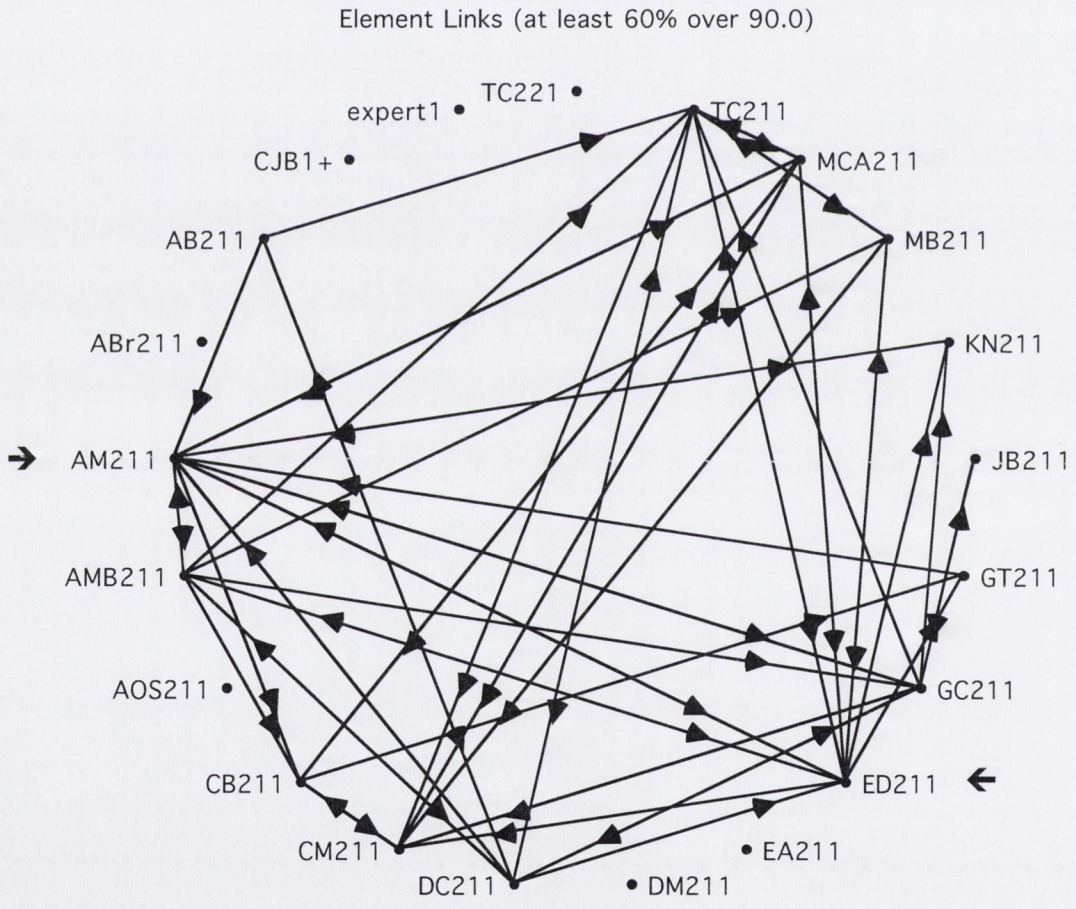

Figure 7.56 Socionets produced by the second years: first set

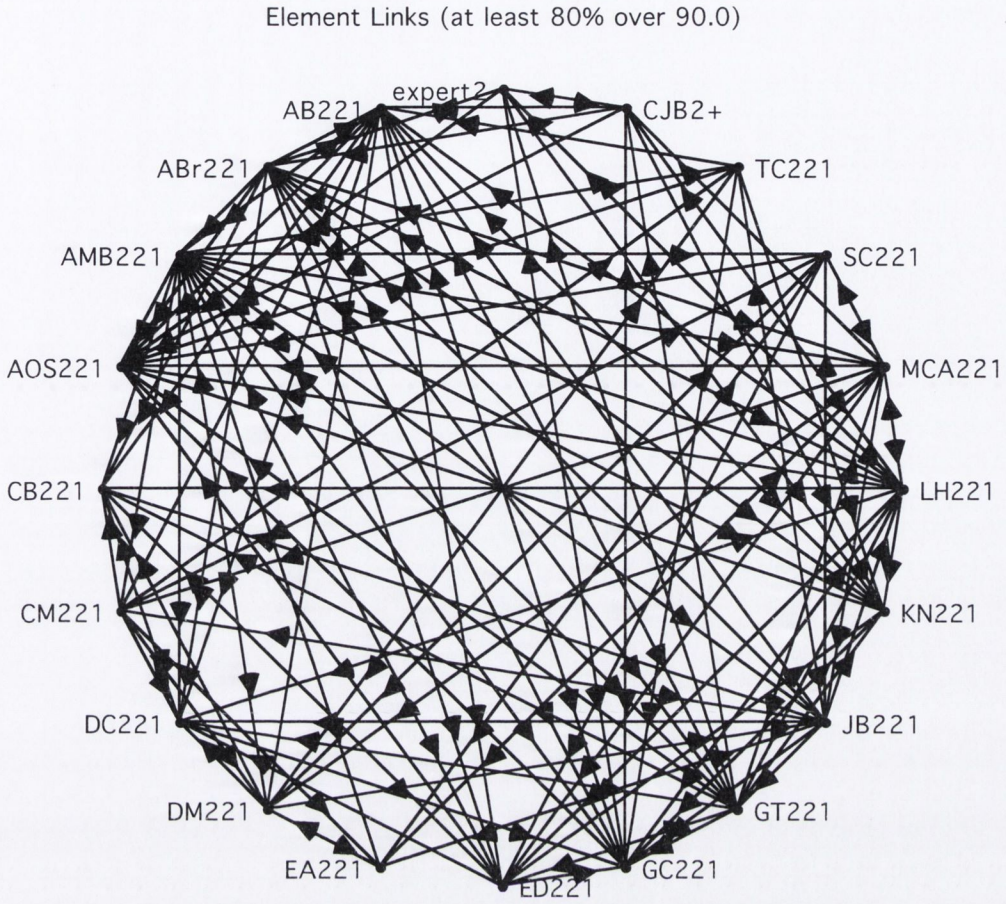

Figure 7.57 Socionets produced by the second years: second set

If we compare the sets of the second year students (Figure 7.56 and 7.57), the second set show a higher degree of consensus. We might assume that when a group of inidividuals cannot achieve consensus "easily", then the stimuli must be creating some cognitive conflict as indeed they were designed to do. The value of the repertory grid analysis is that it can detect such conflict within a class group and then refer back to the original grids to determine the source of the conflict.. In the second set (Figure 7.57) KN222 (whom is the same as KN221) appears to the stereotype.

7.3.4 Third years

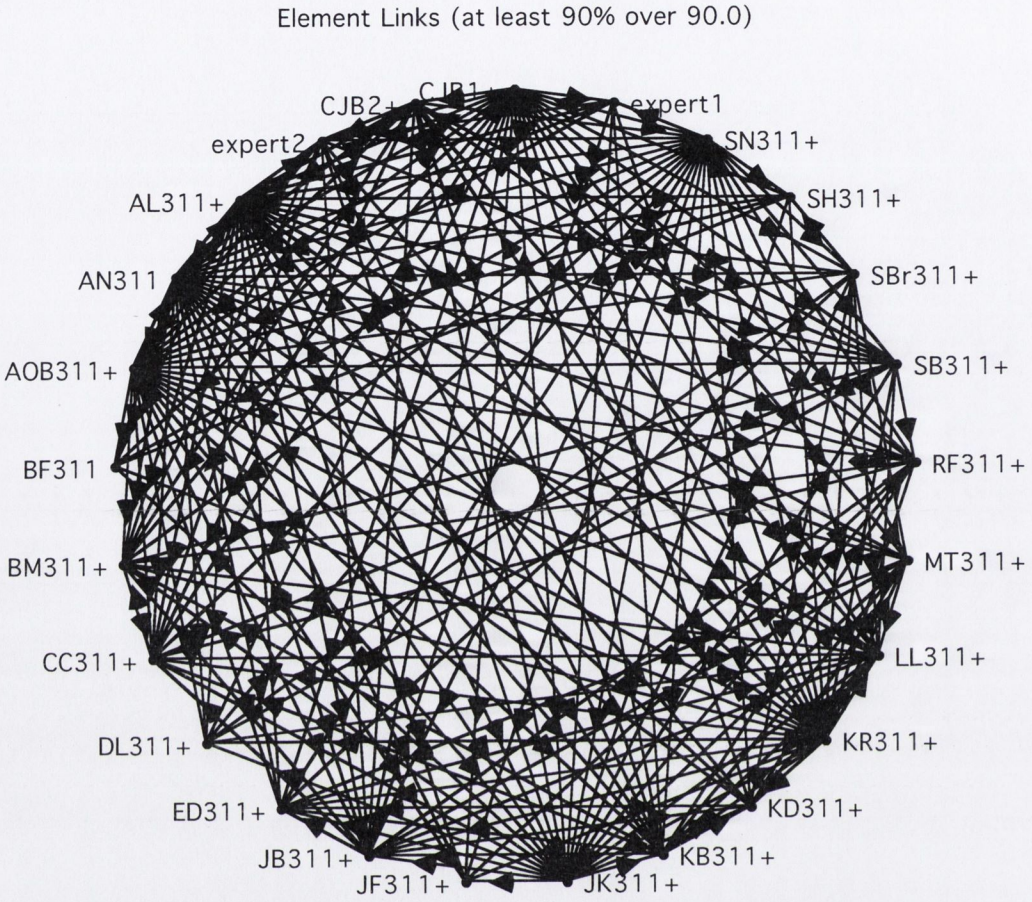

Figure 7.58 Socionets produced by the third years: first set

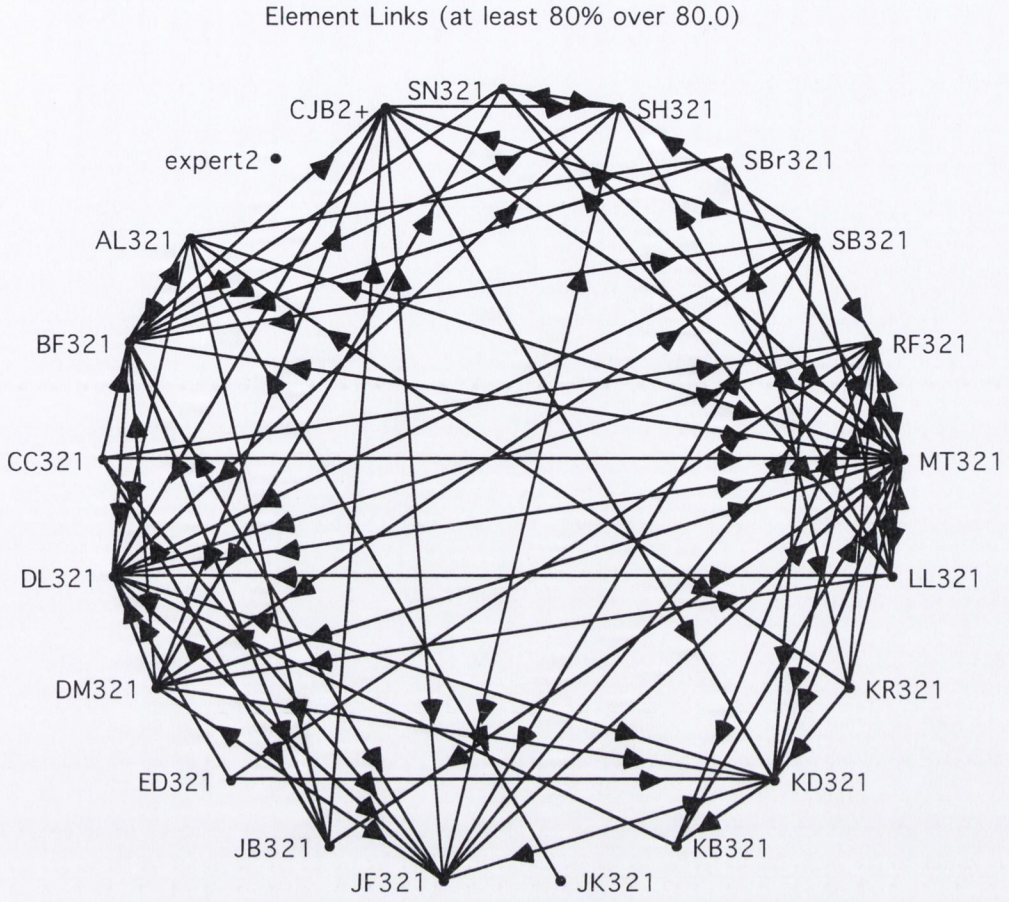

Figure 7.59 Socionets produced by the third years: second set

In the third year group, in the first set (Figure 7.58), a high degree of linkage was achieved at a relatively low set of constraint compared to the second set (Figure 7.59). This was also true for the fourth years (Figure 7.60) but it was all the more marked that at a wide range of parameters, "confluent" (that is, it appeared that all students were linked to all others) linkage occurred indicating an almost uncanny similarity between the grids of the fourth year students. Note that 'expert 2' (the first expert) is an isolate.

7.3.5 Fourth years

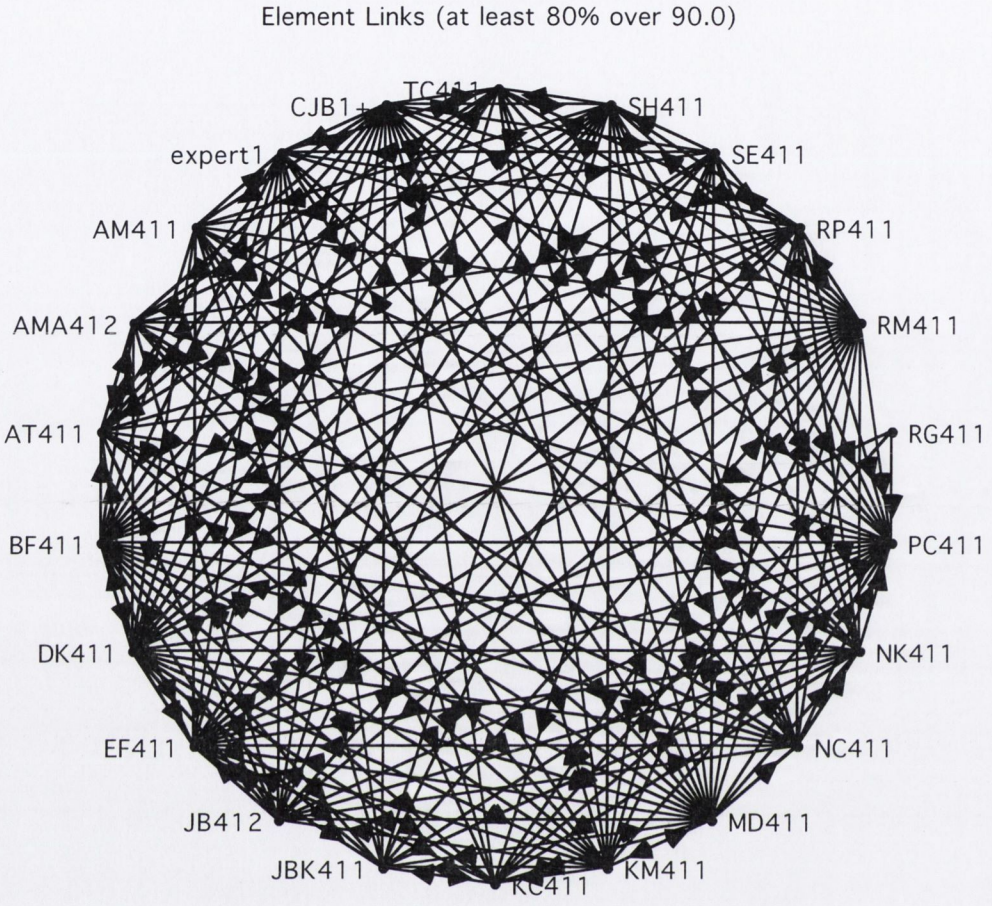

Figure 7.60 Socionet produced by the fourth years: first set

60% at level 70, 80, 90; 70% at level 70, 80

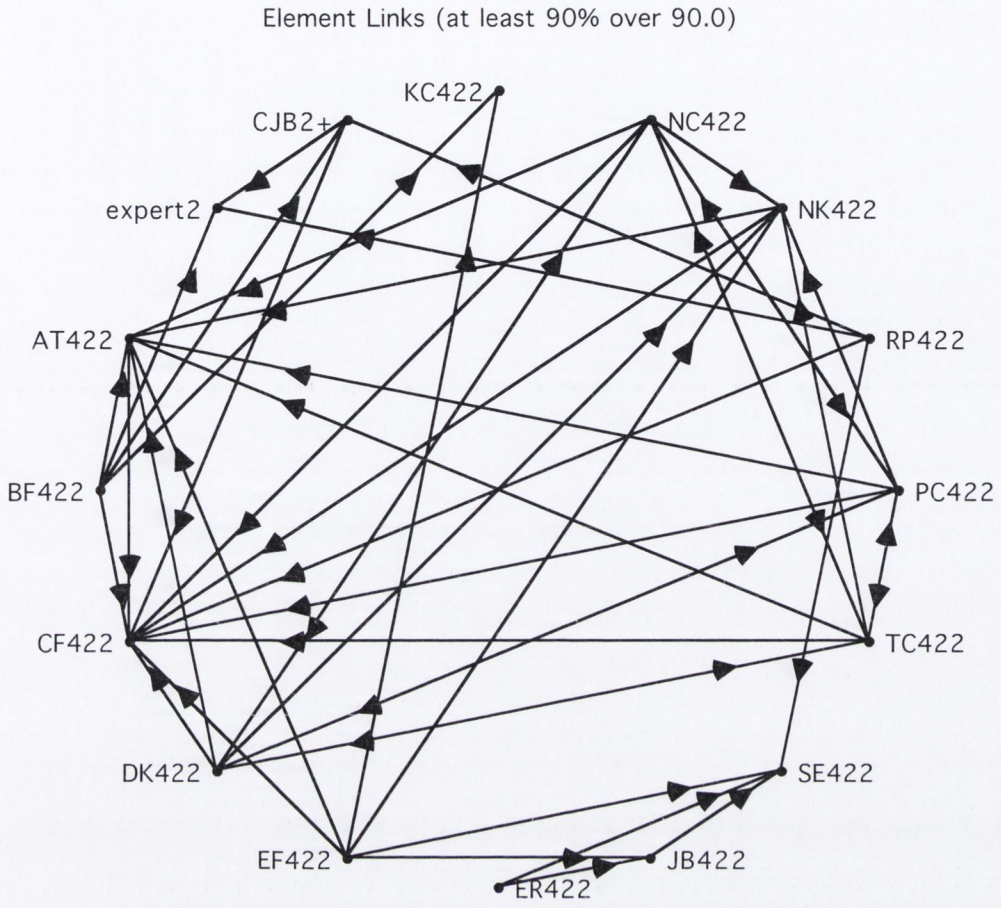

Figure 7.61 Socionets produced by the fourth years: second set

In the fourth year group, there is an almost identical perceived similarity of tthe first set of equids as evidenced by the same result over a number of parameters, (Figure 7.60). This not exactly the case with the second set where a wide variety of interpretations exists among the students, hence a 'disparate' socionet at the lower set of parameters (Figure 7.61), however, relatively speaking there remains a high degree of commonality, compared to, say, the third years, *cf.* Figure 7. 58.

7.3.6 Fifth years

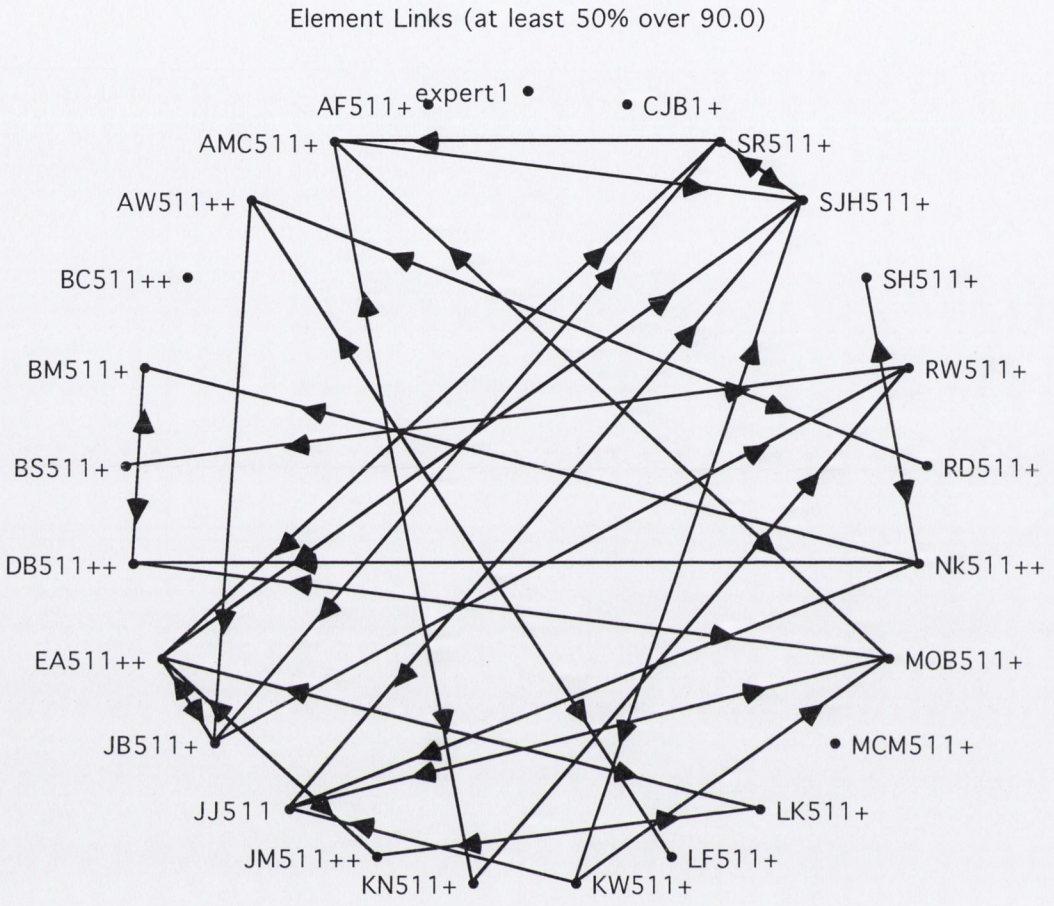

Figure 7.62 Socionets produced by the fifth years: first set

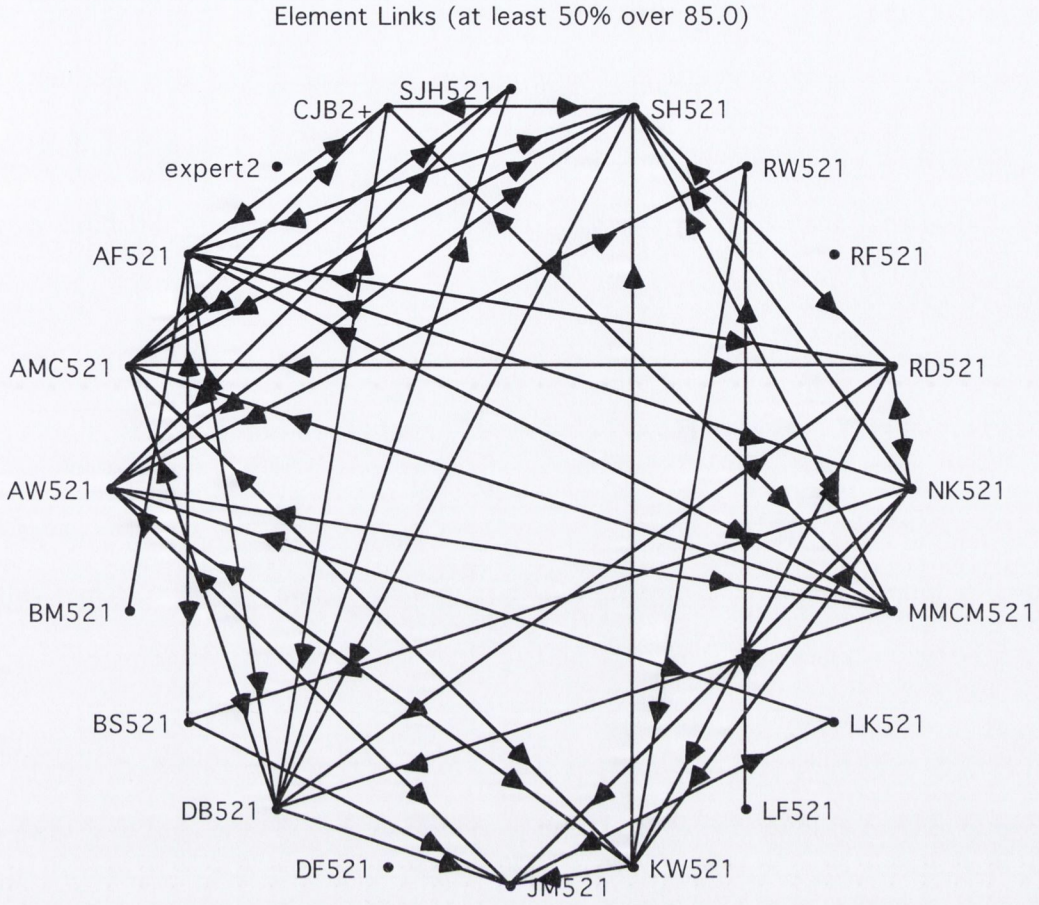

Figure 7.63 Socionets produced by the fifth years: second set

Again, we see from the socionets that the fifth year students found the first set (Figure 7.46) easier to form a consensus with, than the second set (Figure 7.47). This evidenced by the fact that "confluence[36]" was achieved at parameters in the first set, which did not happen at the same parameters in the second set.

Throughout the preceeding socionet diagrams the experts were represented. Table 7.6 shows the number of links that they experts shared with other people. The

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[36] A bacteriological term that describes complete coverage of bacterial colonies on an agar plate. Here it means that each person appears to have links with every other person and the socionet is completely covered with links that cannot be distinguished.

experts did not appear to share much understanding of the constructs with the second and fifth year students as evidenced by the experts forming isolates at a relatively low socionet parameters. Whereas, the experts shared the same construct representations with the third and fourth year students' constructs in the first set. Otherwise the experts did have a modest number of links in the remaining socionets.

Table 7.6 *Table comparing the number of links of the experts with other individuals.*

	First expert biologist (denoted as expert1 in the first set and expert2 in the second set)		Second expert biologist (denoted by CJB1 in the first set and CJB2 in the second set)	
	First Set	Second Set	First Set	Second Set
First year students	3 links	6 links	Isolated	7 links
Second year students	Isolated	7 links	Isolated	9 links
Third year students	Confluent	Isolated	Confluent	9 links
Fourth year students	Confluent	3 links	Confluent	4 links
Fifth year students	Isolated	Isolated	Isolated	5 links

7.3.7 Distillation of the results

The importance of RepGrid 2, however, is not in producing the principal components graph (which other programs will do) but that once a set (usually a maximum of 20) of concept maps/matrices is produced the researcher can compare the maps using a chosen set of parameters. This comparison can then be represented in textual or graphical form. Two parameters were varied: (i) minimum percentage correspondence between grids, and (ii) minimum level (the higher the level chosen the closer the degree of correspondence). The arrows represent linkages which satisfy the parameters chosen, for example in the first socionet, CM111 and JG111 are at least 50% the same as PH111; and NF111 is at least 50% the same as DF111. When the arrow has points going both ways the linkage is reciprocal, i.e., each has the same percentage similarity. The numbers of linkages were tabulated over the five subject groups. Figure 4. shows the total number of linkages at a

given percentage correspondence at level 90. In general, comparing year 1 to year 5 there is an increased degree of correspondence. In first year the most common degree of correspondence is 20% whilst in years 3, 4 and 5 it is 66.7%. The total number of linkages is higher in year 5 than in years 1, 3, and 4. However, the results for year 2 are problematic. The number of linkages at each percentage is higher than expected, so that when added, year 2 has the largest overall set of linkages. The explanation of the pattern of results is bound to be composed of a wide range of influences, including different experiences of schooling and individual differences in the students' experience of everyday life. In all of these year groups there was a different gender balance (skewed to male in each) and mix of student abilities, no attempt was made to relate concept map complexity to ability level. Results can be unreliable if students put down what they perceive as the "right" answer rather than utilising their own personal beliefs. A second administration of the test item and averaging the two grids of each subject would quantify some of this variation. Looking specifically at how students characterised the images presented to them provides some interesting data. Broadly speaking quagga was characterised easily and consistently by the students, the key feature rating a '6' or '5' was 'stripes in a specific place'; zebra tended to be determined by 'stripes regardless of number'. The horse (proper) and appoloosa were drawn to introduce cognitive conflict - they both had stripes on the legs and the shared the same characteristics except that the appaloosa was spotty. However, the features the students had chosen themselves did not help them distinguish the two animals very well. What happens when a new animal is encountered that does not fit currently acquired experience? How the students resolved this was, apparently, to arbitrarily decide which of the two deserved the highest rating ('6') of one feature whilst

ranking a second feature '5' and reversing these. For example, giving 'horse' a '6' and 'appoloosa' a '5' for 'prominent jawbone' and a '5' and '6' for 'long tail with hair' respectively even thought the jawbone and tail were exactly the same in each picture. This seems to be a mechanistic approach as there isn't a real allocation of numbers based on a well thought-out rationale. Another way students resolved the conflict was to assign a feature that separated the appoloosa from the horse altogether. However, this meant that the students were using a feature that did not deserve a rank of 6 for the *appaloosa*, *i.e.*, in terms of formal biology, it was wrong! In both instances there appears to be a mental economy involved merely to overcome the problem, i.e., they chose the simplest, most expedient way to resolve the issues.

Finally, in distinguishing the melanic (a genetic variant) *zebra* and *speckled* (fictitious) *zebra*, to approximately 20% across the cohort tested there was no problem and these animals were mapped close to *zebra*. However, for other students there was a problem; and the above two strategies were employed mapping these animals in isolation or near another animal inappropriately.

The information gained about how the students constructed representations of the equids presented to them is summarised in Table 7.6, however only the main findings are listed. Having examined mammals and equids in some detail, the focus of this thesis will be turned to the study of plants.

Table 7.7 *Details of the information gained from RGA on the visual stimuli used in the study on equids*

English Name	Rationale for inclusion	Observations from the plots of the loadings and original grids
Horse	this is a stereotype of an equid, a basic example but with stripes on its leg.	Typically characterized by the feature: *having a horizontal body,* or *having a fallen mane*
Melanic zebra	a rare form of plains zebra resulting from a genetic state which caused a large deposition of melanin in the coat of this individual.	Often clustered with *speckled zebra*. Clearly, the students have a clear idea in their own minds of what a *zebra* should look like and this was never clustered with *zebra per se*.
Speckled zebra	an imaginary equid	Often clustered with *melanic zebra*
Plains zebra	this is a stereotype zebra, the common image of a zebra	Not differentiated from the *mountain zebra*. Only in some cases did the students notice the larger ears.
Quagga	a subspecies of the plains zebra. It is extinct at present but attempts are being made to 'resurrect' this subspecies.	This could be clustered with *Mesohippus* and *Eohippus* on account of using the feature: having stripes in a specific place even though the three have little relationship between them.
Appoloosa	this is a north American breed or horse with distinctive coat markings that appears counter intuitive to Europeans	Typically classified with *horse per se* and difficult to differentiate from horse with the given features listed. Students were not tempted to focus on the striped legs.
Dartmoor	an ancient breed of horse of a shape and habit that humans would have been more accustomed to than 'modern' thoroughbred types	Not differentiated from *horse per se* despite the difference in the mane (upright in *Dartmoor* ponies, fallen in *horses per se*). Often clustered with *Mesohippus* as the drawing was the same, excepting the feet and the stripes on the rump. In those cases, students are allowing the overall appearance override the tendency by most students to focus on the stripes.
Mountain zebra	a zebra that appears to the untrained eye to have extra stripes	Not differentiated from the *plains zebra*
Eohippus	extinct, a small horse like animal with multiple toes about the size of a large dog	Found difficult to characterise in any way other than using stripes (which were drawn deliberately ambiguously as blotches)
Mesohippus	extinct, a relatively small horse but with cloven feet	Often clustered with *Dartmoor*: see above

Chapter 8. Explorations with natural kinds and repertory grids: *Dicotyledonidae*

Some seeds again are enclosed in a pod (lobo),
some in a husk (dmeni), some in a vessel (angeió)
and some are completely naked (gymnosperma)…

Theophrastus (370 – 285 B.C.)[37]

8.1 Introduction to chapter 8

Figure 8.1 displays a concept map for this chapter.

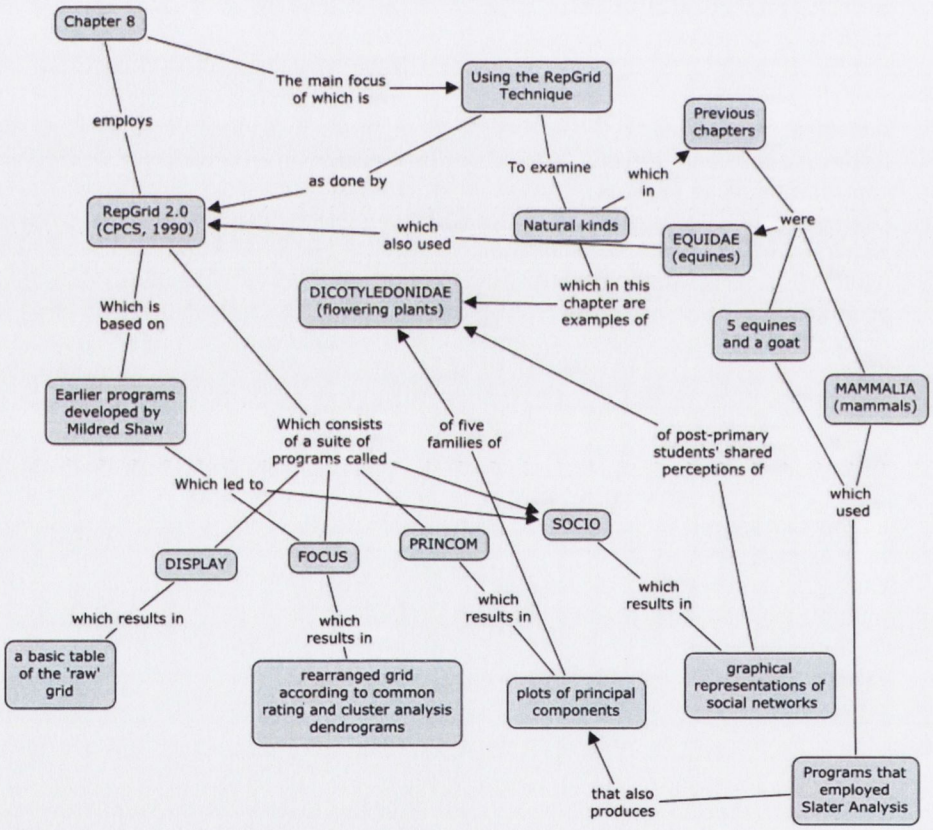

Figure 8.1 Concept map of the main features of this chapter

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[37] Theophrastus is known as the father of taxonomy and in this short quotation, he details a fundamental rule of differentiating plants scientifically: by what manner the seed is carried in the senescent plant. Two groups are still current in modern science: the *angiospermae* and the *gymnospermae*.

Chapter 7 outlined the process of using RGA in the form of the RepGrid 2.0 program and then described a large study of science learners' conceptions of equines as examples of natural kinds. In this chapter, the category of natural kinds explored is the *Dicotyledonidae*: the dicot[38] flowering plants. The main issues examined in this chapter are listed as follows:

1. Plants exist as a spectrum of perceptual difficulty, whereby some groups are more difficult to differentiate than others. It is anticipated that RGA can assist in examining how learners structuralise their approaches to plants

2. Whereas the previous chapters examined the learners' representations of conceptions of a large group of mammals, two sets of six equids and a group of six mammals (five equids and a goat), in education it is desirable that the knowledge a learner has is compared to that that one or more experts in biology possesses. Comparison of a novice's knowledge to an expert's is the core of assessment. It is anticipated that RGA can form the basis of some form of assessment as a result.

3. What kind of differences would arise between a north-west European group (N. Ireland) and western Mediterranean group (Communidad Valenciano) – given that the stimuli were images of flora of north-west Europe?

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[38] These are flowering plants that when the seeds germinate, the emerging plantlet consists of two 'seed leaves' or cotyledons, before the true leaves appear. This group of flowering plants is the most abundant and diverse of all the plant groups.

8.2 Introduction to the study of plants from a cognitive perspective

Plants are different. The term 'plant' has been described as a distinct ontological category from the term 'animal' (Rosch & Mervis, 1975). Perceptions of animals over and against plants have been studied and reported in a number of works (Bell, 1981a; 1981b; Darley, 1990; Kinchin, 1999). Ethnobotanical research has examined the differing taxonomies of Western tutored biology learners versus those of tribal indigenous groups, and the folkbotanical knowledge of these tribal groups has been extensively analysed (Berlin, 1992, 1999). It is evident that tribal indigenous groups possess taxonomies and classification systems that are as rich, and comparable to, formal scientific systems.

Teachers of learners in biology know of the difficulty in inculcating an appreciation of plants as living things, rather than 'background noise' on the perceptual landscape (Schneekloth, 1989; Simmons, 1994; Tunnicliffe, 2001; Tunnicliffe & Reiss, 2000). Recalcitrant students state: *"but plants are boring, they just sit there and do nothing!"* Animals present an immediate problem to humans: how do they move of their own accord? Plants appear as the green backcloth on which animals move. Part of this problem may be that we intuitively represent a living thing as an animate or moving thing, and thus it constrains our attention and possibly the motivation of the biology novice in 'learning' about plants. Wandersee (1986) outlined preference to topics in American high school biology among 136 biology learners and found topics relating to plants to be low down on the list. Yet plants must have presented their own problems to early hominids, and problems that present life or death consequences have an evolutionary weighting and thus become 'adaptive', some of which are listed in Table 8.2. Such problems are considered important by some (Barrett & Fiddick, 2000, p. 252) "*because a proper*

understanding of the adaptive problem that shaped a particular cognitive mechanism is crucial for generating hypotheses about that mechanism's structure". Whereas Barrett & Fiddick (2000) emphasise the role of risk in decision making, they follow other authors (Kühberger, 1998; Rode *et al.*, 1999; Wang, 1996) in believing that situating adaptive problems purely in the context of human foraging is too simplistic. Hence, Table 8.1 expands the range of adaptive problems beyond foraging.

Table 8.1 *Some adaptive questions concerning plants*

Adaptive questions	The significance of such questions
Is it poisonous or 'nice' to eat?	Culinary/nutritional importance
Can it heal? Is it magical?	Medicinal and/or mythological importance
Is it pretty?	Aesthetic importance
Can I grow this?	Agricultural importance as a consequence of whether poisonous or not

8.2.1 Educational implications of studying plants

These problems, however, are only relevant if the individual develops within a plant-enriched environment, and one in which plants have one or more clearly defined functions where such problems present themselves. Today, of course, many humans in modern urban settings do not live in a plant-rich environment and many that do are unaware of it, forming as it does a perceptual backcloth as mentioned earlier. Tunnicliffe and Reiss (2000) explored how school children aged 5 —14 years recognise, identify and group the single members of the following categories, which according to Atran (1990) fall into the following major groups:

- Fungus: strictly, not a plant.
- Bryophyte.
- Pteridophyte.
- Gymnosperm.
- Dicotyledon.
- Monocotyledon.

This typology reflects how curriculum designers in biology typically divide the plant world. Respondents chose 'anatomy' *i.e.* gross perceptual features of the plant as the main reason for 'putting names on' each specimen. Tunnicliffe and Reiss (2000) believe that when a person is presented with a plant specimen, asked to name it, and say what features it possesses that are important to them in giving a name to a plant specimen, (s)he attempts to recall their existing 'mental model of closest fit' (*i.e.*, a prototype), and match that to the plant they observe. Berlin (1999, p. 83) found that in almost all of the 5,000 collections representing 3,000 species and subsequent classificatory decisions that one Maya Amerindian made were '*perceptually based, remarkably consistent and for the most part botanically informed*' even though that person had only the most basic formal education. When one's classification of the flora does not conform with currently recognised phylogenetic boundaries of 'Western' botany, it is generally the case that the organisms in question do indeed share many of the perceptual features in common which justify one's grouping of them as members of the same conceptual category. For example, novices may confuse a pineapple fruit and *Cycas* palm (Figure 8.2) or various members of Asteraceae that possess yellow composite flowers, which are sometimes on botanizing fieldtrips recorded as "ABYC" *i.e.*, 'another bloody yellow composite' (Figure 8.3). Even trained botanists can have difficulty telling species apart, and it would be pertinent to this thesis to

determine if students also experience the same difficulty. For that reason, this family was included in the study following.

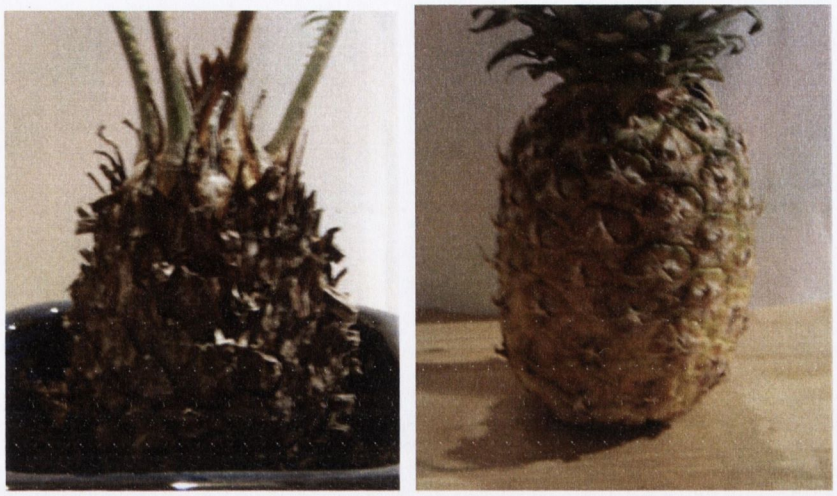


Figure 8.2 Two disparate plant parts that share a superficial perceptual quality

Figure 8.3 *Senecio squalidus:* "Another bloody yellow composite"[39]

[39] The botanist will recognize that this is in fact an uncommon yellow composite in Ireland

This work examines how biology learners discriminate plant families using the repertory grid technique (Fransella *et al.*, 2004; Kelly, 1992; Shaw, 1980; Slater, 1977). The reason for choosing the taxon 'family' is that in plants the 'family' is the basic taxon of recognition (Atran, 1999), whereas in animals it tends to be the genus: the truth of this statement will of course depend on the expertise of the discriminator. Various ethnobotanical studies (Berlin, 1992, 1999; Berlin *et al.*, 1974) compared indigenous peoples' knowledge of flora with that of professional botanists have shown that humans tend to order living things in a directed and structured way, as opposed to arbitrary clumping. Thus, folkbiology and professional biology (*e.g.*. systematics) are comparable in the outcomes they produce. In this work, groups of biology learners were probed for information to construct representations of plant families and compared with those of two professional biologists, of which one is an expert botanist (a graduate in biological sciences majoring in crop productivity), the other is an expert microbiologist (a graduate in biological science majoring in virology). Common to all cultures are a set of features, which constitute a folktaxonomy, for example:

- notions of biological species,
- sequential patterns of naming,
- taxa construction by means of an appreciation of overall pattern,
- over-arching of plant life-form groupings that have no place in modern botanical taxonomy but are nonetheless of obvious ecological significance e.g. 'tree' and 'weed' (*cf.* Bell, 1981a)

That which is common to all cultures would indicate an innate system; by probing learners' modes of classification we can gain some insights into how this innate system

operates in the mind of the learner and develops over time. Berlin (1999) describes three classificatory choices in dealing with new and unfamiliar organisms. The first, and that chosen by many urban dwellers today, is to claim public ignorance. The second strategy is to learn the names the locals use. Tourists do this on trips to foreign countries and children use whatever name parents give them on visits to zoos. Finally, the third strategy, and the one observed in indigenous peoples by Berlin is to conceptually relate new natural kinds with prototypes that were learned as a child, a process known as exemplar comparison; indeed, this is the strategy that is used by the author when botanizing.

Atran (1990) states that there appears to have been a misinformed history of classification in that people support the view that plants were only classified according to their usefulness (Mayr, 1982). Atran believes that the development of taxonomic notions is necessarily preceded by principles of sensory association, habit formation and enumeration. He suggests that no one questions how such rich complex notions about groupings could possibly be acquired. Atran proposes that investigation of the development of biological classification should involve looking at the groupings that have been acquired, then asking what possible cognitive operations enable one to come up with these various biological sorts. Thus there are three lines, which can be consequential, of research in plant classification:

1. How do learners throughout their development classify plants?
2. How do their classifications compare with formal scientific classifications?
3. Why do learners classify the way that they do, what are the underlying psychological processes at work?

8.3 The elicitation of repertory grids of students' conceptions of plants

The primary operation in the classification of living kinds whether for the field naturalist or the museum taxonomist is the aggregation of organisms into basic level taxa, but as Bell (1981a, p. 13) records, the result may be different from how students 'carve up' the living world. The element list was constructed by taking the key points of the formal descriptions of each family and simplifying the language as much as possible. The families were chosen for the range of ease at which specimens may be placed in them, and included Asteraceae for the reason stated earlier on p.207. They also happen to reflect the author's own range of ease in 'learning' to identify and classify flowering plants. Post-primary students, fourteen boys from a grammar school in Northern Ireland; 33 students from a mixed sex cross-phase religious-owned school, Valencian Community, Spain; and two qualified biologists, one a botanist, were given a randomly arranged array of drawings of five sets of dicotyledonous flowering (after Ross-Craig, 1948-9) listed in Table 8.2 . The students were supplied with a range of materials, outlined in the next section with a view to eliciting their classifications through RGA and a sorting task to determine the actual difficulty of recognizing family boundaries.

Subjects were provided with the following:

- A randomly arranged array of botanical drawings by Stella Ross-Craig. An example, is shown in Figure 8.4 (See Appendix 8.1 for all the graphics used as stimuli for this study).

- Worksheet, an extract is given in Table 8.3

- A glossary of the main terms simplified as much as possible, Table 8.4 .
- Drawing of an idealised dicotyledon inflorescence, Figure 8.5 .
- A page of simplified technical descriptions of six dicotyledon families to choose from Tables 8. 6 (English) and 8.7 (Spanish).

Table 8.2 *The five families and the Latin binomial for the five specimens used in each family.*[40]

Family	*Latin binomial*	Number of specimen
Asteraceae	*Hieracium vulgatum*	524
	Leontodon hispidus	61
	Taraxacum officinale	327
	Tragopogon pratense	412
	Sonchus asper	796
Brassicaceae	*Cochleria anglica*	843
	Nasturtium officinale	689
	Cardamine pratensis	501
	Barberea intermedia	479
	Arabis hirsuta	29
Geranaceae	*Erodium glutinosum*	317
	Geranium sanguineum	302
	Geranium robertianum	318
	Geranium dissectum	535
	Geranium pratense	751
Ranunculaceae	*Ranunculus circinatus*	52
	Ranunculus sardous	563
	Ranunculus sceleratus	891
	Anemone nemorosa	951
	Caltha palustris	198
Caryophyllaceae	*Melandrium dioicum*	424
	Dianthus deltoides	761
	Sagina saginoides	83
	Spergularia rupicola	931
	Saponaria officinalis	893

[40] The integer is the label given to the drawings and which the subjects used to identify the specimens.

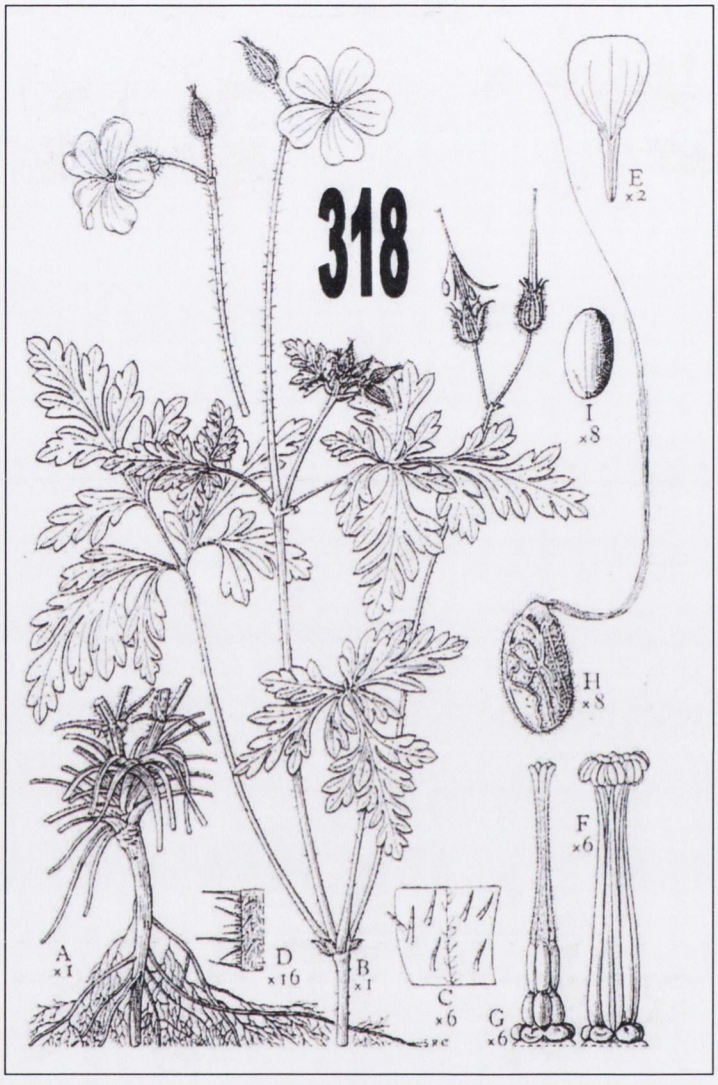


Figure 8.4 An example of one drawing no. 318[41]

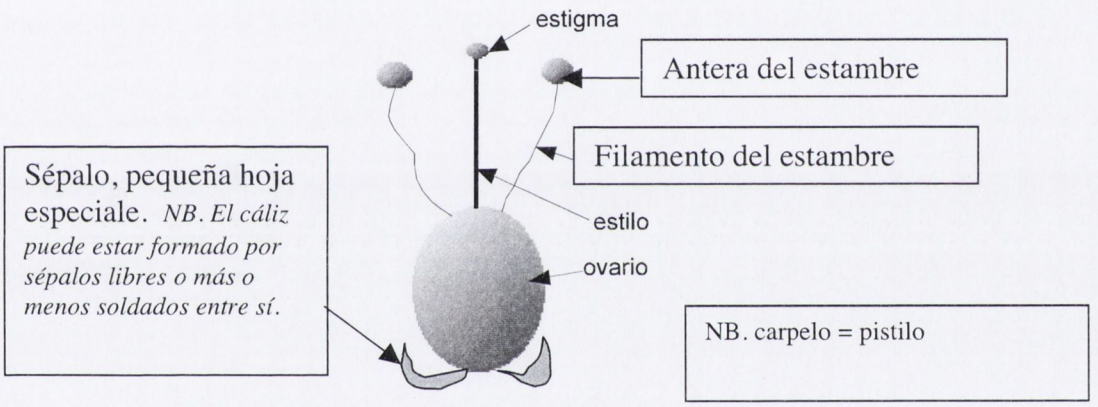
[41] The image is slightly reduced. The original for the questionnaire was A5 thus making the scale correct

Table 8.3 *An extract from the worksheet*

¿Cuál de las siguientes características ha sido la más importante para clasificar las especies de la FAMILIA I?	Which characteristic do you consider the most important in assigning specimens to FAMILY I?
Marque el círculo correspondiente	*Colour in only one button*
❒ tipo / forma de la hoja	❒ shape of leaf
❒ tipo / forma del fruto	❒ shape of fruit
❒ tipo / forma de la semilla	❒ shape of seed
❒ tipo / forma de la flor	❒ shape of flower/floret
❒ tipo / forma de los estambres	❒ shape of stamens
❒ tipo / forma del carpelo	❒ shape of carpels
❒ número de carpelos	❒ number of carpels
❒ número de sépalos	❒ number of sepals
❒ número de pétalos	❒ number of petals
❒ número de estambres	❒ number of stamens

Table 8.4 *The Glossary given to the students in Northern Ireland*

floret	a very small flower, usually one of many
head	a collection of florets
tubular	like a tube
lip	part of a petal extending outwards
suspended	hanging
parachute	a structure which supports the seed in the air, effects air resistance
opposite	facing each other
separate	not joined or fused
fruit	the structure resulting from the fertilisation of the egg cell and the development of the ovary, see diagram
pod	a hollow container, with seeds within
sepal, petal, stamen	see diagram.
calyx	the structure that results when the sepals are fused together
fused	joined to make one thing
alternate	alternating leaves so they cannot be opposite
pinnate	long and thin leaflets of equal size opposite each other on the midrib, with one at the end
palmate	like the palm of the hand with the leaflets coming from roughly the same place
stipules	spikes at the base of the leaf
cultivated	grown commercially
umbel	a head in the shape of an umbrella
rays	line spreading from the same point, like spokes of a wheel
borne	carried
bract	a smaller leaf attached to the flower itself or at the base of the flower



cuadro 1. flor de una dicotiledonea

Figure 8.5 Combined Diagram, glossary

Table 8.5 *The family descriptions given to the subjects, English version*

Family Descriptions
ASTERACEAE
these plants have many tiny flowers called florets, collected together in one head; overall they are daisy-, thistle- or dandelion-like; the florets are tubular or flattened or with five lips; the fruit is a single seed suspended from a white hairy parachute.
BRASSICACEAE
these plants have leaves which are opposite each other; the flowers have 4 sepals which are separate; the flowers also have separate petals which form a typical cross. The fruit is a pod which can be a disc, long thin tube, a tube bulging in two or more places or ball-like.
RANUNCULACEAE
these plants have leaves which are usually alternate, often with the edge deeply cut. Flowers can be large and showy with 5, sometimes more, separate sepals or petals or both. Yellow is a common colour. The stigmas and the styles are very small. The flowers have numerous stamens. The fruiting head is a collection of small dried fruits.
GERANIACEAE
these plants have leaves which are very divided, alternate and often hand-like. The flowers can be singly, in twos, or in larger collections. There are 5 petals, each having a notch cut into it, 5 sepals and 5 stamens. The fruit has 5 seeded portions which are joined to make a distinctive "beak" which springs apart when it matures and dries.
CARYOPHYLLACEAE
these plants have leaves which have simple shapes: oval or long and thin; they are mostly opposite each other with each pair at right-angles to the one below and above. The flowers have five petals, each petal usually has a notch cut into it and may range in size from almost microscopic to quite large. Numbers of the other parts vary but many have 5 sepals, between 8 to 10 stamens and they may have a double stigma. Wild forms are usually white but garden varieties are usually pink.
APIACEAE
these plants have leaves which have various shapes. Flowers are borne in typical umbels consisting of rays like the spokes of an umbrella, often with conspicuous flower-leaves called "bracts". Each floret has five petals, each can be of varying sizes. There are usually five stamens. The fruit has two parts, each pressed close together, separating when "ripe"

Table 8.6 *The family descriptions given to the subjects, Spanish version*

Clave para Las Familias Florales

ASTERACEAE

Flores: muchas y minúsculas llamadas inflorescencias, agrupadas en cabezuelo; como la margarita; las flores pueden tener forma tubular, aplanada o con cinco labios; el fruto tiene una única semilla suspendida de un vilano blanco (a modo de paracaídas de melena blanca).

BRASSICACEAE

Hojas: alternas /enfrentadas

Flores: con cuatro sépalos separados. Las flores también tienen pétalos separados formando una cruz típica. El fruto es una legumbre o silicua de forma circular (como un disco), tubular (tubo fino y alargado, o de tubo que se abulta en dos o más porciones) o con forma esférica (como una bola).

RANUNCULACEAE

Hojas: alternas generalmente hendidas

Flores: grandes y llamativas en ramilletes terminales de 5, a veces más, sépalos o pétalos separados. El amarillo es el color más común. Los estigmas y los estilos son muy pequeños. Las flores tienen numerosos estambres. El fruto contiene pequeñas semillas coriáceas.

GERANIACEAE

Hojas: muy divididas, alternas y con forma de mano.

Flores: individuales, o en grupos de dos o más flores. 5 pétalos (cada uno tiene una hendidura), 5 sépalos y 5 estambres. Los frutos tiene 5 porciones (lóculos) que se ensamblan para formar una cápsula o " pico distintivo " que se desprende cuando madura y se seca.

CARYOPHYLLACEAE

Hojas: planas, ovales o alargadas.

Flores: con cinco pétalos, cada pétalo tiene una hendidura. Su tamaño puede variar de casi microscópico a enorme, con 5 sépalos, de 8 a 10 estambres que pueden tener un estigma doble. Las especies silvestres son generalmente blancas.

APIACEAE

Hojas: formas variables.

Flores: las inflorescencias (umbelas) típicas son como las varillas de un paraguas, con flores visibles en forma de hojas llamadas "brácteas ". Cada flor tiene cinco pétalos, que pueden ser de diferente tamaño. Tienen por lo general cinco estambres. El fruto tiene dos cotiledones.

The subjects were asked to arrange the drawings into the five families, that being the basic taxon of recognition in plants according to Atran (1999), and then to reflect on how they did this by answering direct questions on a worksheet regarding their choice of features.

They were then asked to rank their means of selecting members of a family. The Northern Ireland group were asked to rank three elements where 1=highest, and unchosen features were ranked '4'. Originally, the class teacher had been concerned that asking the students to rank more than three elements would not have produced meaningful data as they would have suffered from questionnaire fatigue and arbitrarily allocated ranks. Having completed the questionnaire with the class, it was found that no such fatigue occurred, thus in the next administration of the questionnaire, a larger number of ranks would be elicited. Hence, the Valencian Community group was asked to rank five elements where 1= highest, and unchosen features were ranked '6'. Furthermore, in the case of the grids produced by the Northern Ireland group, the grids consist of a small number of elements, which may compromise the calculation of principal components. As a result of this difference between the two groups, caution must be exercised when comparing across these groups.

By ranking each feature against each family, a matrix of the data is produced. The statistical analysis of the matrix in repertory grid analysis provides the greatest use in studying the learning and construction of knowledge in a given domain. The data was collected from the learners, the elicitation stage, and entered manually in the computer

package RepGrid 2.0. However, it is possible for individual subjects to enter all the data themselves and proceed through the suite of programs.

8.4 The analyses of the repertory grids: DISPLAY, FOCUS, PRINCOM, and SOCIO

The same set of four analyses: DISPLAY, FOCUS, PRINCOM, and SOCIO, employed in Chapter 7 was also used in this chapter. Since these were described in detail in Chapter 7, only a brief overview is provided following.

The basic part of the program called 'DISPLAY' automatically draws the matrix of the data. The DISPLAYed grids for all the subjects are provided in Appendix 8.2.1 . Then the next step is to align sets of ranks within the matrix, which are similar and perform an automated cluster analysis on the 'constructs' and 'elements'. This is done by the 'FOCUS' part of the program. Finally, the stage labelled 'PRINCOM' performs a principal components analysis on the matrix and draws a Cartesian plane, using the first two principal components as co-ordinates. Elements and constructs may be plotted separately or together. Finally, grids from any number of individuals, limited only by the memory allocation to the RepGrid program and the memory available on the computer one uses, may be compared by a similarity algorithm 'SOCIO' which plots a graphical network of the links between each grid — the link being a chosen degree of similarity.

8.4.1 The results of FOCUS

The FOCUSsed grids of all the subjects are provided in Appendix 8.2.2 . The ranked data was assembled into a matrix for each person in both groups[42], entered into the RepGrid 2 program and analysed using cluster analysis. Table 8.7 shows an example of the printout from the RepGrid 2.0 program for the FOCUS analysis. The output of the FOCUS analysis (Figure 8.6) displays a dendrogram of the families in the top left hand corner of the figure, and a dendrogram of the elements in the bottom left hand corner of the figure. This is in effect one type of folktaxonomic tree of these plant families for those respective people, VASC138[43] and AMPRSL6[44], the representative grids chosen for this discussion. These were chosen because VASC138 had an 'average' number of links to the biologists in the analysis of their respective grids; and AMPRSL6 was chosen because he had the only links with the biologists at a high level of constraint set in the software. With respect to choice of salient features to distinguish families, VASC138 gave *Asteraceae* and *Ranunculaceae* the closest match with 92% similarity. To a botanist, this result may at first seem strange, because of the array of five families, visual perception of the structure of the flowers of the representatives of the families would place the four families that have inflorescences of a small number of flowers together first and *Asteraceae* with members having compound inflorescences would be last to be linked to the other families. AMPRSL6 gave *Asteraceae* and *Caryophyllaceae* the closest match with *Brassicaceae*

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[42] Northern Ireland and Valencia

[43] The system of coding works as follows: 'VA' denotes 'male', 'SC' denotes which school, '13' which year and '8' which student.

[44] The system of coding for the N. Ireland students works as follows: 'AM' denotes the student, 'PRS' denotes the school, and 'L6' the year.

and *Geraniaceae* not far behind. It appears from the element choice that classifying plants was not done on the basis of the information supplied to either groups, and perhaps this was because the information was too detailed and caused 'questionnaire fatigue'. For a classroom study, there was simply too much information given, however, the author had considered that the students were senior biology students. Instead, the students appeared to work things out from the pictures alone rather than the descriptions, so that choosing elements about the carpels in the *Asteraceae* is problematic as these cannot be observed in the pictures. The Valencian students utilized more elements than the northern Irish students, which remains unexplained. The question of questionnaire fatigue and at what point does this impact on the quality of the choice of elements and the scoring. This is the subject of future work.

Table 8.7 *Example of output of the FOCUS calculation*

Element Matches

*	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
E1 *	100	56	44	24	20	40	12	12	12	36
E2 *	56	100	48	60	64	36	48	56	56	32
E3 *	44	48	100	40	60	64	52	44	52	60
E4 *	24	60	40	100	72	60	80	88	80	72
E5 *	20	64	60	72	100	64	84	84	92	52
E6 *	40	36	64	60	64	100	72	64	64	72
E7 *	12	48	52	80	84	72	100	92	92	68
E8 *	12	56	44	88	84	64	92	100	92	68
E9 *	12	56	52	80	92	64	92	92	100	60
E10 *	36	32	60	72	52	72	68	68	60	100

Construct Matches

*	R1	R2	R3	R4	R5
R1 *	100	72	64	80	64
R2 *	72	100	92	76	76
R3 *	64	92	100	68	76
R4 *	80	76	68	100	68
R5 *	64	76	76	68	100

*	L1	L2	L3	L4	L5
R1 *	24	36	36	28	44
R2 *	36	24	24	36	28
R3 *	36	24	24	40	28
R4 *	28	36	40	24	40
R5 *	44	28	28	40	24

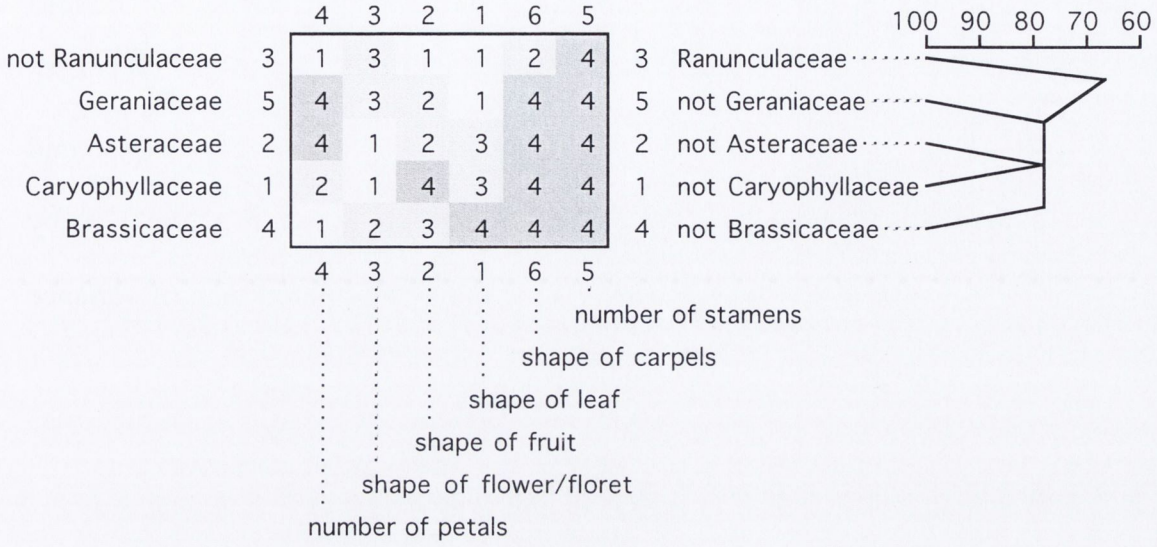
Element Links

E5	linked to E9	at	92.0
E7	linked to E8	at	92.0
E7	linked to E9	at	92.0
E4	linked to E8	at	88.0
E4	linked to E10	at	72.0
E6	linked to E10	at	72.0
E2	linked to E5	at	64.0
E3	linked to E6	at	64.0
E1	linked to E2	at	56.0

Construct Links

L2	linked to L3	at	92.0
L1	linked to L4	at	80.0
L2	linked to L4	at	76.0
L3	linked to L5	at	76.0

FOCUS: AMPRSL6
Elements: 6, Constructs: 5, Range: 1 to 4, Context: dicotyledon



FOCUS: VASC138+
Elements: 10, Constructs: 5, Range: 1 to 6, Context: dicotyledon

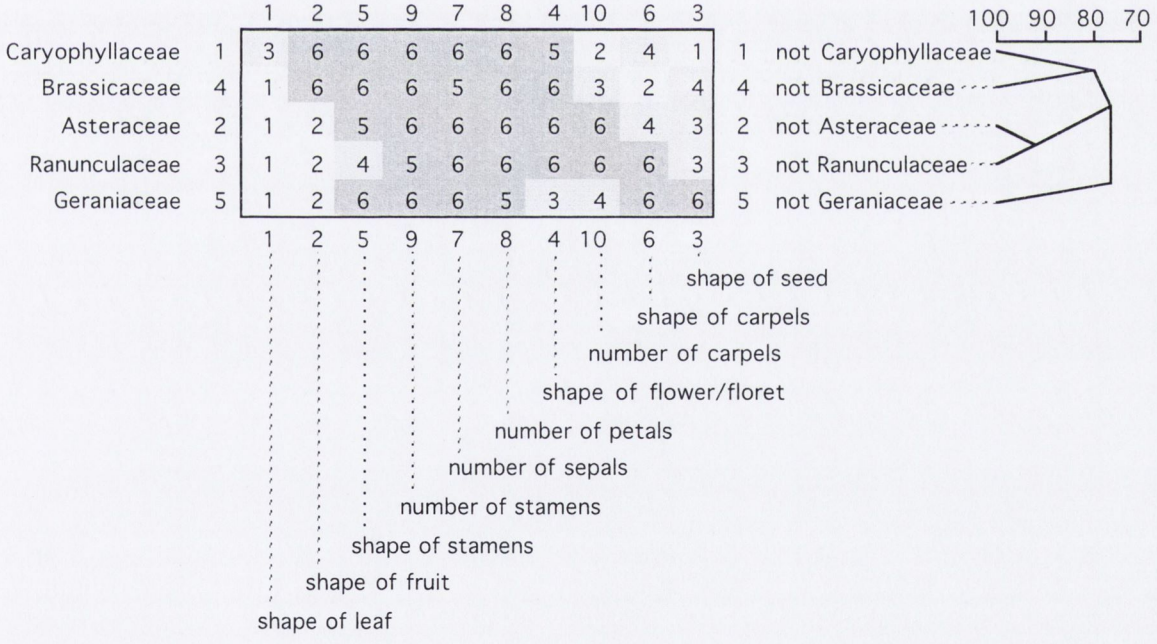


Figure 8.6 Results for AMPRSL6 (N. Ireland) VASC138 (Valencia)

8.4.2 The results of PRINCOM

The principal loadings plots for all the subjects are provided in Appendix 8.2.3 . Principal components were calculated from correlation tables by the PrinCom analysis (Table 8.8). Concept maps in the form of Cartesian Planes, plotted by taking the first and second principal component loadings as co-ordinates, were produced for each of the subjects by choosing the two components which accounted for the highest percentage of variance (Table 8.8, lower left segment).

Table 8.8 *Example of output of the PRINCOM calculation*

Construct Correlations

*	C1	C2	C3	C4	C5
C1 *	1.00	0.35	0.23	0.69	0.11
C2 *	0.35	1.00	0.91	0.51	0.57
C3 *	0.23	0.91	1.00	0.26	0.57
C4 *	0.69	0.51	0.26	1.00	0.26
C5 *	0.11	0.57	0.57	0.26	1.00

Percentage of Variance for each Component

*	C1	C2	C3	C4	C5
1 *	56.79	25.59	10.50	6.12	1.01

Construct Loadings on each Component

*	C1	C2	C3	C4	C5
C1 *	3.325	4.092	-0.219	2.155	-0.112
C2 *	5.282	-1.212	-1.347	-0.696	-0.910
C3 *	4.780	-2.349	-1.812	0.424	0.818
C4 *	3.939	3.437	0.926	-2.049	0.351
C5 *	3.868	-2.459	3.325	0.661	-0.028

Element Loadings on each Component

*	C1	C2	C3	C4	C5
E1 *	7.030	-0.450	0.845	-0.818	0.498
E2 *	2.491	-4.085	-0.157	0.258	-0.517
E3 *	2.383	2.231	-2.428	1.623	-0.245
E4 *	-1.755	-0.860	2.045	1.077	-0.293
E5 *	-1.764	-1.267	-1.521	-0.187	0.429
E6 *	0.122	2.674	-0.179	-1.909	-0.639
E7 *	-2.899	0.182	-0.093	-0.885	0.136
E8 *	-2.907	-0.732	0.488	-0.026	-0.160
E9 *	-2.812	-0.715	-0.756	-0.101	0.501
E10 *	0.110	3.023	1.754	0.968	0.290

Two main forms of conceptual framework were observed for both N. Ireland and Valencia students. (i) In one set in N. Ireland, the families appeared to have been differentiated in an all-or-nothing way, constrained by the choice of a small number of features (Figure 8.7).

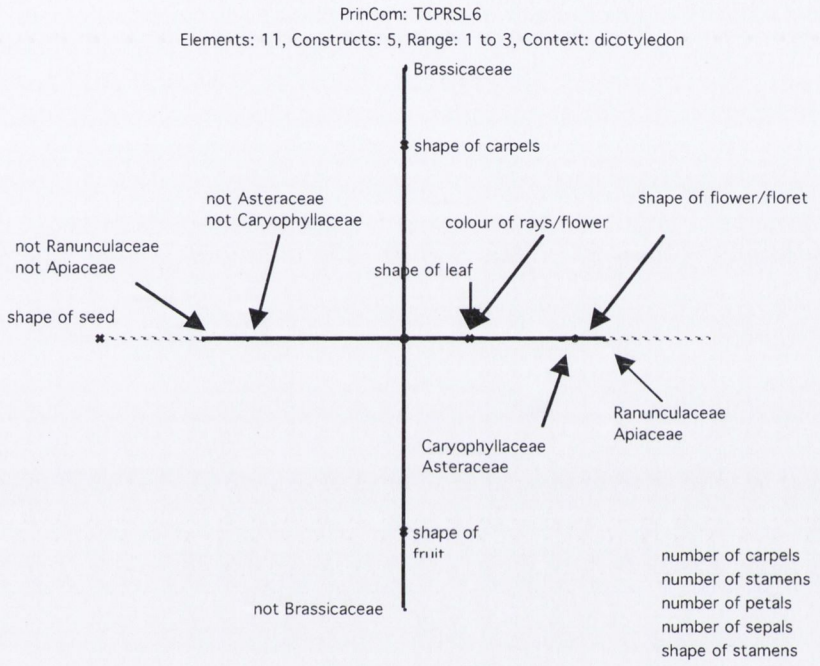


Figure 8.7 Constrained choice student, Northern Ireland
(variance accounted for: C1 = 55.62%, C2 = 20.00%)

In Figure 8.7, Brassicaceae was defined most by this person by the *shape of carpels* – which would not be the 'normal' way of defining brassicas – this does however illustrate how forcing students to work within constraints of element choice can lead to peculiar choices. At the other end of the brassica vector, however, the student has chosen shape

of fruit as the important feature for excluding brassicas; the fruit pods of brassicas are important features aiding the identification of members of this family in late summer / autumn. The other four families however, were defined, in pairs, by an equilibrium of *shape of seed,* negatively, and *shape of leaf, colour of rays/floret* and *shape of flower/floret,* positively. It may appear incongruous to find certain pairs of plant families emerging, because they apparently have little in common. However, it must be remembered that the classification derived by this method is not a 'natural classification' but rather a sort of classification based on which variables (*i.e.*, elements) are used, rather than their values.

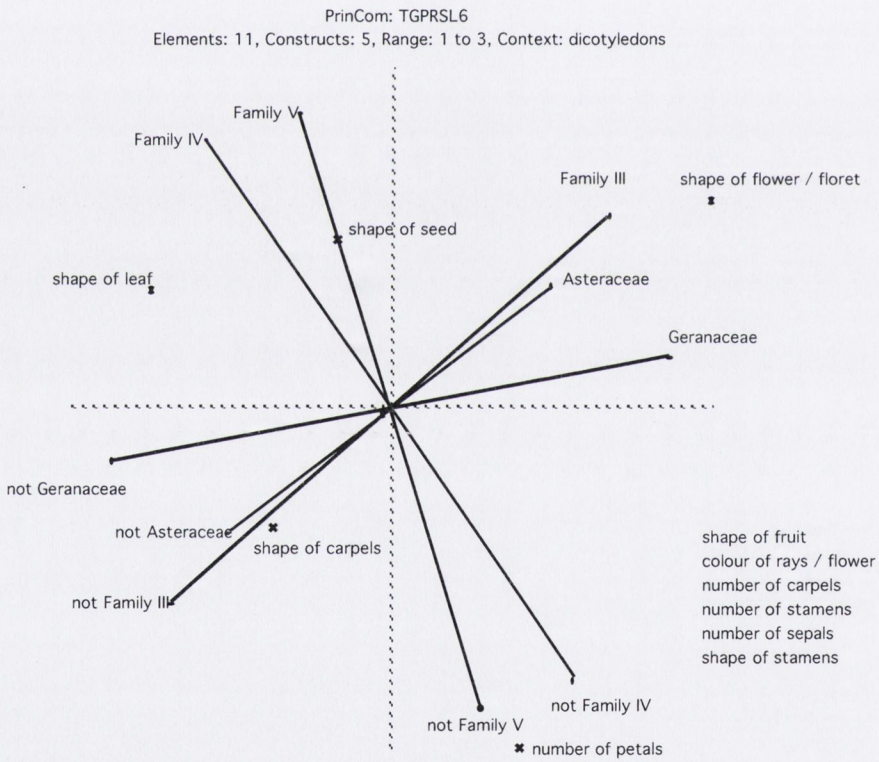


Figure 8.8 More open choice student, Northern Ireland
(variance accounted for: C1 = 45.06%, C2 = 32.63%)

In another set, Figure 8.8, a wider variety of choice was made, perhaps consciously, aiming to use a different first choice for each family, thus making an arbitrary structure. This observation was repeated in Valencia (Figures 8.9, 8.10). Indeed, a greater variety in the scoring of features has separated the axis of the constructs more than in the experts' concept maps, Figure 8.11 (chemist/microbiologist) and Figure 8.12 (botanist).

In Figure 8.9, the student has clustered three families together which are defined according to shape of leaf. In school science, there tends to be the misconception that plants can be told apart by the shape of the leaves. This notion begins with a study of trees, and indeed, trees can be told apart by the shape of their leaves – when in leaf. In Figure 8.10, the student has produced a complex picture of how they view plants with the families being differentiated with a range of differing features. Very little clustering is evident in such a system.

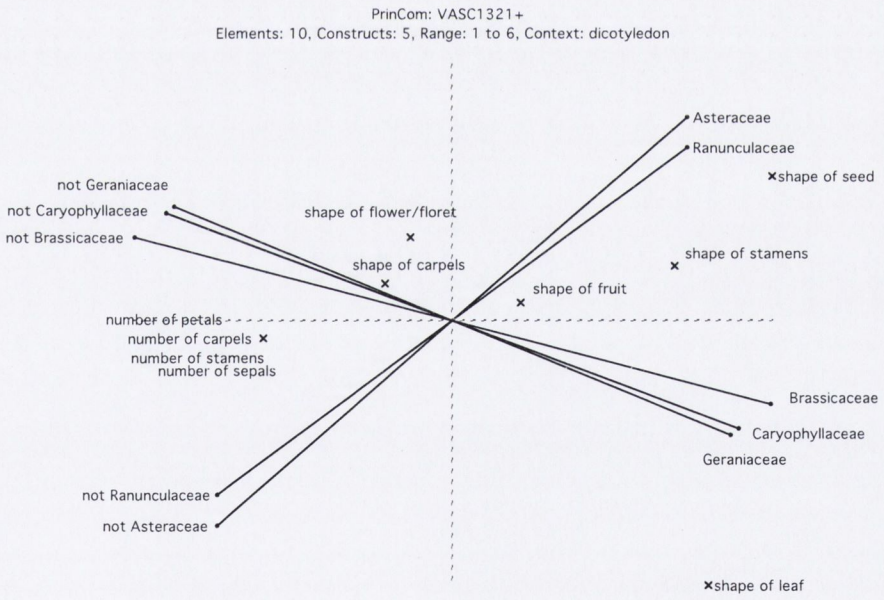


Figure 8.9 Constrained choice student, Valencia
(variance accounted for: C1 = 65.66%, C2 = 18.16%)

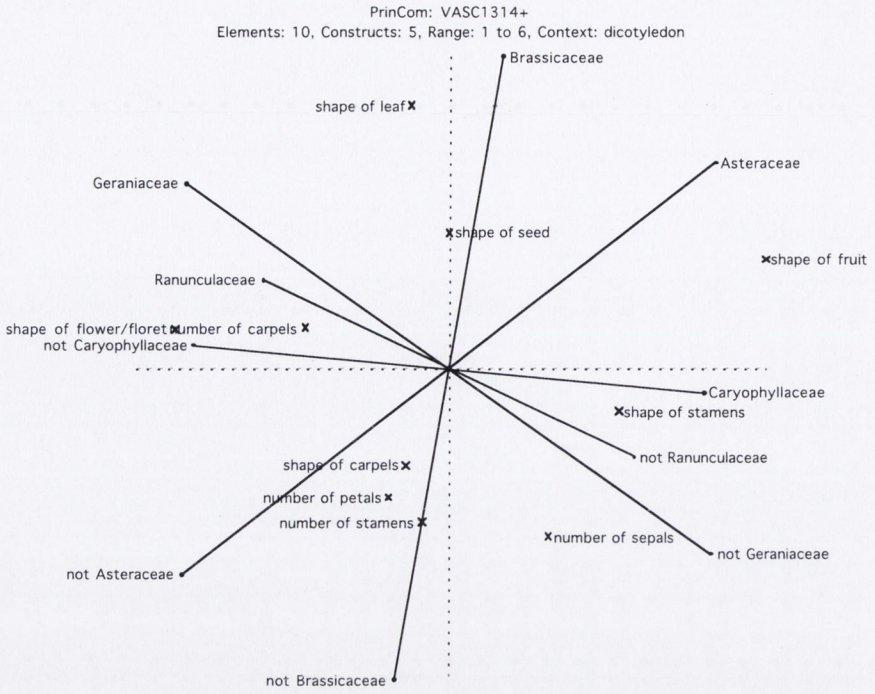


Figure 8.10 More open choice student, Valencia
(variance accounted for: C1 = 41.89%, C2 = 31.53%)

In Figure 8.11 (chemist/microbiologist), the *Asteraceae* is a most ambiguous family hence we see its pole is very small – appearing almost at the origin but in Figure 8.12 (botanist), *the shape of the flower* and *the shape of the fruit* are the key elements. In Figure 8.12, a balance between the *shape of fruit* and *number of petals/shape of seed* defined *Brassicaceae*. In Figure 8.9, *Brassicaceae* was defined most by the *number of petals/number of stamens*, *i.e.*, 4, and a balance between *shape of leaf* and *shape of fruit*.

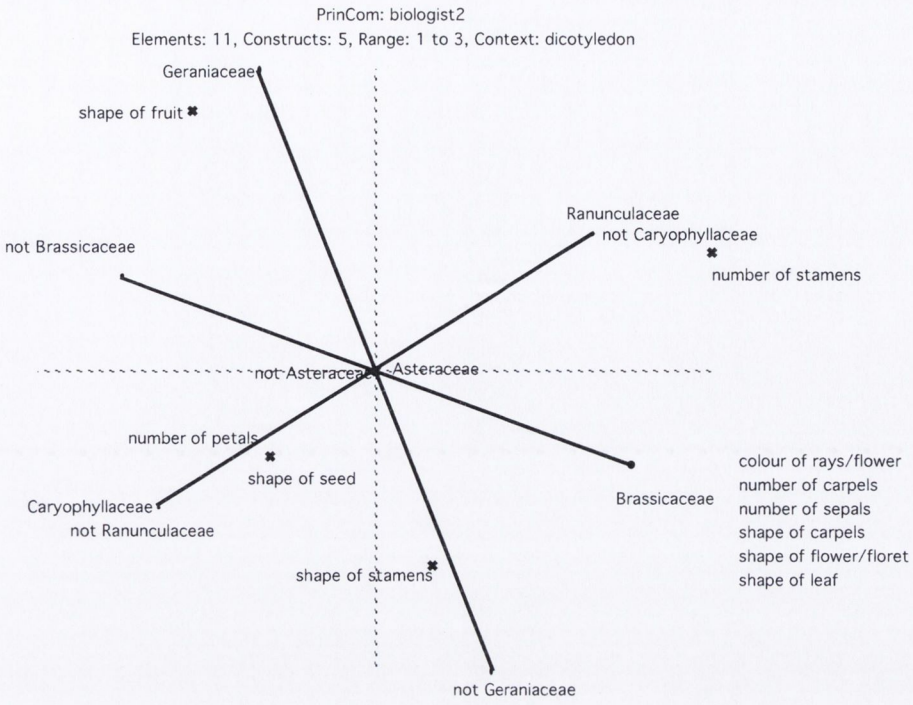


Figure 8.11 Concept Map of Chemist/Microbiologist
(variance accounted for: C1 = 39.57%, C2 = 26.61%)

It is not always the case that students having a grid that translate into a principal components' plot similar in shape to Figure 8.12 make the same choices as the experts. One should not aim to compare the overall shape of the plots produced, as this can be misleading. The user should compare the direction of the vectors, and the relative position of the elements plots in relation to these vectors. It is necessary to return to the original grids and compare these, row by row and column by column for each pair of grids in the sample. Hence the desirability of using a computer in order to produce the principal components' plots.

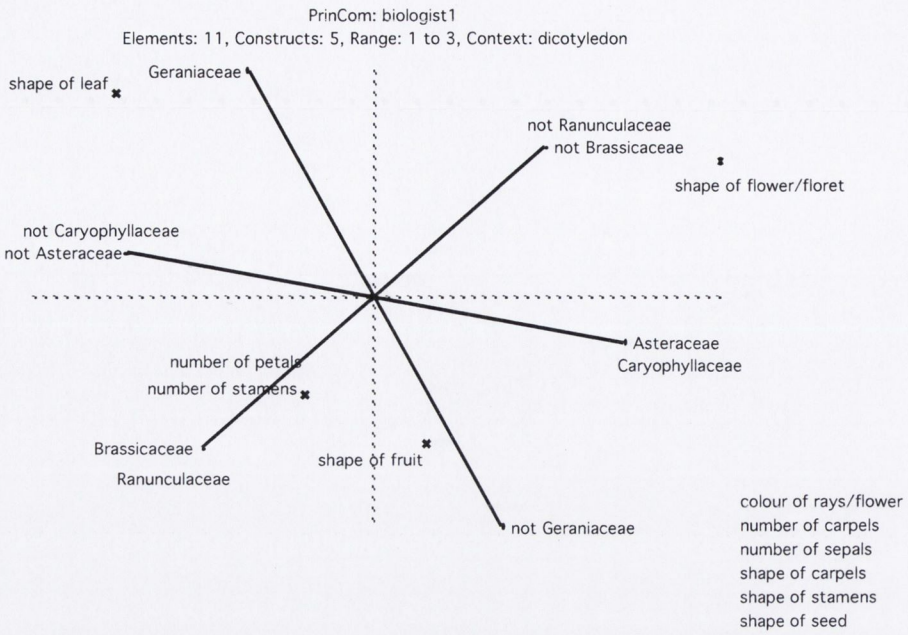


Figure 8.12 Concept Map of Expert Botanist
(variance accounted for: C1 = 54.19%, C2 = 20.93%)

In Figure 8.12, the expert botanist, defined the *Geraniaceae* foremost using the element *shape of leaf, Brassicaceae / Ranunculaceae* using *number of petals* and *number of stamens*; and the *Asteraceae / Caryophyllaceae* vectors (positive ends) lies between *shape of flower/floret* and *shape of fruit*. The botanist was constrained to use a feature for *Geraniaceae* that was different from *Ranunculaceae* and *Brassicaceae i.e., number of petals.* Interestingly, *Ranunculaceae* has greater variation in *number of petals* than *Brassicaceae.* One might also not agree that *shape of fruit* should not define *Geraniaceae* given the distinctive fruit dispersal method.

8.4.3 The results of SOCIO

A range of examples are provided in Appendix 8.2.4 . Using the 'SOCIO' program the concept maps can be compared, Figures 8.13 – 8.16 by plotting 'links' between the

subjects based on the degree of shared understanding the subjects have. Once a set threshold is passed, a link is plotted with an arrow showing the direction of the 'sharing'. From these plots we can observe who shares a way of thinking with the expert botanist, *'biologist 1'* and who does not, or with *'biologist 2'*, the microbiologist.

The lines connecting two subjects show that a link exists in the way elements are chosen to describe the common constructs and in the ranks given to the elements. An arrow shows the 'direction' of the similarity, since it is a percentage similarity it is not necessarily reciprocal, in which case the arrow is bi-directional. Any two, or more, persons' conceptual frameworks can be compared in this way. From such diagrams, the researcher may at a glance determine which students share greatest meaning with experts (such as a teacher), *e.g.*, AMPRSL6 in Figure 8.13 (LHS), by setting the parameters of the drawing of the links to be highly constrained. In this case only a small number of students are linked to the experts. The diagrams also show who is isolated in their thinking *e.g.* NDPRSL6 in Figure 8.13 (both diagrams). The sociogrids, however, say nothing about the original information, only that such information is shared by a number of individuals or not, as the case may be.

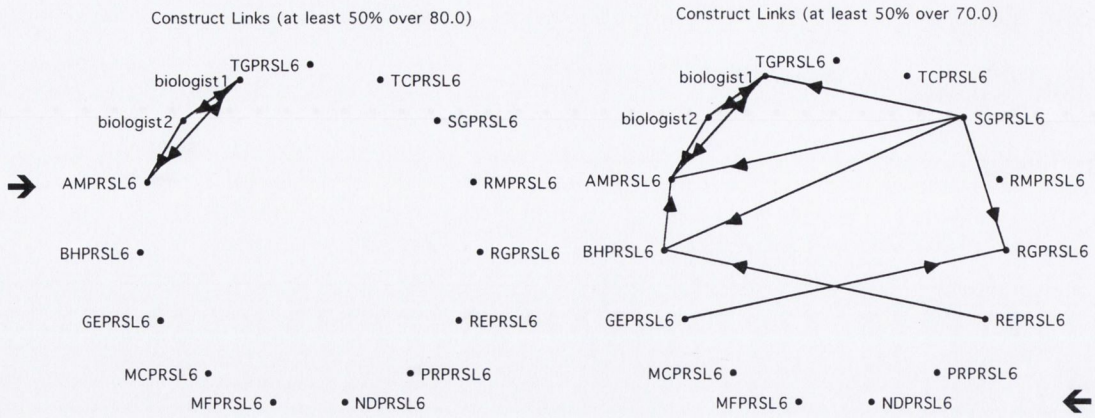


Figure 8.13 Sociogrids for the N. Ireland Group, AMPRSL6, NDPRSL6 arrowed

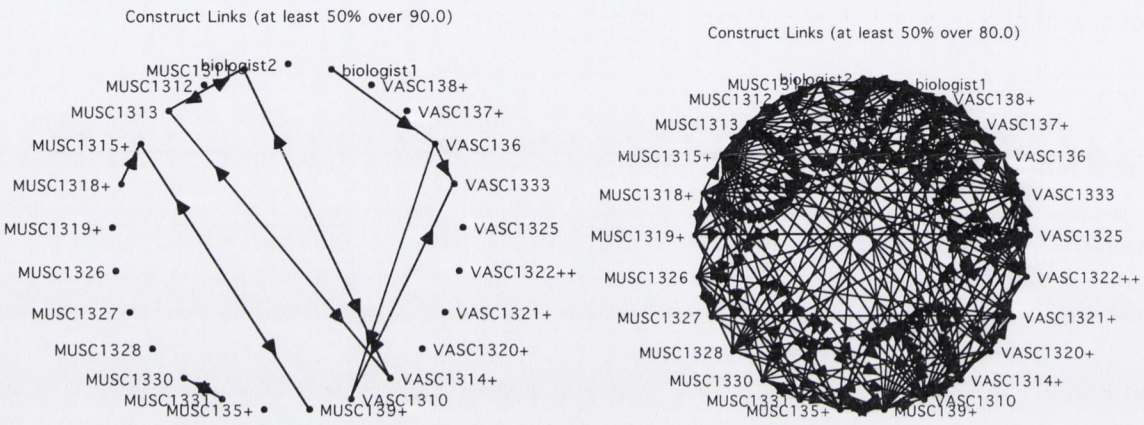


Figure 8.14 Sociogrids for the Valencia Group

In Figures 8.13 and 8.14, the chosen parameters for the sociogrid comparison were different because the 50% at level 90 yielded no links in the N. Ireland group. Diagrams like those in Figures 8.13 and 8.14 have an important use in diagnostic testing of students' conceptual frameworks as they provide a snapshot of the group's shared experience. Should individuals not have any links at all, then this may be due to a gap in their understanding – assuming that those with the links share some form of 'correct' interpretation of the experience. Should a significant number of individuals not have any shared understanding with the experts – assuming they hold the 'correct' view – at any

level of constraint, then it shows that these individuals need some form of remedial attention.

In the next section, the experts and three selected students have been extracted from the dataset and compared using SOCIO.

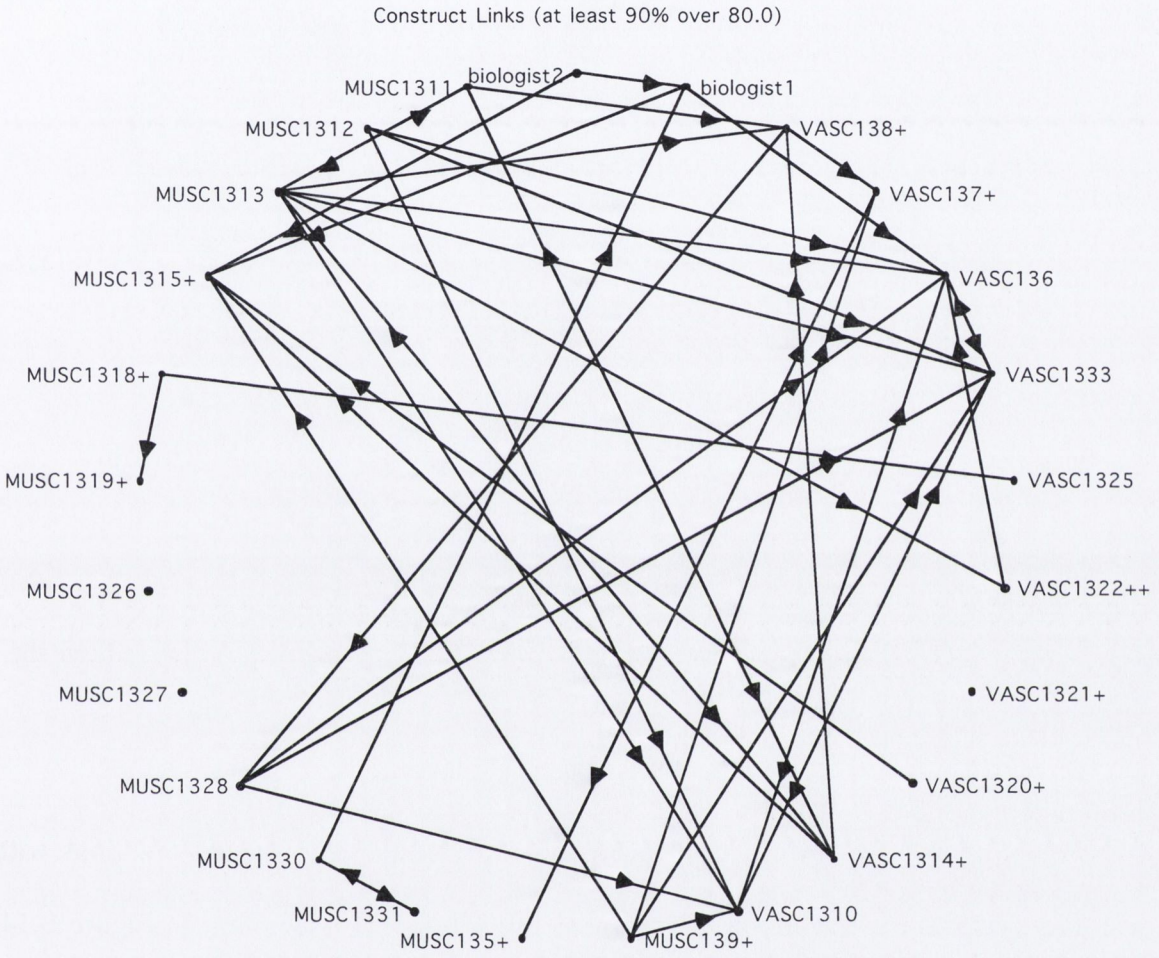


Figure 8.15 Sociogrid for the Valencia Group, 90% over 80.0

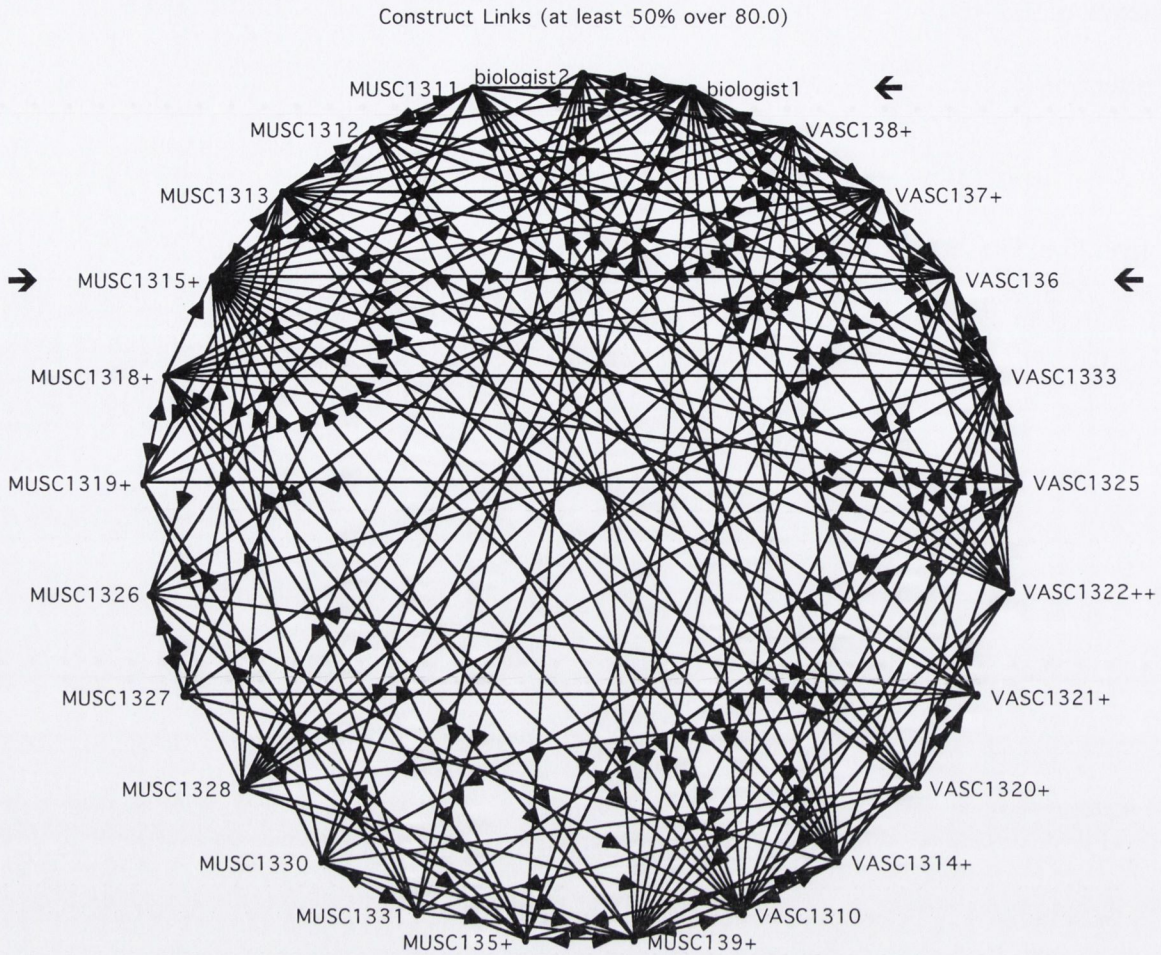


Figure 8.16 Sociogrid for the Valencia Group (Figure 8.14, LHS, enlarged) Arrows indicate the biologists and MUSC1315 and VASC136

In Figure 8.13. AMPRSL6 stand apart from the others as having few links with other individuals except the biologists in the 50% over 80.0 socionet. In Figure 8.14, VASC136 stood out as the only student who shared understanding above the 50% over 90.0 threshold. In Figure 8.15 and 8.16, MUSC1315 stands out as a student with a very individual perception of the plants in the study, having more links than any other individual; yet in terms of 'correct' answers, her scoring of correct selection of groups was average. Getting the right answer may not be the most important thing. Rather making

the correct choice of feature by which to discriminate families is a fundamental aspect of classifying, and part of teaching novice learners in biology to 'see' in a scientific way.

If the three students outlined above and the experts' grids are compared using SOCIO (Figure 8.17), we see that biologist 1, MUSC1315 and VASC136 mutually share (as indicated by reciprocal arrows) the way they constructed their understanding of the plants in the set presented to them. Biologist 2 shared some understanding with MUSC1315; and VASC136 shared some understanding with AMPRSL6.

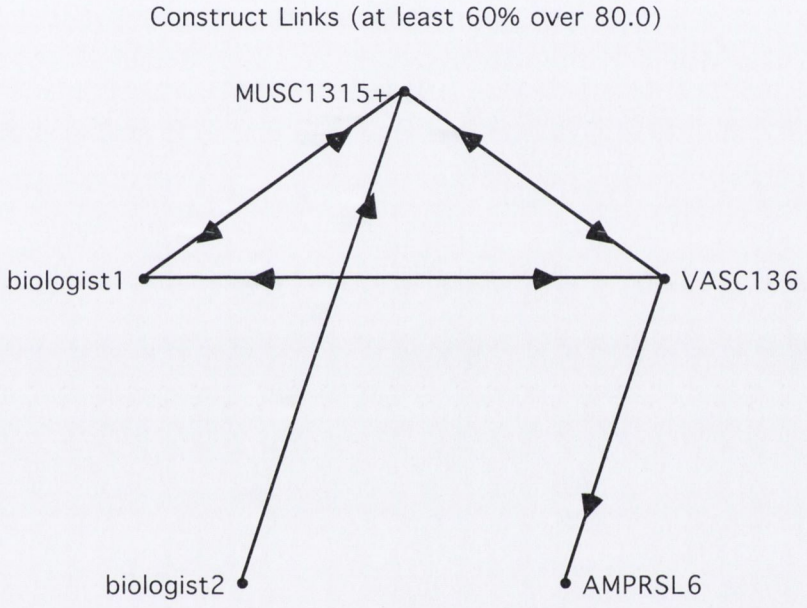


Figure 8.17 Sociogrid of the two experts and three notable students

8.4.4 Which families were easier for the students to work with?

It was discernible which families of flowering plants were not easy to distinguish and those that were (Figure 8.16). Introducing non-prototypical or non-exemplary stimuli reduced the ability of the subject to assign the name of the family correctly; and showed that the students used a different set of criteria to those of the experts. These two facets appeared to be linked, as experts do not use perceptual prototypes to assign binomials to plants. For example, the Geraniaceae specimens were made up of only two genera that would presuppose a collection made up of two types, however the genus *Geranium* can be perceived as having more than one prototype. The Northern Irish students found this family the most difficult to work with. In their locale only one member of the family is common, but all the others dwell in more specialised Irish habitats away from where they lived. On the other hand the Spanish students had less difficulty with this family, is it coincidental that more species and genera of this family occur in the Valencian Community? Further work is required to ascertain the degree of enculturation.

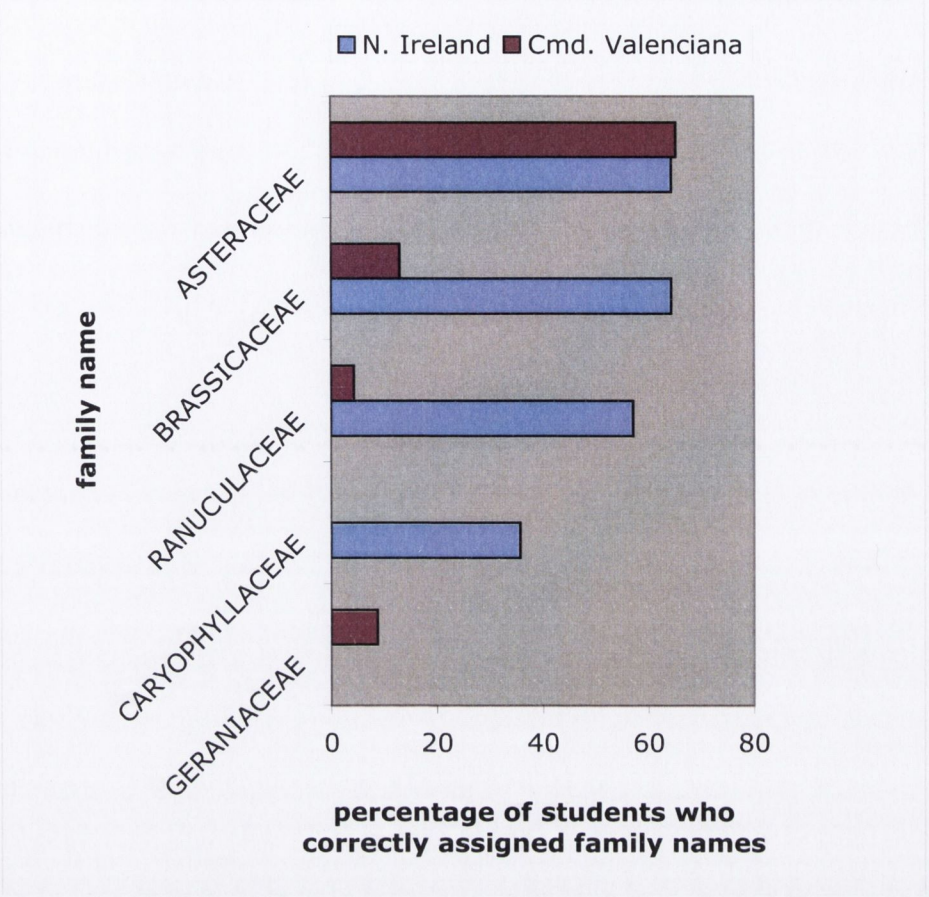


Figure 8.19 Percentage of students who correctly assigned family names to groups of plant scale drawings

8.4.5 Distillation of the results

A number of issues were outlined at the start of this chapter, we now examine how well they were addressed. Having used RGA as a means of assisting the examination of how learners structuralise their approaches to plants, we have seen that some students operate in a constrained choice mode or a more open choice mode (see for example Figures 8.7 and 8.8).

Whereas the previous chapters examined the learners' representations of conceptions of a large group of mammals, two sets of six equids and a group of six mammals (five equids and a goat), in education it is desirable that the knowledge a learner has is compared to that that one or more experts in biology possesses. Comparison of a novice's knowledge to an expert's is the core of assessment. We saw that some students formed a close relationship in terms of similarity of their conceptions to the conceptions of the experts, whilst others did not. Further, it was noticeable that students had a varying degree of similarity of conception with each other (see for example, Figure 8.17). We can conclude that RGA can form the basis of some form of assessment as a result, but it seems likely that it will be some type of formative and summative assessment since the individual and group are both examined.

In this study the plant stimuli used were a number of the well-known set of botanical prints by Stella Ross-Craig. The concepts under investigation were the families (rather than the plants themselves) to which these specimens belong. There are a number of alternative approaches and studies that require further investigation, for example, not providing the list of features to draw on and seeing whether the same 'cuts' are made

between groups (families). It was also of interest, as both a botanist and an educator, to see how well the students could assign the pile of pictures into family groups – given that the stimuli were images of flora of north-west Europe? The ability of the Valenciano group to deal with the north-west European flora was in no way worse than the northern Irish group, notwithstanding some cultural differences. This might imply that an underlying classificatory framework was at work when the students were asked to carry out the task. To that end, the fundamental ontological plant grouping – the family – was used.

Chapter 9 Final discussion and conclusion

Vulgo enim dicitur: iucundi acti labores[45]

Cicero (106 – 43 B.C.)

9.1 Recapitulation of the preceding chapters

In this final chapter of the PhD thesis, the important findings that have been obtained in each of the introductory chapters will be discussed as to how they have informed the results. The results in chapters 5, 6, 7 and 8, will be recapitulated, and recommendations based on these results will be put forward. We began Chapter 1 with a biographical note, therefore it is fitting that the thesis should end with a biographical note also.

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[45] *It is commonly said, it is good to finish work.*

9.1.1 Recap of chapter 1

In Chapter 1, the author attempted to lay out what would be the objectives of the work presented in this thesis. The main aims were (i) to investigate biological natural kinds concepts and (ii) an investigation of students' classifications of the said biological natural kinds concepts. In order to do this a methodology would be needed, and it was decided that repertory grid analysis should be the chosen methodology. Repertory grid analysis was, as we have seen, developed by George Kelly, an Irish-American of dissenter stock who gained a broad education and experience in the fields of education, psychology, and mathematics. It was the fusion of these three fields that was to inform the development of repertory grid analysis. The area of mathematics that was applicable was geometry, which served as both a model and analogy for Kelly's psychological work. Geometry provided a logic with which to describe the structure of thoughts insomuch as it was used to describe the structure of conventional space. Kelly developed the term psychological space to mean one's thought structure. In this work, the thoughts that were focussed on were concepts, and of a particular kind.

9.1.2 Recap of chapter 2

In Chapter 2 of there was a brief review of the different kinds of concepts that there are in academic literature in general. This was done with a view to explaining the phrase *biological natural kind concepts*, the type investigated in this thesis. Three main types of concept were differentiated: nominal kinds, natural kinds, and artifacts. It was pointed out that there has been a long history of discussion about these different types of concepts, going back to the early enlightenment. The focus of this work was on natural

kinds. Natural kinds appear to have constraining properties in terms of perception, and in this thesis it was hoped that some of these would be investigated.

9.1.3 Recap of chapter 3

Chapter 3 was a technical review of classification. In this chapter, the classical view of concepts was revisited; however the main point of the chapter was to demonstrate the computational aspect of classification. Whereas the author considered himself competent in classification, identification, the use of keys, and taxonomy, the idea that classification has a computational basis was new and the work by Estes provided the impetus to investigate this aspect further. On p. 31, the author indicated that classification cannot be done purely on the basis of perceptual, *i.e.,* visual, reasoning. Through RGA, the students were asked to make explicit their computation of the groups of living kinds without knowing that they were forming such groups of living kinds. This is the reverse of the 'usual' way that living kinds are studied in school science. In school science, students are often prompted to make groups without any knowledge of the process of their own thought processes. Fuzzy set logic was mentioned as an alternative model for compositional classification in terms of name construction notwithstanding its shortcomings. Also mentioned were the types of concepts called prototypes and exemplars. On p. 33, the author discussed whether there is a prototype of zebra, horse, mammal and plant. The work in this thesis would add to the idea that prototypes alone cannot explain the way humans classify living kinds since constraints imposed on the subject will divert attention to visual information. To conclude noting that visual reasoning and prototype referencing are each alone insufficient, it appears that humans

require both systems to engage with the world efficiently.

9.1.4 Recap of chapter 4

In Chapter 4 different kinds of conceptual frameworks were reviewed. In fact, in reading for this chapter the author came to discover that conceptual frameworks are much more pervasive in the way humans tend to explain the way the world is than the author had heretofore realized. The chapter was especially concerned with conceptual frameworks called concept maps of which there are many kinds. Chapter 4 focussed especially on concept maps because they are regarded as an innovative means of representing knowledge and reality. There have been a few, but not altogether successful, attempts at turning concept maps into a form of assessment. These methods were unsuccessful because the protocol for scoring the different parts of the concept map are assigned in a somewhat arbitrary fashion, and open to interpretation by the facilitator. Chapter 4 was further concerned about the relationship between concept maps and repertory grid analysis in the way it provides a map of sorts; the diagrams produced following principal components analysis are usually plots of the first and second loadings components. They are typically scatter-graphs on a Cartesian plane with points representing the elements and vectors representing constructs. It has been claimed that such a plot is in effect a concept map. Just how far one can take this analogy is still a matter for debate.

9.1.5 Recap of chapter 5

In Chapter 5, the protocol of the repertory grid analysis was described. Chapter 5 provided a brief overview describing how the mathematics and theory behind the analysis generates the so-called "geometry of psychological space". Following this review and a

description of meaning of the terms encountered in repertory grid analysis, a small study was outlined using principal components analysis as is done by the Circumgrids III program. In this short study consisting of 11 participants of senior science, whom were asked to consider six terms of animals: five of which are equids and the other a goat. This study was made initially to see if semantic information in numerical form could be represented in graphical form having been processed through a matrical analysis system; the answer to this issue was affirmative. Not only were the six concepts represented in the geometry of psychological space, it was clear that the concept of goat was distinguishable from the other five concepts, and that this was uniformly elicited. The grids produced also identified a notion of zebra that was highly constrained. In other words in perceiving *zebra* it is *stripes* that rules the perception of the animal in spite of the fact that it is first, according to scientists, a horse-like animal.

However, this initial study demonstrated clearly what the analysis could do in order to quantify these fine scale problems relating to the categorization of living things. We see that there is a natural way to categorize a word, *i.e.*, there is a computational process were features are (i) extracted, (ii) loaded in some way, and salient ones (iii) combined in the mind. The effect of this process is that some living kinds are grouped together to the exclusion of others in the *perceptual* group.

It was also discovered that not only could an individual's concept be represented in a matrix of rows and columns, individuals could be compared both *introspectively* (two grids of the one person) and *interspectively* (two grids of different people). The matrices from both occasions can be subtracted; this finds the difference between the matrices producing the so-called "difference matrix". If the difference matrix has many zeroes in

it and only a small number of integers, the perception of the concepts concerned is fairly rigid and inflexible, and it has not developed. This would have an implication in learning situations where ultimately what one is trying to do is to bring about change in the way that students perceive the world around them. The absence of change would be indicative of the failure to learn. Further, chapter 5 also mentioned a small number of ways such as averaging grids (Table 5.20 – 5.21), and calculating the city block distances between constructs (Figure 5.10) that whole class groups could be characterized. Finally, there is also a simple way of determining the so-called metrics of *intensity* and *consistency* of each individual as well as grids involving elements and constructs.

9.1.6 Recap of chapter 6

In Chapter 6, a study of mammals was undertaken, the grids elicited and analyses performed. One cluster of concepts in the principal components plots that was significant was the *dangerous* animal cluster, which interestingly contained *bat* in the same group as *wolf* and *gorilla*. This appeared to be a cultural constraint. So too was the fact that *goats* and *cows* fitted into a cluster of animals, which firstly *had horns* and then *gave milk*. These latter two features were placed close to the *cow-goat* cluster and they are not very ambiguous. A further two features have a greater ambiguity which affect construct *sheep*: these are *we can eat them* and they *have hooves*. *Koala, beaver, otter,* and *duckbill platypus* were characterized as *little known*. Thus we see that when students are presented with a list of features to choose from they do indeed select and categorize a set of constructs. There appears to be a natural in-built compulsion to categorize. Even though the students could have selected all features for each and every construct they

chose not to do so, exhibiting a remarkable economy in the number of features that are used to characterise living things. This would be consistent in a situation where a fast determination of the nature of what an animal is would be required. Having to process a large number of features would be detrimental to survival. A human does not always use an extensive list of features should he or she choose to do so – there is a system whereby one feature have a greater perceptual weight over another, e.g., *stripes* over *hooves*. Thus we see two systems of categorization available to humans. The first is an instinctual system which categorizes animal on the basis of a small number of features, maybe even as low as one; the second is an intellectual system which categorizes animals on the basis of any number of features, in fact as many as that allows the animal to be categorized exclusively.

9.1.7 Recap of chapter 7

In Chapter 7 rather than looking globally at a large set of animals, it was decided to hone in on a smaller set of equids. Two separate groups were chosen because the program was being operated at the minimum construct number of six. Six seemed to be a very manageable number, since in the case of the Cartesian plots in Chapter 6 the large number of constructs often made the graphical output difficult to read. This was definitely not the case of a plot of six constructs. The inspiration for this chapter came from reading Darwin's *Origin of Species*. In it, he describes the weird and wonderful types of equids that occur in many parts of the world (at that time). He also describes cases of where reversions of some of the features of the equids to earlier evolutionary forms is common. This reversion exhibits itself in the form of stripes or bars on the coat

of the animal. It was considered interesting to see whether horse-like animals could be classified by students if the structure of their feet was altered and so extinct forms of ancestors/relatives of the *horse* were used. We see that *zebra* are classified most strongly according to the presence of stripes and that *horses* are classified more strongly in terms of horse-like shape. But if we look at the direction of the poles in the grid, the opposing end of *horse (i.e., not-horse)* is located close to *zebra* so that even though it that they are opposites, they are clustered together. An important feature of RGA is that it plots constructs as vectors, which have direction thus the type of categorization done using RGA uses the negative inferences as much as positive inferences. What is further interesting about this particular cluster is that *zebra* and *horse* were the clear perceptual non-varietal stimuli in this set. Although the *quagga* is a distinct species, it was seen as a varietal. The *appaloosa* is a varietal of *horse*, the *melanic zebra* is a not-so-common varietal of *zebra* and *speckled zebra* a fictitious varietal of *zebra*. The students in general did not distinguish the equids along these lines at all.

9.1.8 Recap of chapter 8

In Chapter 8 the author attempted to see if RGA could be used to make explicit the system of classifying living things as it is applied to plants. This was of particular interest since the author is a trained botanist. He had been involved in botany in one form or another since childhood but had not considered the processes that were being used in his own mind. Also, he had noticed during his time as a secondary school teacher how students had difficulty with classifying and naming plants in general. It could not be merely put down to the students having a different experience of plants from the author

since the difficulty was in the learning and no expectation of outcome was enforced. This study was carried out in two schools: one in the north of Ireland and the other in Valencia in Spain. Two techniques were uncovered in the students' (of both locations) processing of their perception of plants. One was a expedient method which involved extremes in scoring and the other was measured which involved a relative scoring of elements against plant constructs. One student in Valencia showed a remarkable likeness to the botanist in the way she perceived the plants.

9.2 How well were the aims of the thesis addressed

The aims of the thesis were twofold (p. 5, 12). This main aim of this work was to present a novel adaptation of RGA in science education in relation to BNKCs and to examine the mental structure of such concepts in secondary level students and how they related to each other. The secondary aim concerned uncovering the kind of perceptions that students had of BNKCs, and examining the classificatory structures that students had of BNKCs. RGA was to be the tool that allowed the author to fulfill this secondary aim. Page 13 provided the specific objectives of the four empirical studies.

The study on *mammalia* provided the most information on the BNKCs themselves, how single features can have an overruling influence and how cultural constraints can come into play. The studies on *equidae* and *dicotyledonidae* provided the most information on the process of classification. More than one system of classification operates with regard to plants, and cultural constraints can override scientific knowledge. The subsidiary aim concerned RGA. Without RGA, it is doubtful whether such a vast amount of rich data could have been collected and whereas RGA entails a

theoretical/philosophical background, which was not explored in this thesis, the central feature of RGA that assisted the analysis of the data was principal components analysis (PCA). Of course PCA exists in stand-alone programs and general statistical packages such as SPSS; however, the theoretical/philosophical background, although unexplored, did inform the computer program developers that allowed further analyses to be utilized such as cluster analysis and SOCIO. George Kelly attempted to investigate the mind using a geometry of psychological space. I believe that this thesis has contributed towards understanding how BNKCs are structured in psychological space. Bioinformatics and phylogenetic also use PCA and cluster analysis, and the mathematical techniques used in both overlap. Further work will examine the relationship between these fields more clearly. In the next section, I will outline very briefly some areas for future research before finishing with a biographical note.

9.3 Other directions

Having worked with repertory grids at length, it became obvious that it would be desirable to have some form of automated interpretation of the grids elicited from students. However, in order to program a computer to carry out an interpretation, the programmer would have to be clear what kind of interpretation would be made. Thus, any automated interpretation is constrained by the programming abilities of the programmer and cannot uncover any deeper insights than those the programmer would otherwise make. Such a system awaits the development of artificial intelligence. And indeed it is in the area of human-machine studies that research into automated interpretation has been made. Typically, by automated interpretation, researchers in

human – machine studies (*e.g.*, Gaines & Shaw, 2003) mean a process whereby a rule is induced from the grid. This refers back to Chapter 4 where the propositional nature of concept maps was discussed (p. 43).

Gaines and Shaw (1995) describe how, in terms of the logic and visual language, there is a natural construction of a distance between two concepts, x and y, as shown in Figure 9.1. Let u be some minimal upper bound of x and y – *subsuming* both of them, and l some maximal lower bound – *subsumed by* both of them. Let U be the extension (see earlier, p. 21, regarding the use of the words "intension" and "extension") of u, and L the extension of l over an array of individuals. If x and y are identical, U and L will be also, otherwise, L will be empty. According to Gaines and Shaw (1995) therefore, a natural distance measure is the number of individuals that are in U but not L:

"x distance y" $\quad d(x,y) = CU - CL$ *Equation 9.1*

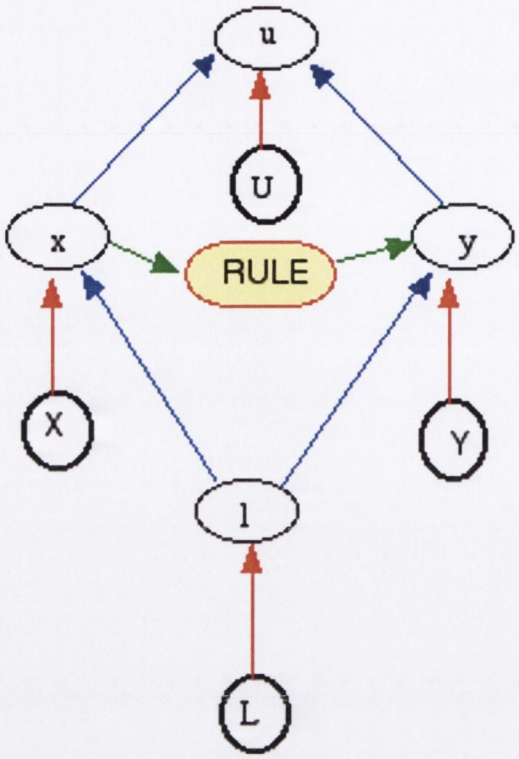

Figure 9.1 Induction of rules between concepts

where *CU* and *CL* are the cardinalities of *U* and *L* respectively. This measure satisfies the triangle inequality and can be normalized by dividing by its maximum possible value, *CU*. It is clearly dependent on the array of individuals involved, but this is appropriate to measuring concept distance in an extensional context (Gaines and Shaw, 1995). A further point is that Figure 9.1 is remarkably similar to a Bayes net. Bayes nets are directed acyclic graphs that satisfy the so-called Markov condition (Glymour, 2000). In Bayesian logic, the relationships between variables are denoted by probabilities. Thus in Bayesian terms, Figure 9.1 describes the connection between *x* and *y* through the interplay of *u* and *l*. The probability of a natural kind being *x* or *y* is a product of probabilities of the other variables and whether they are independent of not. Figure 9.1 is a rather complex example though, so consider the following simpler example in Figure

9.2 .

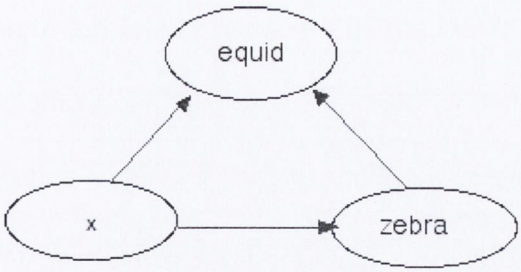

Figure 9.2 Simple Bayes net of an array of biological natural kinds concepts

In Figure 9.2, the mystery entity, *x*, appears to have a relationship with *equid*, and it appears to have a relationship with *zebra*. *Zebra*, in turn has a relationship with *equid*. Let us suppose, though, that *zebra* exist independent of *x* but not of *equid* and *equid* can exist independently of both *x* and *zebra*, and *x* is dependent on both *equid* and *zebra*. Thus, *x* is an *equid* and a type of *zebra*. The probability distribution for such a situation is given in Equation 9.2.

$$prob(equid,zebra,x) = prob(equid \mid zebra,x)prob(zebra \mid x)prob(equid)$$

Equation 9.2

Glymour (2000, p. 191) supports the view that Bayes nets have a role to play in describing the categorization of biological natural kinds. He believes that "*fashioning kinds is fashioning variables, deciding when perceptual or historical differences should be used to separate things into distinct kinds, and when they should be ignored*." The decision part of this process is key to the ability to categorise.

The distance measure is a count of the numbers of individuals that fall under the opposite pole of the other construct. Note that it is not invariant if one construct is reversed. This construction generalizes to scales with more than three points. If these

scales are numbered linearly it computes a "city block" distance measure (see earlier, p. no.) which is precisely that used in construct clustering algorithms such as FOCUS (Shaw, 1980). These distance measures, when applied to the constructs of one person, enable natural clusters to be seen that may be grouped as part of a coherent concept, for example, in that they are all contributors to an explanatory dimension.

The measures used in the induction of a rule linking to concepts are also readily derived as shown in Figure 9.1 . CX is the number of "predictions" made by concept x as the left hand side of a rule, and CL is the number which are correct. Thus, the measures of the validity of inducing the rule, $x \rightarrow\!\!\!\rightarrow y$, are:

Prior probability of y $\quad p(y) = {}^{CY}\!/_{CU}$ *Equation 9.3*

Probability correct $x \rightarrow\!\!\!\rightarrow y$ $\quad p(x \rightarrow\!\!\!\rightarrow y) = {}^{CL}\!/_{CX}$ *Equation 9.4*

Probability by chance $x \rightarrow\!\!\!\rightarrow y$ $\quad c(x \rightarrow\!\!\!\rightarrow y) = I_{p(y)}(CX - CL, CL + 1)$ *Equation 9.5*

where $I_{p(y)}$ is the incomplete beta function summing a binomial distribution tail (Gaines, Gaines and Shaw, 1995). These measures are those used by INDUCT (Gaines, 1989) in inducing rules from datasets. As an "add-on" application to RGA INDUCT searches for potential rules whereby a target predicate may be deduced from some of the others, and constrains the search to rules whereby the probability that they arise by chance is less than some prescribed threshold. The basic search techniques have been well documented by Cendrowska (1987) but for practical applications they need to be controlled by these probabilistic measures, and also to be extended to generate rules with exceptions as these are both more compact and more in accordance with human practice (Gaines, 1991b).

Figure 9.3 shows the INDUCT output for a grid from Chapter 6. The INDUCT algorithm generates rules of the "IS A" type. In Figure 9.3, the rules have been left unlabelled; typically rules can be defined by names or codes that adds to the detail displayed and thus can generate confusion. The first rule is a default statement, but then exceptions are numbered in brackets and listed beneath the rule. The construct mule is related to/is similar to a zebra, there are two exceptions to this rule, being *chestnut* and *short face/small head.*

```
-> zebra = zebra (2)
  +: thick neck, horse shape
 |- mule = not mule -> zebra = not zebra (2)
 |   +: chestnut, short face or small head
 |  |- goat = not goat & horse = not horse -> zebra = zebra (1)
 |  |   +: stripes
 |  |~ horse = not horse -> zebra = not zebra (1)
 |  |   +: hardly any mane or tail

Overall Evaluation
  Correct 6/6   100.00%
```

Figure 9.3 Output of the INDUCT program

Such a system of inferring rules from grids would be very useful as it is an objective method of inference from grids. Although the principal components plots are created objectively using principal components' analysis, the plots require some interpretation, and there is a tendency to emphasise certain pieces of information to the neglect of other important facts. INDUCT creates an exhaustive set of rules.

9.5 Other domains

This thesis has dealt, for reasons of integrity of the study, only with biological natural kinds concepts; however, other domains could be investigated using RGA. Fetherstonhaugh (1984) used repertory grid technique to probe students' ideas about

energy; Winer and Vazquez-Abad (1995) examined the potential of RGA in assessing conceptual change in physics; and Bezzi (1996) used RGA to study conceptual learning in geology. Whereas these divers areas seem to deal with other domains adequately, they took widely different approaches to using RGA. None of the three mentioned studies dealt with natural kinds concepts, for example. An important area, and an additional one concerning natural kinds concepts is chemistry. Typically cited examples of natural kinds concepts are "gold" and "atom". Figure 9.4, 9.5, 9.6 are the DISPLAY, FOCUS, & PRINCOM outputs respectively for an artificial grid elicitation for seven chemistry concepts. Figure 9.4 – 9.6 shows that a classificatory framework in chemistry allows rich information concerning students' understanding of common chemistry concepts to be manifested. As we saw in Chapter 3, the author attempted to show that classification was important to every part of our intellectual life.

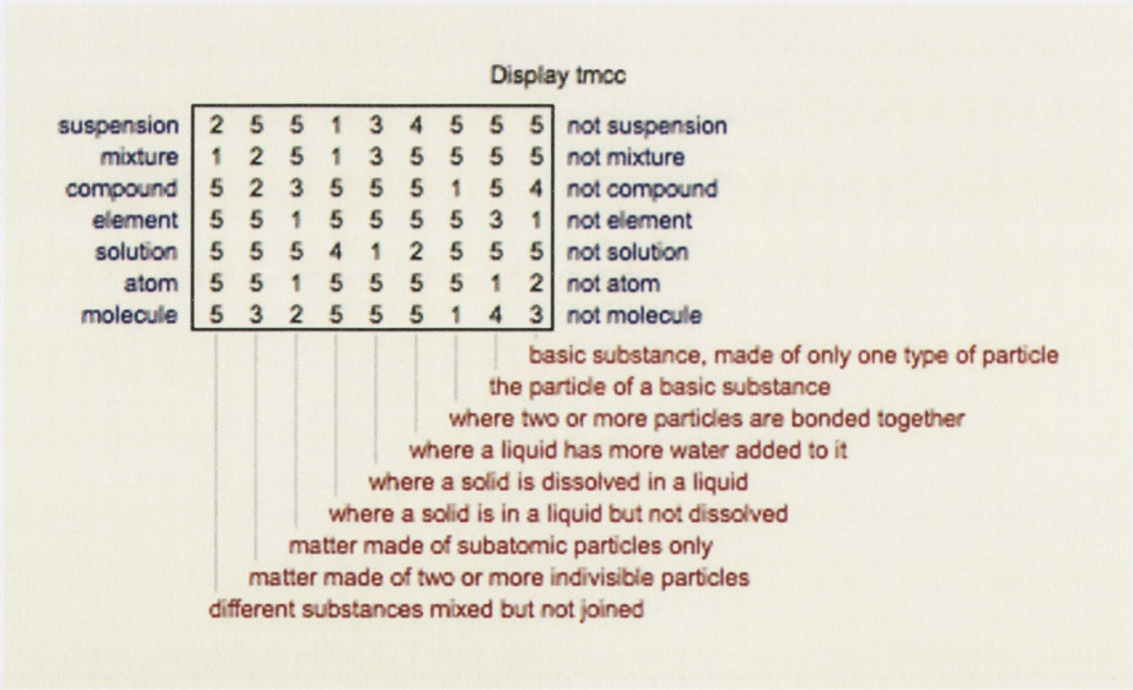

Figure 9.4 DISPLAY of seven chemistry concepts

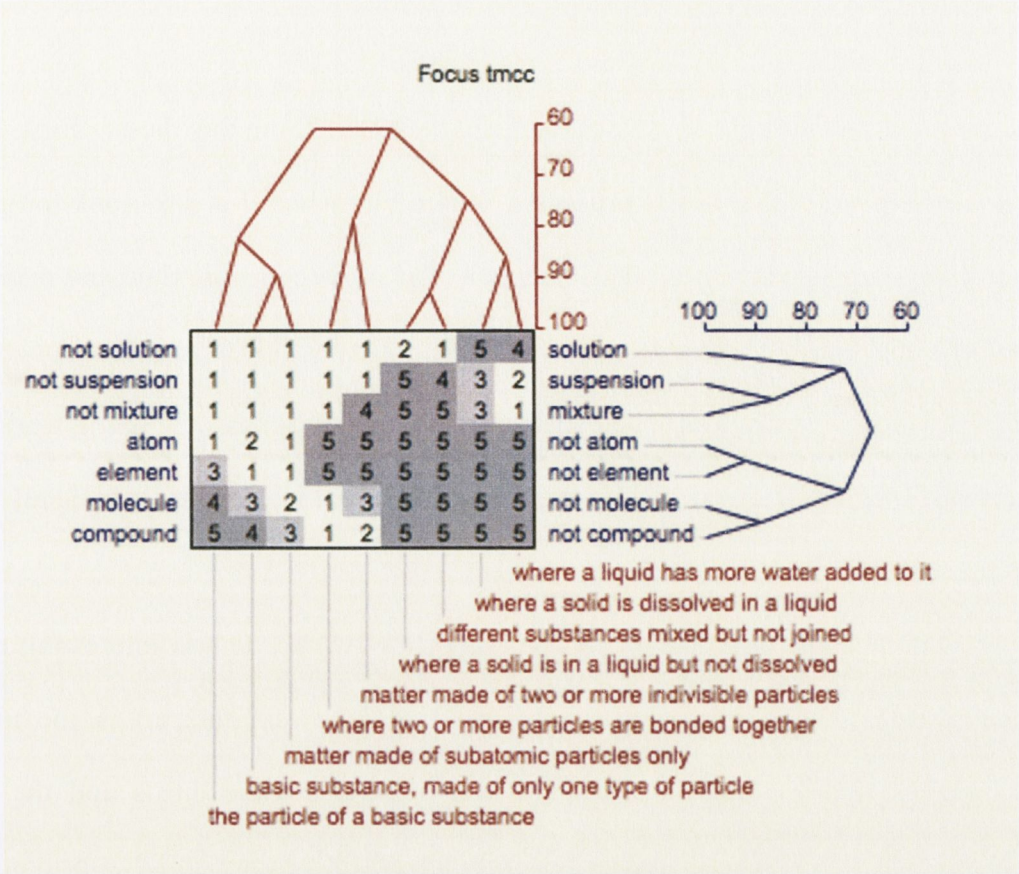

Figure 9.5 FOCUS of seven chemistry concepts

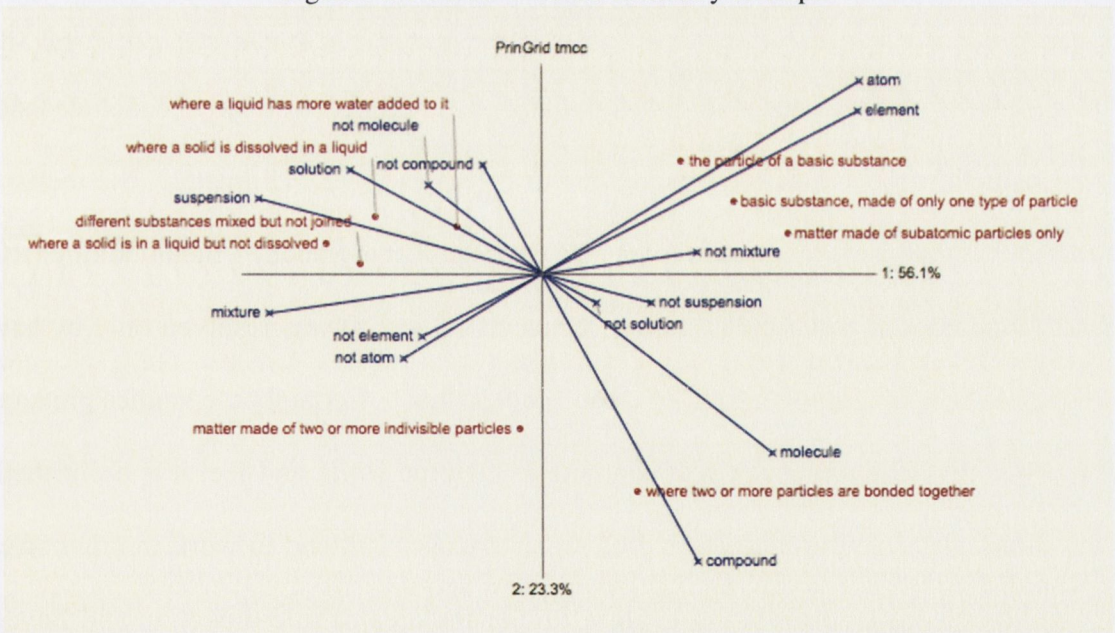

Figure 9.6 PRINCOM of seven chemistry concepts

9.6 Ending biographical note

It is important to highlight the things learned about BNKCs in this thesis. First, I found out something about the mental processes behind that which I always took for granted: identifying animals and plants. The term 'species' as a concept is fluid and many other types of concepts may have a similar fluidity. That is not to say that concepts are relativistic, however, not everyone constructs their conceptions of the living world in the same way. Generally, very generally, we do; but looking at the finer detail we see cultural constraints making their presence felt.

A number of things surprised me about this work. It was interesting that the metric used in the cluster analysis program (Minkowski metric) is the norm in phylogenetic studies, thus a continuum exists between this thesis and the formal phylogenetic studies. Those studies deal with the objective through DNA or protenomic sequencing, this study deals with the subjective through the perceptions of living kinds. A second surprise was when unrelated reading on Bayes nets lead me to conclude that the rule induction process of RGA is similar to Bayesian logic. Ultimately, the thesis was difficult in one major respect: the tension between a study about a methodology (RGA) and a study about a particular class of concepts (BNKCs) was resolved only by having two aims, one dealing with each of these "contestants". Certainly the studies produced a huge quantity of data, which will continue to give me work, as I feel it is unfinished, in the future as will a further refining of the protocols. I intend to work in other science domains such as chemistry and explore further the area of rule induction and Bayesian

logic. I have learned so much and yet feel that I now know so little: ultimately, to discover more of how the mind of the learner works is my goal.

Bibliography

Adey, P., Robertson, A., & Venville, G. (2002). Effects of a cognitive stimulation programme on Year 1 pupils. *British Journal of Educational Psychology, 72*, 1-25.

Anderson, T. H., & Huang, S.-C. C. (1989). On using concept maps to assess the comprehension effects of reading expository text.: Center for the Studying of Reading. University of Illinois at Urbana-Champaign.

Anon. (2006a). George A. Kelly [Electronic Version]. Retrieved 12th March 2006 from http://www.oikos.org/kelen.htm.

Anon. (2006b). Repertory Grid Analysis [Electronic Version]. Retrieved 14th March 2006 from http://www.nuis.ac.jp/~hadley/publication/gridpresent/repgridprocedure.htm.

Aristotle. *Historia Animalium Book 1*. Translated by Peck, A.L. (1979) G. P. Goold (Ed.), *The Loeb Classical Library* (Vol. I). Cambridge, MASS: Harvard University Press / Heinemann Ltd.

Atran, S. (1990). *Cognitive foundations of natural history: towards an anthropology of science* (3rd, digital ed.). Cambridge: Cambridge University Press / Maison des Sciences de l'Homme.

Atran, S. (1999). Itzaj Maya folkbiological taxonomy: cognitive universals and cultural particulars. In D. L. Medin & S. Atran (Eds.), *Folkbiology*. Cambridge, MASS: MIT Press.

Ausubel, D. P. (1963). *The psychology of meaningful verbal learning*. New York: Grune and Stratton.

Ausubel, D. P. (1968). *Educational psychology: a cognitive view*. New York: Holt, Rhinehart and Winston.

Barrett, H. C., & Fiddick, L. (2000). Evolution and risky decisions. *Trends in Cognitive Sciences, 4*(7), 251-252.

Bell, B. F. (1981a). What is a plant? Some children's ideas. *New Zealand Science Teacher, 21*, 10-14.

Bell, B. F. (1981b). When is an animal, not an animal? *Journal of Biological Education, 15*(3), 213-218.

Berlin, B. (1992). *Ethnobiological classification: principles of categorization of plants and animals in traditional societies*. Oxford: Princeton University Press.

Berlin, B. (1999). How a folkbotanical system can be both natural and comprehensive: one Maya Indian's view of the plant world. In D. L. Medin & S. Atran (Eds.), *Folkbiology*. Cambridge, MASS: MIT Press.

Berlin, B., Breedlove, D. E., & Raven, P. (1974). *Principles of Tzeltal plant classification*. New York: Academic Press.

Best, J. B. (1995). *Cognitve Psychology* (4th ed.). New York: West Publishing Company.

Bezzi, A. (1996). Use of Repertory Grids in Facilitating Knowledge Construction and Reconstruction in Geology. *Journal of Research in Science Education, 33*(2), 179-204.

Bieri, J. (1955). Cognitive complexity-simplicity and predictive behavior. *Journal of Abnormal and Social Psychology*, 51, 262-268.

Boeree, C. G. (2006). George Kelly [Electronic Version]. Retrieved 12th March 2006 from http://www.ship.edu/~cgboeree/kelly.html.

Brook, A., Driver, R., & Johnston, K. (1989). Learning processes in science: a classroom perspective. In J. Wellington (Ed.), *Skills and processes in science education: a critical analysis*. London: Routledge.

Brown, A. L. (1990). Domain-specific principles affect learning and transfer in children. *Cognitive Science, 14*, 107-133.

Brown, C. R. (1995). *The effective teaching of biology*. London: Longman.

Bruner, J. S., Goodnow, J., & Austin, G. A. (1956). *A Study of thinking*. New York: Wiley.

Bullock, M., Gelman, S. A., & Baillargeon, R. (1982). The development of causal thinking. In W. J. Friedman (Ed.), *The developmental psychology of time* (pp. 209-254). New York: Academic Press.

Buzan, T. (2002). *Use your head*. London: BBC.

Caine, R. N., & Caine, G. (1994). *Making connections: teaching and the human brain*. Menlo Park, CA.: Addison-Wesley Publishing Company.

Carey, S. (1985). *Conceptual change in childhood*. Cambridge, MASS: MIT Press.

Carey, S. (1994). On the origin of causal understanding. In D. Sperber & A. J. Premack (Eds.), *Causal cognition*. Oxford: Oxford University Press.

Cendrowska, J. (1987) An algorithm for inducing modular rules. *International Journal of Man-Machine Studies 27*(4) 349-370.

Chambers, W. V., & Grice, J. W. (1986). Circumgrids: a repertory grid package for persoal computers. *Behaviour Research Methods, Instruments & Computers, 18*, 468.

Chambers, W. V., & Grice, J. W. (1987). Circumgrids. *Clinical Psychology Review: Software Survey Section, 7*(I - IV).

Collins, A. M., & Quillian, M. R. (1969). Retreval time from semantic memory. *Journal of Verbal Learning and Verbal Behaviour, 8*, 241-248.

Cosmides, L., & Tooby, J. (1994). Origins of domain specificity: the evolution of functional organisation. In L. A. Hirschfield & S. A. Gelman (Eds.), *Mapping the mind: domain specificity in cognition and culture*. Cambridge: Cambridge University Press.

Darley, W. M. (1990). The essence of "plantness". *American Biology Teacher, 52*(6), 354-357.

Darwin, C. R. (2001). *The origin of species* (1st ed. reprint). London: Penguin Books Ltd.

Denney, N. W. (1972). A Developmental Study of Free Classification in Children *Child*

Development, 43(1), 221-232.

Driver, R. (1983). *The pupil as scientist*. Milton Keynes: Open University Press.

Dunteman, G. H. (1989). *Principal Components Analysis*. London: Sage Publications.

Edmondson, K. M. (2000). Assessing science understanding through concept maps. In J. J. Mintzes, J. H. Wandersee & J. Novak (Eds.), *Assessing understanding: a human constructivist view* (pp. 15-40). San Diego, CA: Academic Press.

Estes, W. K. (1996). *Classification and Cognition* (Vol. 22). Oxford: Oxford University Press.

Everitt, B. (1974) Cluster analysis. New York, Wiley.

Fetherstonhaugh, T. (1994). Using the repertory grid to probe students' ideas about energy. *Research in Science and Technological Education, 12*(2), 117-127.

Fielding, A.H. (2007) *Cluster and classification techniques for the biosciences*. Cambridge, Cambridge University Press.

Fisher, K. M. (2000). Overview of concept mapping. In K. M. Fisher, J. H. Wandersee & D. E. Moody (Eds.), *Mapping biology knowledge* (Vol. 11). Dordrecht: Kluwer Academic Publishers.

Fisher, K. M., Wandersee, J. H., & Moody, D. E. (Eds.). (2000). *Mapping biology knowledge* (Vol. 11). Dordrecht: Kluwer Academic Publishers.

Fransella, F., Bell, R., & Bannister, D. (2004). *A manual for repertory grid technique*. Chichester: John Wiley & Sons Ltd.

French, R. (1994). *Ancient Natural History: Histories of Nature* (1st ed. Vol. First). London: Routledge.

Gaines, B.R. (1989) *An ounce of knowledge is worth a ton of data: quantitative studies of the trade-off between expertise and data based on statistically well-founded empirical induction*. Proceedings of the Sixth International Workshop on Machine Learning. 156-159. San Mateo, California: Morgan Kaufmann.

Gaines, B.R. (1991) Integrating rules in term subsumption knowledge representation servers. AAAI'91: Proceedings of the Ninth National Conference on Artificial Intelligence. 458-463. Menlo Park, California: AAAI Press/MIT Press.

Gaines, B. R., & Shaw, M. L. G. (1995, 30th July 1995). Collaboration through concept maps. Retrieved 2nd May, 2003, from http://ksi.cpsc.ucalgary.ca/articles/CSCL95CM/

Gärdenfors, P. (2004) *Conceptual spaces: the geometry of thought*. Cambridge, MASS: MIT Press.

Gelman, S. A., Coley, J. D., & Gottfried, G. M. (1994). Essentialist beliefs in children: the acquisition of concepts and theories. In L. A. Hirschfield & S. A. Gelman (Eds.), *Mapping the mind: domain specificity in cognition and culture* (pp. 341-366). Cambridge: Cambridge University Press.

Gelman, S. A., & Markham, E. M. (1986). Categories and induction in young children. *Cognition, 23*, 183-209.

Gelman, S. A., & Markham, E. M. (1987). Young children's inductions from natural kinds: the role of categories and appearances. *Child Development, 38*, 213-244.

Gelman, S. A., & Medin, D. L. (1993). What's so essential about essentialism? A different perspective on the interaction of perception, langauge, and conceptual knowledge. *Cognitive Development, 8*, 157-168.

Gelman, S. A., & Wellman, H. M. (1991). Insides and essences: early understandings of the non-obvious. *Cognition, 38*, 213-244.

Gentner, D. (1983) Structure-mapping: a theoretical framework for analogy. *Cognitive Science, 7,* 155 – 297.

Glinert, I. P. (Ed.). (1990). *Visual programming environments: paradigms and systems*. Los Alamitos. California: I.E.E.E. Computer Society Press.

Grabmeier, J. and Rudolph, A. (2002) Techniques of cluster algorithms in data mining. *Data Mining and Knowledge Discovery, 6,* 303-360

Greeno, J. (1983). Response to Philips. *Educational Psychology, 18*(2), 75-80.

Grice, J. W. (2003, 26th July). Annotated output for coordinate grid procedure. Retrieved 5th August, 2004, from http://www.idiogrid.com/coordannotated.pdf

Grice, J. W. (2004). Idiogrid: Idiographic analysis with repertory grids (Version 2.3). Stillwater, Oaklahoma.

Grice, J. W., & Hopper, M. (2002). The relaibility of the coordinate grid data. *Psychological Reports, 91*, 1235-1243.

Glymour, C. (2000) *Bayes nets as psychological models*. In F.C. Keil and R.A. Wilson (Eds.), *Explanation and cognition*. Cambridge, MASS: MIT Press .

Hahn, U., & Chater, N. (1997). Concepts and Similarity. In K. Lamberts & D. Shanks (Eds.), *knowledge, concepts and categories* (1st ed., Vol. 1, pp. 43-92). London: Psychology Press.

Hambleton, R. K., H., S., & Rogers, J. H. (1991). *Fundamentals of item response theory*. Newbury Park: Sage Publications.

Heinze-Fry, J. A., & Novak, J. D. (1990). Concept mapping brings long-term movement toward meaningful learning. *Science Education, 74*, 461-472.

Hibbard, K. M., & Novak, J. D. (1975). Audio-tutorial elementary school science instruction as a method for studying of children's concept learning: Particulate nature of matter. *Science Education, 59*(4), 559-570.

Horton, P. B., McConney, A. A., Gallo, M., Woods, A. L., Senn, G. J., & Hamelin, D. (1993). An investigation of the effectiveness of concept mapping as an instructional tool. *Science Education, 77*, 95-111.

Hull, D. (1965). The effect of essentialism on taxonomy - two thousand years of stasis. *British Journal for the Philosophy of Science, 15*, 314-326.

Inhelder, B., & Piaget, J. (1964). *The growth of logic in the child: classification and seriation*. London: Routledge and Kegan Paul.

Irwin, S. W. B., McCloughlin, T. J. J., & Fried, B. (1991). Scanning and Transmission Electron Microscopical Observations on the Tegument of Excysted Metacercariae and

Adults of Zygocotyle lunata. *The International Journal of Helminthology, 65*, 270-274.

Jankowicz, D. (2004). *An easy guide to repertory grids*. Chichester: John Wiley & Sons Ltd.

Johnson-Laird, P. N. (1983). *Mental models*. Cambridge, MASS.: Harvard University Press.

Kaufman, L. and Rousseeuw, P.J. (1990) *Finding groups in data: an introduction to cluster analysis*. New York, Wiley.

Keil, F. C. (1996). *Concepts, kinds, and cognitive development*. Cambridge, MASS: MIT Press.

Kelly, G. (1969). A mathematical approach to psychology. In B. Maher (Ed.), *Clinical psychology and personality: the selected papers of George Kelly*. New York: Wiley.

Kelly, G. (1955/1992). *The psychology of personal constructs: volume one – a theory of constructs* (2nd ed. reprint). London: Routledge.

Kinchin, I. A. (1999). Investigating secondary-school girls' preferences for animals or plants: a simple 'head-to-head' comparison using two unfamiliar organisms. *Journal of Biological Education, 32*(2), 95-99.

Kinchin, I. M. (2000a). Using concept maps to reveal understanding: a two-tier analysis. *School Science Review, 81*(296), 41-46.

Kinchin, I. M. (2000b). Concept mapping in biology. *Journal of biological education, 34*(4), 178-183.

Kinchin, I. M. (2001). If concept mapping is so helpful to learning biology, why aren't we all doing it? *International journal of Science Education, 23*(12), 1257-1269.

Kinchin, I. M., Hay, D. B., & Adams, A. (2000). How a quantitative approach to concept map analysis can be used to aid learning by illustrating patterns of conceptual development. *Educational Research, 42*(1), 43-57.

Kofsky, E. (1966). A scalogram study of classificatory development *Child Development,*

37(1), 191-204.

Kripke, S. (1972a). Naming and necessity. In D. Davidson & G. Harman (Eds.), *Semantics of natural language*. Dordrecht: Reidel.

Kripke, S. (1972b). Identity and necessity. In M. K. Munitz (Ed.), *Identity and individuation*. New York: New York University Press.

Kühberger, A. (1998). The influence of framing on risky decisions: a meta-analysis. *Organizational Behavior and Human Decision Processes, 75*(1), 23-55.

Laffey, J. M., & Singer, J. (1997). Using mapping for cognitive assessment in project-based science. *Journal of Interactive Learning Research, 8*(3-4), 363-387.

Lawson, M. J. (1997). Concept mapping. In J. P. Keeves (Ed.), *Educational research methodology and measurement: an international handbook* (2nd ed., pp. 291-296). Oxford: Pergamon.

Lehman, J. D., Carter, C., & Kahle, J. B. (1985). Concept mapping, vee mapping and achievement: results of a field study with black high school students. *Journal of Research in Science Teaching, 22*(7), 663-673.

Liu, X. (1994, 8 April 1994). *The validity and reliability of concept mapping as an alternative science assessment when item response theory is used for scoring*. Paper presented at the Annual meeting of the American Education Research Association, New Orleans.

Locke, J. (1690/1964). *An essay concerning human understanding*. New York: Meridian.

López, A., Atran, S., Coley, J., Medin, D. L., & Smith, E. E. (1997). The tree of life: universals of folkbiological taxonomies and inductions. *Cognitive Psychology, 32*, 251-295.

Lurie, E. (2004)(Ed.) *Essay on classification by Louis Agassiz*. Harvard: Belknap Press.

Lyai, C. H. C. (2005). Crumbling foundations: the erosion of the taxonomic base of biology. *School Science Review, 87*(319), 65-74.

Mann, T. (1940). *Magic mountain*. New York: Vintage.

Markham, E. M. (1989). *Categorization and naming in children: problems in induction*. Cabridge, MASS: MIT Press.

Markham, K., Mintzes, J. J., & Jones, M. G. (1994). The concept map a research and evaluation tool: further evidence of validity. *Journal of Research in Science Teaching, 31*, 91-101.

Marr, D. (1982). *Vision: a computational investigation into the human representation and processing of visual information*. New York: W. H. Freeman & Co.

Martin, B. L., Mintzes, J. J., & Clavijo, I. E. (2000). Restructuring knowledge in biology: cognitive processes and metacognitive reflections. *International Journal of Science Education, 22*(3), 303-323.

Mayr, E. (1982). *The growth of biological thought*. Cambridge: Harvard University Press.

McCloughlin, T. J. J., & Irwin, S. W. B. (1991). The Occurrence of Eye Flukes in Fish from the Erne Catchment Area. *Irish Naturalists' Journal, 23*(10), 409-414.

McClure, J. R., & Bell, P. E. (1990). Effects of an environmental education-related STS approach instruction on cognitive structures of preservice teachers: Pennsylvania State University. ERIC database file reference number ED 341 582.

McQuitty, L.L. (1960) Hierarchical linkage analysis for the isolation of types. *Educational and Psychological Measurement, 20*, 55 – 67.

Medin, D. L. (1975). A theory of context in discrimination learning. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 9, pp. 263-314). New York: Academic Press.

Medin, D. L., & Atran, S. (Eds.). (1999). *Folkbiology*. Cambridge, Mass: MIT Press.

Medin, D. L., & Ortony, A. (1989). Psychological essentialism. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning*. Cambridge: Cambridge University Press.

Medin, D. L., & Schaffer, M. M. (1978). Context theory of classification learning. *Psychological Review, 85*, 207-238.

Medin, D. L., & Wattenmaker, W. D. (1987). Category cohesiveness, theories, and cognitive archaeology. In U. Neisser (Ed.), *Concepts and conceptual development: ecological and intellectual factors in categorisation*. Cambridge: Cambridge University Press.

Mervis, C., & Rosch, E. (1981). Categorisation of natural objects. *Annual review of psychology, 32*, 89-115.

Minsky, M. L., & Papert, S. A. (1969). *Perceptrons*. Cambridge, Mass: MIT Press.

Mintzes, J. J., Wandersee, J. H., & Novak, J. (1997). *Teaching science for understanding*. San Diego: Academic Press.

Murphy, G. L. (2002). *The big book of concepts*. Cambridge, MASS: MIT Press.

Neisser, U. (1987). *Concepts and conceptual development: ecological and intellectual factors in categorisation*. Cambridge: Cambridge University Press.

Nicoll, G., Francisco, J., & Nakhleh, M. B. (2001). An investigation of the valu of using concept maps in general chemistry. *Journal of Chemical Education, 78*(8), 1111-1117.

Novak, J. (1979). Applying psychology and philosophy to the improvement of laboratory teaching. *The American Biology Teacher, 41*(8), 466-474.

Novak, J. (1980). Learning theory applied to the biology classroom. *The American Biology Teacher, 42*(5), 280-285.

Novak, J. (1981). Applying learning psychology and philosophy of science to biology teaching. *The American Biology Teacher, 43*(1), 12-20.

Novak, J. D. (1966). The role of concepts in science teaching. In H. J. Klausmeier (Ed.), *Analysis of concept learning*. New York: Academic Press.

Novak, J. D. (1966). The role of concepts in science teaching. In H. J. Klausmeier (Ed.), *Analysis of concept learning*. New York: Academic Press.

Novak, J. D. (1972). Audio-tutorial techniques for individualised scores instruction in the elementary school. In H. Triezenberg (Ed.), *Individualized science: like it is* (pp. 14-30). Washington, DC: National Science Teachers' Association.

Novak, J. D. (1990). Concept mapping: a useful tool for science education. *Journal of Research in Science Teaching, 27*(10), 937-949.

Novak, J. D., & Gowin, D. B. (1984). *Learning how to learn*. New York: Cambridge University Press.

Novak, J. D., Gowin, D. B., & Johansen, G. T. (1983). The use of concept mapping and knowledge Vee mapping with junior high school science students. *Science Education, 67*(5), 625-645.

Novak, J., & Musonda, D. (1991). Tracing conceptual change in preservice teachers. A twelve-year longitudinal study of science concept learning. *Annual Educational Research Journal, 28*, 117-153.

Nussbaum, J., & Novak, J. (1976). An assessment of children's concepts of the earth utilizing structured interviews. *Science Education, 60*(4), 535-550.

Okebukola, P. A. (1990). Attaining meaningful learning of concepts in genetics and ecology; an examination of the potency of the concept-mapping technique. *Journal of Research in Science Teaching, 27*, 493-504.

Okebukola, P. A., & Jegede, O. J. (1989). Students' anxiety towards and perception of difficulty of some biological concepts under the concept-mapping heuristic. *Research in Science and Technological Education, 7*(1), 85-92.

Osherson, D. N., & Smith, E. E. (1981). On the adequacy of prototype theory as a theory of concepts. *Cognition, 9*, 35-58.

Osherson, D. N., & Smith, E. E. (1982). Gradeness and conceptual combination. *Cognition, 12*, 299-318.

Pankratius, W. J. (1990). Building an organised knowledge base: concept mapping and achievement in secondary school physics. *Journal of Research in Science Teaching,*

27(4), 315-333.

Pankratius, W. J., & Keith, T. M. (1987, 26th-27th March 1987). *Building an organised knowledge base: concept mapping in secondary school science*. Paper presented at the 35th annual meeting of the National Science Teachers' Association, Washington DC.

Peacocke, C. (1999). *A study of concepts* (2nd ed.). Cambridge, MASS: MIT Press.

Pearsall, N. R., Skipper, J. E. J., & Mintzes, J. J. (1997). Knowledge restructuring in the life sciences: a longitudinal study of conceptual change in biology. *Science Education, 81*(193-215).

Philips, D. C. (1983). On describing a student's cognitive structure. *Educational Psychology, 18*(2), 59-74.

Piaget, J. (1926). *the language and thought of a child*. New york: Harcourt Brace.

Pinker, S. (1997). *How the brain works*. London: Viking.

Popper, K. (1950). *The open society and its enemies*. Princeton, NJ: Princeton University Press.

Putnam, H. (1975). The meaning of meaning. In H. Putnam (Ed.), *Mind, language and reality* (Vol. 2). London: Cambridge University Press.

Quine, W. V. O. (1960). *Word and object*. Cambridge, MASS: MIT Press.

Quine, W. V. O. (1977). Natural kinds. In S. P. Schwartz (Ed.), *Naming, necessity and natural kinds*. Ithaca, NY: Cornell University Press.

Ratcliff, R. (1978). A theory of memory retrieval. *Psychological Review, 85*, 59-108.

Robinson, A. H. (1982). *Early thematic mapping in the history of cartography*. Chicago: University of Chicago Press.

Robinson, W. R. (1999). A view of the science education research literature: concept map assessment of classroom learning. *Journal of Chemical Education, 76*(9), 1179.

Rode, C., Cosmides, L., Hell, W., & Tooby, J. (1999). When and why do people avoid unknown probabilities in decisions under certainty? Testing some predictions from

optimal foraging theory. *Cognition, 72*, 269-304.

Rosch, E. (1975). Cognitive representations of semantic categories. *Journal of Experimental Psychology: General, 104*, 192-233.

Rosch, E., & Mervis, C. (1975). Family resemblances: studies in the internal structure of natural categories. *Cognitive Psychology, 8*, 382-439.

Ross-Craig, S. (1948-9). *Drawings of British plants being illustrations of the species of flowering plants growing naturally in the British Isles*. London: G. Bell and Sons.

Roth, W.-M., & Roychoudhury. A. (1993). The concept map as a tool for the collaborative construction of lnowledge: a microanalysis of high school physics students. *Journal of Research in Science Teaching, 50*(5), 503-534.

Ruiz-Primo, M. A., Schultz, S. E., Li, M., & Shavelson, R. J. (2001). Comparison of the reliability and validity of scores from two concept-mapping techniques. *Journal of Research in Science Teaching, 38*(2), 260-278.

Ruiz-Primo, M. A., Schultz, S. E., & Shavelson, R. (1996, April). *Concept-map based assessment in science: an exploratory study*. Paper presented at the Annual conference of the American Educational Research Association, New York, NY.

Ruiz-Primo, M. A., Shavelson, R., & Schultz, S. E. (1997, March). *On the validity of concept map based assessment interpretations: an experiment testing the assumption of hierarchical concept-maps in science*. Paper presented at the Annual conference of the American Educational Research Association, Chicago, IL.

Ruiz-Primo, M. A., & Shavelson, R. J. (1996). Problems and issues in the use of concept maps in science assessment. *Journal of Research in Science Teaching, 33*(6), 569-600.

Rumelhart, D. E., & Ortony, A. (1977). The representation of knowledge in memory. In R. C. Anderson, R. J. Spiro & W. E. Montague (Eds.), *Schooling and the acquisition of knowledge*. Hillsdale, NJ: Erlbaum.

Russell, B. (1945). *A history of western philosophy*. New York: Simon & Schuster.

Sagan, K. (1991). *Cosmos* (2nd ed.). London: Pioneer.

Samejima, F. (1969). Estimation of latent ability using a response pattern of graded scores. *Psychometrika monograph supplement, 4*(2).

Schau, C., & Mattern, N. (1997). Use of map techniques in teaching applied statistics courses. *The American Statistician, 51*, 171-175.

Schau, C., Mattern, N., Weber, R., Minnick, K., & Witt, C. (1997, March). *Use of fill-in concept maps to assess middle school students' connected understanding of science*. Paper presented at the Annual conference of the American Educational Research Association, Chicago, IL.

Schneekloth, L. H. (1989). 'Where did you go?' 'the forest.' 'what did you see?' 'nothing.' *Children's Environments Quarterly, 6*, 14-17.

Schreiber, D. A., & Abegg, G. L. (1991, 7-11 April). *Scoring student-generated concept maps in introductory college chemistry*. Paper presented at the Annual meeting of the National Association for Research in Science Teaching, Lake Geneva, WI.

Schwartz, S.P. (1977)(Ed.). *Naming, necessity, and natural kinds*, Ithaca: Cornell University Press.

Schwartz, S. P. (1978). Putnam on artifacts. *Philosophical Review, 87*, 566-574.

Schwartz, S. P. (1980). Natural kinds and nominal kinds. *Mind, 89*, 182-195.

Shaw, M. L. G. (1980). *On becoming a personal scientist: interactive computer elicitation of personal models of the world*. London: Academic Press.

Shaw, M. L. G., & Gaines, B. R. (1995, 4th August). Kelly's geometry of psychological space and its significance for cognitive modelling. Retrieved 13th June, 1997, from http://ksi.cpsc.ucalgary.ca/articles/NewPsych92/References

Shayer, M. and Adey, P. (1999). Cognitive Acceleration through Science Education II: its effect and scope. *International Journal of Science Education, 21*(8), 883-902.

Shayer, M. and Adey, P. (2003). Not just Piaget; not just Vygotsky, and certainly not Vygotsky as alternative to Piaget. *Learning and Instruction, 13*, 465-485.

Simmons, D. A. (1994). Urban children's preferences for nature: lessons for environmental education. . *Children's Environments Quarterly, 11*, 194-203.

Slater, P. (1964). *The principal components of a repertory grid.* London: Vincent Andrew.

Slater, P. (1972). The measurement of consistency in repertory grids. *British Journal of Psychiatry, 121*, 45-51.

Slater, P. (Ed.). (1977). *The measurement of intrapersonal space by grid technique: dimensions of intrapersonal space* (Vol. 2). London: Wiley.

Smith, E. E., & Medin, D. L. (1981). *Categories and concepts*. Cambridge, Mass: Harvard University Press.

Smith, E. E., & Osherson, D. N. (1984). Conceptual classification with prototype concepts. *Cognitiv science, 8*, 337-361.

Smith, E. E., Osherson, D. N., Rips, L. J., & Keane, M. (1988). Combining prototypes: a selective modification model. *Cognitiv science, 12*, 485-527.

Starr, M., & Krajcik, J. (1990). Concept maps as a heuristic for science curriculum development: toward improvement in process and product. *Journal of Research in Science Teaching, 27*, 987-1000.

Stavridou, H., & Solomonidou, C. (1998). Conceptual reorganization and the construction of the chemical reaction concept during secondary education. *International Journal of Science Education, 20*(2), 205-221.

Stensvold, M. S., & Wilson, J. T. (1990). The interaction of verbal ability with concept mapping in learning from a chemistry laboratory activity. *Science Education, 74*(4), 473-480.

Stow, W. (1997). Concept mapping – a tool for self assessment? *Primary Science Review, 49*, 12-15.

Surber, J. R. (1984). Mapping as a testing and diagnostic device. In C. D. Holley & D. F. Dansereau (Eds.), *Spatial learning strategies: techniques, applications and related issues*

(pp. 213-233). Orlando, FL: Academic Press.

Symington, D. and Novak, J.D. (1982). Concept mapping for curriculum development. *The Victorian Institute of Educational Research, 48*, 3 – 11.

Thorndike, E. L. (1913). *Educational psychology* (Vol. II). New York: Teachers' College, Columbia University.

Traverse, A. (1996). Nomenclature and Taxonomy: Systematics. In J. M. Jansonius (Ed.), *Palynology: Principles and Applications* (Vol. 1, pp. 11-28). College Station, Texas: American Association of Stratigraphic Palynologists Foundation.

Tunnicliffe, S. D. (2001). Talking about plants – comments of primary school groups looking at plant exhibits in a botanical garden. *Journal of Biological Education, 36*(1), 27-34.

Tunnicliffe, S. D., & Reiss, M. J. (2000). Building a model of the environment: how do children see plants? *Journal of Biological Education, 34*(4), 172-177.

Wallace, J. D., & Mintzes, J. J. (1990). The concept map as a research tool: exploring conceptual change in biology. *Journal of Research in Science Teaching, 27*(10), 1033-1052.

Wandersee, J. H. (1990). Concept mapping and the cartography of cognition. *Journal of research in science teaching, 27*(10), 923-936.

Wang, X. T. (1996). Domain-specific rationality in human choice: violoations of utility axioms and social contexts. *Cognition, 60*, 31-63.

Wellman, H. M. (1990). *The child's theory of mind*. Cambridge, MASS: MIT Press.

White, R., & Gunstone, R. (1989). *Probing understanding*. London: Falmer Press.

Wilerman, M., & MacHarg, R. A. (1991). The concept map as an advance organiser. *Journal of Research in Science Teaching, 28*, 705-711.

Wilson, J. M. (1993, August). *The predictive validity of concept-mapping: relationships to measures of achievement*. Paper presented at the Third International Seminar on

Misconceptions and Educational Strategies in Science and Mathematics, Ithaca, Cornell University.

Winer, L. R., & Vazquez-Abad, J. (1995, April 18-22). *The potential of repertory grid technique in the assessment of conceptual change in physics*. Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco.

Wittgenstein, L. (1953). *Philosophical investigations*. Oxford: Blackwell.

Zadeh, L. A. (1965). Fuzzy Sets. *Information and control, 8*, 338-353.