

A SOCIOCULTURAL APPROACH TO
CONCEPTUAL CHANGE LEARNING IN FIRST
YEAR PHARMACY STUDENTS

Volume 1

A thesis submitted in fulfillment of the requirements for the degree
of Doctor of Philosophy in the Faculty of Education and Social
Work at The University of Sydney

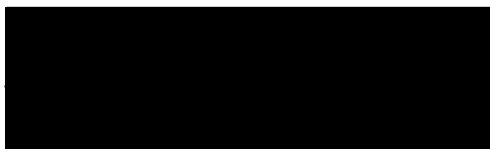
Erica Jane Sainsbury
March 2009

AUTHOR'S DECLARATION

This is to certify that:

- I. this thesis comprises only my original work towards the Doctor of Philosophy Degree;
- II. due acknowledgement has been made in the text to all other material used;
- III. the thesis does not exceed the word length for this degree;
- IV. no part of this work has been used for the award of another degree; and
- V. this thesis meets the *University of Sydney's Human Research Ethics Committee (HREC) requirements for the conduct of research.*

Signature:



Name: Erica Jane Sainsbury

Date: 31 March 2009

How do I know what I think until I hear what I say?

Gordon Wells *Dialogic Inquiry*, 1999, page 107

ABSTRACT

This thesis describes a sociocultural approach to conceptual change learning among first year pharmacy students at the University of Sydney, Australia. Observations over many years with first year students have consistently identified student difficulties in learning a number of topics, and in particular recognising differences in meaning of the same terms when used in two different but related contexts, chemistry and pharmacy. In this thesis, a general discourse model of conceptual change is proposed which highlights the context dependence of meaning, and illustrates the process of cognitive socialisation by which students become able to engage in meaningful discourse with members of the pharmacy community. The sociocultural nature of this model is emphasised by situating both the outcomes and processes of conceptual change within discursive practices and analysing the interdependent emergence of unique individual and group trajectories as students engage in collaborative discourse and problem-solving activities in formal classrooms. The use of Rogoff's (1998) planes of analysis approach as an analytical framework reinforces the sociocultural basis of the model by emphasising the intertwining of the individual and social through alternately foregrounding each against the background of the other. The character of collaboration is specifically investigated by focusing on the semiotically mediated development of shared thinking and creation of zones of proximal development, as they are supported by structured teaching and modeling. Cognitive socialisation proceeds by means of the appropriation of concepts and discursive practices (Wells, 1999a) pertinent to the pharmacy community, and this appropriation is brought about through the reciprocal and transformative processes of internalisation and externalisation (Valsiner, 1998).

In the empirical study reported in this thesis, eleven students from a cohort of 190 enrolled in a first year pharmacy subject were selected to participate in an intensive qualitative investigation of their learning, which encompassed the analysis of classroom activities to illuminate the processes of conceptual change, and interviews to elucidate conceptual change outcomes. Classroom activities were carried out within weekly workshops where the students worked in two groups of five and six respectively, and the analysis was based on video and audio recordings of the groups as they worked. Three interviews were carried out with each student over a 36 week period in order to investigate changes in their conceptual understanding from the beginning to the end of the teaching semester, and the persistence of change five months later. The two groups, which became designated as PC (persistent change) and TC (transient change), differed significantly in both outcomes and processes, and a local situated derivative of the general discourse model emerged as an explanation of the relationships between outcome and process in the specific context of the study. The local model highlighted features of the learning environment which acted as both affordances and constraints on conceptual change, including the nature of intra-group interactions, the group culture which was created thereby, the quality of intersubjectivity that was evident, and the emergence of zones of proximal development. In terms of outcomes, members of the PC group demonstrated learning of new concepts relating to pharmacy and discrimination between the contexts of chemistry and pharmacy which persisted at least until the end of the study, whereas members of the TC group were

considerably less successful in developing contextual discrimination and retaining their learning beyond the end of the teaching semester. With regard to processes, the PC group demonstrated highly productive interactions during workshops, which created a collaborative and cooperative culture, marked by high levels of shared thinking, consideration of others which was apparent in extensive and inclusive discussion, and effective use of the teaching and learning supports which were available. In contrast, members of the TC group engaged in more competitive behaviours and less productive interactions, which resulted in a culture characterised by individual effort, low levels of shared thinking, less consideration of others, sparse discussion and substantially less effective use of teaching and learning supports. Further, individual perceptions of the purposes of the workshops intertwined with the goals of the participants to create qualitative differences in the focus of each group. A strong learning focus emerged within the PC group whose members perceived the workshops as opportunities for enhancing their conceptual understanding, and an equally strong focus emerged within the TC group on completing the task with a view to performing well in examinations. Thus, the differences between the two groups in interactions and processes were closely and interdependently linked with the differences in conceptual change outcomes of their members, and the model provided an apposite explanation of the observed differences.

Comparison of the findings with the results of a survey of the entire cohort suggests that the outcomes were common to the whole group, thus validating the extrapolation of the findings to the population, and a number of broad implications for teaching emerge from interpretation of the findings. The extent to which the model is able to be generalised beyond the immediate context is evaluated, and it is apparent that the model highlights critical dimensions for the design of learning environments, and provides a useful framework for interpretation of the interactions which occur within them. The findings of this study thus provide new insight into both the processes and outcomes of conceptual change learning which complement existing approaches, and suggest both directions for further research and means of improving learning and instruction in formal education settings. Of particular consequence is the emergence of a more complex role of friendship in shaping conceptual change learning, which reveals distinct differences from previous findings relating to collaboration in learning (Barron, 2003) and which suggests a potentially fruitful avenue of future investigation.

The thesis concludes with a discussion of the contribution of the study to the theory and application of conceptual change research, and highlights the unique contribution of a discursive model grounded in sociocultural theory. Importantly, the model and analysis illustrate the interdependence of the individual and social, and provide a clear contrast to approaches which focus primarily or preferentially on one as an influence on the other. The general and local models, together with the research methodology and analytical approach are consistent with sociocultural principles, and are capable of providing a useful means of addressing the current tension between individual and social dimensions of conceptual change learning.

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DEDICATION

This thesis is dedicated to my family

to my father, Kevin Sainsbury, who died too soon

to my mother, Noela Sainsbury and my brother, Michael Sainsbury
who are faintly astonished that this day has actually arrived

and to my niece Nicola Sainsbury
whose life will see conceptual change beyond what we can currently imagine

TABLE OF CONTENTS

VOLUME 1

Abstract	i
Acknowledgements	iii
Dedication	iv
List of Tables	xii
List of Figures	xii
Glossary and abbreviations	xiii
Human Ethics Committee approval	xv
CHAPTER 1 INTRODUCTION	1
CHAPTER 2 LITERATURE REVIEW	7
2.1 Sociocultural theories and approaches to learning and development	7
• Introduction	7
• Interdependence of individual and social worlds	9
• The mediational role of tools and signs	13
• Collaborative learning and intersubjectivity	17
• Zone of proximal development	21
• Conclusion	24
2.2 Conceptual change	24
• Introduction	24
• The origins of conceptual change theory	24
• The nature of concepts	25
• The classical approach	26
• Theoretical developments 1: Conceptual change learning as an individual phenomenon	28
• Theoretical developments 2: The significance of context for conceptual meaning	37
• Theoretical developments 3: Towards a sociocultural approach	38
2.3 Conceptual change in 'Acids and bases'	51
2.4 Conclusion	53

CHAPTER 3	A DISCOURSE MODEL OF CONCEPTUAL CHANGE: DESCRIPTION AND RATIONALE	55
3.1	Introduction	55
3.2	A discourse model of conceptual change	55
	• The nature of concepts – discursive tools	56
	• Evidence of change – discursive proficiency	56
	• Mechanisms and processes of change – cognitive socialisation	57
3.3	The specific model – broad overview	58
3.4	The model – detailed description and rationale	59
	• The discursive nature of concepts	59
	• Cognitive socialisation	60
	• Context and situated conceptual understanding	61
	• Emergence of community membership and individual understanding – ‘talking science’	64
	• Semiotic mediation – transformative internalisation and externalisation	66
	• Collaborative learning and intersubjectivity	69
	• Zone of proximal development	71
	• Structured teaching and modeling	72
	• Conceptual change outcomes	74
	• Interdependence of individual and social	75
3.5	Research questions	77
CHAPTER 4	POPULATION STUDIES	79
4.1	Introduction	79
4.2	Context for the study	79
4.3	Data collection methodology	80
	• Instrument	80
	• Initial survey	81
	• Final survey	81
4.4	Analysis	82
	• Demographic data, attitudinal variables, multiple choice and true/false responses	82
	• Short answer responses	82
4.5	Results	82
	• Response rates	82
	• Demographic data	83
	• Attitudes to chemistry	84
	• Conceptual understanding	84
4.6	Discussion of results	88
	• Comparison with previous research findings	88
	• Conclusions and implications of conceptual understanding results	89

4.7	Selection of sample	90
	• Process	90
	• Comparison with population data	91
4.8	Conclusion	91
CHAPTER 5 RESEARCH METHODOLOGY: CLASSROOM STUDIES AND INTERVIEWS		93
5.1	Introduction	93
5.2	Classroom studies	93
	• Context	93
	• Data collection	94
	• Data analysis	95
5.3	Interviews	96
	• Scheduling	96
	• Protocol	96
	• Interview content	97
	• Data analysis	98
5.4	Data interpretation and presentation	99
CHAPTER 6 CONCEPTUAL CHANGE OUTCOMES		100
6.1	Introduction	100
6.2	Dimensions of conceptual change	101
	• Changes to existing understanding	101
	• Concepts new to pharmacy	102
6.3	The transient change (TC) group	102
	• Group composition	102
	• Extent and nature of conceptual change – summary	104
	• Janine	104
	○ Initial conceptual framework	104
	○ Janine’s trajectory	105
	○ Janine’s perception of the change in her understanding	109
	○ Summary of Janine’s conceptual development	110
	• Geoffrey	110
	○ Geoffrey’s perception of the change in his understanding	110
	○ Summary of Geoffrey’s conceptual development	111
	• Larry	112
	○ Initial conceptual framework	112
	○ Larry’s trajectory	114
	○ Larry’s perception of the change in his understanding	121
	○ Summary of Larry’s conceptual development	121

•	Lucy	123
○	Initial conceptual framework	123
○	Lucy's trajectory	124
○	Lucy's perception of the change in her understanding	132
○	Summary of Lucy's conceptual development	132
•	Emma	133
○	Emma's perception of the change in her understanding	134
○	Summary of Emma's conceptual development	134
6.4	The persistent change (PC) group	136
•	Group composition	136
•	Veronica	137
○	Initial conceptual framework	137
○	Veronica's trajectory	138
○	Veronica's perception of the change in her understanding	142
○	Summary of Veronica's conceptual development	143
•	Denise	143
○	Denise's perception of the change in her understanding	144
○	Summary of Denise's conceptual development	144
•	Isabelle.....	146
○	Isabelle's perception of the change in her understanding	147
○	Summary of Isabelle's conceptual development	147
•	Jasmine	148
○	Initial conceptual framework	148
○	Jasmine's trajectory	149
○	Jasmine's perception of the change in her understanding	154
○	Summary of Jasmine's conceptual development	155
•	Kellie	156
○	Kellie's perception of the change in her understanding	157
○	Summary of Kellie's conceptual development	157
•	Alicia	158
○	Initial conceptual framework	158
○	Alicia's trajectory	159
○	Alicia's perception of the change in her understanding	163
○	Summary of Alicia's conceptual development	163
6.5	Assessment outcomes	164
6.6	Overall summary	164

CHAPTER 7	GROUP PROCESSES AND CONCEPTUAL CHANGE LEARNING	167
7.1	Introduction	167
7.2	The content space: talking about acids and bases within workshops	167
	• The extent of the discourse	167
	• The nature of the discourse	171
	○ Changes to existing understanding	171
	▪ Transient change group	171
	▪ Persistent change group	173
	○ Concepts new to pharmacy	174
	▪ Transient change group	174
	▪ Persistent change group	179
7.3	The relational space: interactions and group dynamics	187
	• Transient change group	189
	○ Participation in discursive interactions	189
	○ Interpersonal behaviours	197
	○ Group culture	204
	○ Intersubjectivity	208
	○ Roles of the tutor	213
	• Persistent change group	218
	○ Participation in discursive interactions	218
	○ Interpersonal behaviours	225
	○ Group culture	227
	○ Intersubjectivity	230
	○ Roles of the tutor	232
7.4	Participants' perspectives on the relational space	237
	• Transient change group	237
	• Persistent change group	246
7.5	Impact of the recording equipment	250
	• Transient change group	250
	• Persistent change group	251
7.6	Overall summary	251
CHAPTER 8	DISCUSSION AND INTERPRETATION OF RESULTS	252
8.1	Introduction	252
8.2	Conclusion – a situated process model of conceptual change learning and cognitive socialisation	252
	• Cognitive socialisation	254
	• Group interactions	254
	○ Cooperation and competition	255
	○ Status	255

o	Extent and nature of discourse	256
o	Learning or task focus	257
o	Persistence	258
o	The example of phenol and alcohol	258
•	Culture and intersubjectivity	259
o	Culture – collaborative or individual	259
o	Intersubjectivity	260
•	Zones of proximal development	260
o	Transient change group	261
o	Persistent change group	262
•	Structured teaching and modeling	264
o	Transient change group	264
o	Persistent change group	265
•	Learning trajectories and the emergence of nascent cognitive socialisation	266
8.3	Relationship of the situated process model to the general discourse model	267
8.4	Sample and population studies	268
8.5	Generalisation of the findings to other settings	269
8.6	Implications for teaching	270
8.7	Methodological issues	271
•	Study design and methodology	271
•	The teacher as researcher	272
8.8	Directions for future research	273
8.9	Conclusions	274
•	Findings of the empirical study	274
•	Relationship to previous research on collaboration	275
•	The role of friendship in establishing and maintaining group culture ..	275
•	Contribution of the study to conceptual change theory and practice ...	276
REFERENCES	279

VOLUME 2 APPENDICES

APPENDIX A	PRIOR CONCEPTUAL CHANGE RESEARCH ON 'ACIDS AND BASES'	296
APPENDIX B	TABULATED RESULTS FROM POPULATION STUDY	301
APPENDIX C	TIMELINE FOR STUDY	307
APPENDIX D	SEMI-STRUCTURED INTERVIEW QUESTIONS	308
APPENDIX E	STRUCTURES OF MOLECULES	311

APPENDIX F PARTICIPANT TRAJECTORIES (CHAPTER 6)	312
APPENDIX G EXCERPTS FROM INTERVIEW TRANSCRIPTS	342
APPENDIX H CRITICAL EPISODES FOR ANALYSIS OF THE CONTENT SPACE	455
APPENDIX I EXCERPTS FROM WORKSHOP TRANSCRIPTS	458
APPENDIX J IMPACT OF THE RECORDING EQUIPMENT	499

LIST OF TABLES

Table 2.1	Patterns of discourse displayed by two groups of primary school children when solving mathematical problems	44
Table 2.2	Markers of coordination displayed by two groups of primary school children when solving mathematical problems	45
Table 4.1	Details of cohort and response rates: initial and final surveys	301
Table 4.2	Demographic characteristics of the cohort	301
Table 4.3	Attitudes towards chemistry in initial and final surveys	302
Table 4.4	Responses to closed questions about conceptual understanding ...	303
Table 4.5a	Student responses to the task 'List the major characteristics of acids/bases.'	304
Table 4.5b	Student responses to the questions 'What is meant by the pK_a of an acid/base?' and 'What information does it provide about the acid/base?'	304
Table 4.5c	Student responses to the question 'What is the difference between a strong acid/base and a weak acid/base of the same concentration?'	305
Table 4.6a	Population and sample characteristics – background	305
Table 4.6b	Population and sample attitudes to chemistry (initial survey)	306
Table 6.1	Drug molecules analysed by participants in interviews 2 and 3	102
Table 7.1	Code descriptions for analysis of workshop discourse	168-169

LIST OF FIGURES

Figure 6.1	Larry's representation of the table	115
Figure 6.2	Larry's approach to multiple dissociation (with annotation)	120
Figure 7.1	Total speaking turns in each workshop	169
Figure 7.2	Number of speaking turns of each type in each workshop	170
Figure 8.1	Situated process model of conceptual change learning and cognitive socialisation	253
Figure 8.2	Trajectories towards and away from cognitive socialisation	267

GLOSSARY AND ABBREVIATIONS

acid and base	See page 63
Ag	Chemical symbol for silver
(aliphatic) alcohol	Hydroxyl (OH) group which is not directly attached to a benzene ring
amide	Group in which a nitrogen atom is directly attached to a carbonyl (C=O) group
amine	Group containing a basic nitrogen (N) atom which is attached only to hydrogen atoms and/or sp^3 hybridised carbons
carboxylic acid	Molecule containing COOH group: the hydrogen atom is lost in the dissociation process
chemistry	see page 63
delta G	Gibbs' free energy: thermodynamic parameter important in equilibrium
equilibrium	State of balance in a reaction or process where the forward process is occurring at the same rate as the reverse process
equilibrium constant	Ratio of the concentration of products to the concentration of the reactants in a chemical reaction or process when equilibrium is reached
H^+ ion	Proton, produced from an acid as a result of acid dissociation: the relative concentrations of H^+ and OH^- ions determine the pH of a solution
Henderson-Hasselbach equation	Equation which relates the state of ionisation of acids and bases to the pK_a of the molecule and the pH of the solution in which it is dissolved
HSC	Higher School Certificate: the certificate awarded to students who successfully complete secondary school in NSW
IELTS	International English Learning and Testing System: a test of an individual's communication skills in listening, reading, writing and speaking
ionisation	see page 185
IPS	Introductory Pharmaceutical Science: Unit of study in which the investigation was conducted
K_1 and K_2	Symbols used to denote equilibrium constants at different temperatures
K_a and K_b	Equilibrium constants for the dissociation in water of acids and bases respectively. K_a describes the loss of a proton (H^+ ion), while K_b describes the loss of a hydroxide ion (OH^-). * See note below.
Kelvin	Temperature scale beginning at absolute zero: on this scale the freezing point of water is 273 degrees
K_{sp}	Solubility product constant; equilibrium constant for the dissolution of ionic species
NSW	The State of New South Wales; part of the Commonwealth of Australia
OH^- ion	Hydroxide ion, produced from a base as a result of base dissociation; the relative concentrations of H^+ and OH^- ions determine the pH of a solution
orange book	Course notes for IPS
PC group	Persistent change group

pH	Calculated from the hydrogen ion concentration of a solution by taking the negative base 10 logarithm
pharmacy	see page 63
phenol	Hydroxyl (OH) group which is directly attached to a benzene ring
pKa	Calculated from the Ka by taking the negative base 10 logarithm
protonation	See page 185
R	Gas constant: value approximately 8.314×10^{-3} kilojoules/mole
S	Solubility value
sp ² hybridised	Carbon atom which is attached to three other atoms, one of which by a double bond (eg C=O)
sp ³ hybridised	Carbon atom which is attached to four other atoms by single bonds only
strength	Measure of the tendency for an acid or base to donate or accept protons, and to dissociate in water
strong (chemistry)	Dissociates completely in water to form ions
strong (pharmacy)	Possessing a pKa below 7 for an acid, or above 7 for a base
T	Temperature on Kelvin scale
TC group	Transient change group
van't Hoff isochore	Equation relating the value of the equilibrium constant for a process to the temperature at which it is carried out
VCE	Victorian Certificate of Education: the final secondary school qualification offered in Melbourne, equivalent to the NSW HSC.
Victoria	A State in the Commonwealth of Australia
weak (chemistry)	Dissociates partially in water to form ions
weak (pharmacy)	Possessing a pKa above 7 for an acid, or below 7 for a base
S ₁ and S ₂	Symbols used to denote solubility at different temperatures
ZPD	Zone of proximal development: see page 71
* Note:	Ka requires the protonated form of the drug to be on the left hand side of the equation, and the reaction proceeds by the loss of a proton so that the basic form is present on the right hand side. For acids, the equilibrium is intuitive, but for bases, the species on the left hand side must be the conjugate acid: this requires the addition of the proton to form the structure on the left hand side, and its subsequent loss to form the original base structure on the right hand side. The latter is somewhat counter-intuitive and a source of potential confusion.

HUMAN ETHICS COMMITTEE APPROVAL



COPY

HUMAN ETHICS COMMITTEE

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Dr R Walker
Faculty of Education
A35

17 May 2001

Dear Dr Walker

Title: *A sociocultural perspective on conceptual change learning by first year Pharmacy students at the University of Sydney*

Ref No: 01/04/43

I am pleased to inform you that the Human Ethics Committee at its meeting on 23/04/01 approved your protocol on the above study. Please note that subject to annual monitoring returns, the approved protocol is valid for five years.

In order to comply with the *National Statement on Ethical Conduct in Research Involving Humans*, and in line with the Human Ethics Committee requirements the Chief Investigator's responsibility is to ensure that:

- (1) The individual researcher's protocol complies with the final and Committee approved protocol.
- (2) Modifications to the protocol cannot proceed until such approval is obtained in writing.
- (3) The confidentiality and anonymity of all research subjects is maintained at all times, except as required by law.
- (4) All research subjects are provided with a Subject Information Sheet and Consent Form.
- (5) The Subject Information Sheet and Consent Form be on University of Sydney letterhead and include the full title of the research project and telephone contacts for the researchers.
- (6) The following statement appears on the bottom of the Subject Information Sheet:
Any person with concerns or complaints about the conduct of a research study can contact the Manager of Ethics and Biosafety Administration, University of Sydney, on (02) 9351 4811.
- (7) The standard University policy concerning storage of data and tapes should be followed. While temporary storage of data or tapes at the researcher's home or an off-campus site is acceptable during the active transcription phase of the project, permanent storage should be at a secure, University controlled site for a minimum of five years.
- (8) A progress report is provided by the end of each year. Failure to do so will lead to withdrawal of the approval of the research protocol and re-application to the Committee must occur before recommencing.
- (9) A report and a copy of the published material is provided at the end of the project.

Yours sincerely

Professor Jeff Sigafos
Chairman
Human Ethics Committee

cc. Ms E Sainsbury, Faculty of Pharmacy A15,

CHAPTER 1 INTRODUCTION

The ways in which humans learn and develop during their lives are diverse and complex, ranging from the first interactions of a newborn baby with the world, to the creation of new understandings and knowledge by experts within a discipline, and many theories have been advanced to describe and explain these processes. One such theory, sociocultural theory, locates all human learning and development within social interactions situated in specific cultural and historical contexts, and focuses on the ways in which social practices are learned by novices in each generation. Although these ways vary enormously between contexts, they all share a reliance on some form of collaboration, usually between a more capable person or expert and a novice or group of novices, in which shared understandings develop through joint participation in activities.

Common to all sociocultural approaches is the recognition that the individual cannot be studied in isolation from the social, and that “individual, interpersonal and cultural processes are not independent entities” (Rogoff, 1998, p. 687), since all human activities take place within a cultural and historical context. Research grounded in sociocultural theory therefore focuses not only on individuals, but also on the interactions between them, within the broader settings in which these interactions occur. The purpose of such research is not to examine the effect of the context on the individual, but rather to explore how the processes at work in a setting or activity result in changes in the participating individuals, in the activity itself, and in the broader context in which the activity is situated. Because the significance of interaction is highlighted, a strong emphasis is placed on the mediation of these interactions by cultural tools, particularly language and representational systems, thus discourse is both the primary means by which collaboration is created and maintained, and an outcome of learning, as the novice actively learns to participate in discursive practices appropriate to the context.

Conceptual change as a description of learning has been investigated extensively through the past three decades and has provided rich accounts of both successful learning and situations where learning is more difficult. From the original model proposed by Posner, Strike, Hewson and Gertzog in 1982, many fruitful lines of research have arisen to explain both the spontaneous development of intuitive ideas about the world and the learning of more formal concepts through schooling. In relation to the latter, the conceptual change approach has been employed in a range of domains, primarily scientific domains such as physics, biology and chemistry, but also in mathematics, history and others. The ‘change’ itself has been described in a number of ways, from replacement of faulty ideas by means of instruction, through consideration of the contextual basis of conceptual meaning, to a recognition of the importance of considering social factors as influences on change. The methodologies for investigations of conceptual change have also evolved with the increasing contextualisation of meaning, with testing of factual recall of concepts gradually giving way to evaluation of problem-solving capabilities, both alone and in cooperation with others.

A considerable body of research has demonstrated that many students experience significant difficulty in learning scientific explanations for phenomena for which they have already developed robust commonsense explanations, and that even students who have completed extensive study in particular domains such as physics (eg Champagne, Klopfer & Anderson, 1980; Trowbridge & McDermott, 1980; Peters, 1981; Clement, 1982; McCloskey, 1983; Whitaker, 1983; Halloun & Hestenes, 1985) retain fundamental misconceptions about underlying principles and processes. Conceptual change as a method of learning scientific concepts has thus been employed in an attempt to describe, explain and predict how, why and when changes in conceptual understanding occur.

Any changes in conceptual understanding, and the concomitant development of greater expertise, almost inevitably involve learning to communicate using the discourses of the specific scientific discipline, which may include spoken, written and symbolic discourses (examples of the latter include mathematical and chemical symbols, equations, graphs and diagrams). Sociocultural theory therefore provides a useful framework within which to study the processes of conceptual change, through its emphasis on collaborative tool-mediated learning of social and discursive practices within a relevant context.

Sociocultural approaches to learning and development have become increasingly prominent in the educational literature (John-Steiner & Mahn, 1996; Rogoff, 1998; Valsiner, 1997a, b; Lantolf, 2000) and are beginning to make an impact on conceptual change research, which has benefited from an increasing perception of the importance of situating the process in its social context (Driver, Asoko, Leach, Mortimer & Scott, 1994; Schnotz, Vosniadou & Carretero, 1999; Limón & Mason, 2002a; Sinatra & Pintrich, 2003a; Leach & Scott, 2003, 2008; Vosniadou, 2008a). Originally described by Posner et al (1982) rather narrowly as a process occurring within the minds of individuals, and resulting in the replacement of misconceptions with scientifically accurate understanding, researchers in the past three decades have come to appreciate the potentially greater breadth of the conceptual change construct through consideration of the influence of context and the social. Of particular significance is the recognition that conceptual understanding cannot be separated from its context, and the acknowledgement that many apparent misconceptions may in fact result from a mismatch between the ways in which different individuals perceive the context. Considerable interest has focussed on exploring the difference between 'scientific' and 'commonsense' accounts of conceptual knowledge (Driver et al, 1994; John-Steiner & Mahn, 1996), and on evaluating the validity or legitimacy of these alternatives based on context (Linder, 1993). Several investigators have highlighted the critical role of language in mediating conceptual change, through its function in the making and communication of sense and meaning in different situations (Driver et al, 1994; Mortimer, 1995; Dekkers & Thijs, 1998; Kelly & Green, 1998; Greeno, Benke, Engle, Lachapelle & Wiebe, 1998; Säljö, 1999; Givry & Roth, 2006; Brown & Hammer, 2008; Inagaki & Hatano, 2008; Roth, 2008). Approaches which adopt an overtly sociocultural perspective on conceptual change have also been reported (Leach & Scott, 2003, 2008), although empirical research based on these approaches is lacking.

Research into conceptual change relating to the chemistry topic of 'Acids and bases' is relatively sparse and in general appears not to be based in any specific theory. While common misconceptions have been identified, instructional efforts directed towards change have been largely unsuccessful, leading researchers to conclude that students' ideas about acids and bases are robust and resistant to transformation (Garnett, Garnett & Hackling, 1995). Little investigation of collaborative student discourse as a means of promoting change has been reported, and little recognition has been paid to the different meanings of terminology within different contexts, in particular the different ways in which two or more domains use common words to communicate different notions and solve different types of problems. In particular, no research has been undertaken to investigate the changes in understanding of acids and bases which pharmacy students must undergo when they begin to encounter pharmacy-specific problems for which their previous 'chemistry' understanding is no longer sufficient or relevant. Thus research which focuses on conceptual change as the development of both discursive proficiency and contextual discrimination, and which is grounded in the sociocultural notions of collaboration, discourse and contextually embedded learning will be of value and significance. Research of this nature is reported in this thesis in relation to the meanings which are communicated within the chemistry and pharmacy communities by terms relating to the topic area of acids and bases, and the different types of problem-solving which are mediated by these different meanings.

Chapter 2 is divided into two major sections, and provides a review of the literature relating to both sociocultural theories and approaches to learning and development and conceptual change. In relation to the former, the contribution of Vygotsky is highlighted and his notions of the social origins of higher mental functioning which develop through mediation of socially available cultural tools are discussed as the basis for the critical concepts of collaboration, internalisation, intersubjectivity and zones of proximal development. Two different models of the interdependence of personal and social worlds, participation and internalisation, are evaluated and compared, and a means of integrating the strengths of both is discussed. Mediation of learning and development by cultural tools including language and representational signs is highlighted as a means of the socialisation of individuals into new communities of practice and discourse.

Developments in the history of conceptual change theory and research are traced in the second half of the chapter, and are divided broadly into approaches which centre on the individual either alone or as affected by context, and approaches which seek to link the individual and social more closely. The original cognitive model as proposed by Posner et al (1982) is introduced as the forerunner of later developments, which are outlined as modifications and revisions of the original approach. Within each tradition, the meaning of 'concept' is considered together with the ways in which changes in concepts are described, and with aspects which influence or shape the directions of change. Approaches which have been described as sociocultural are evaluated, and a distinction drawn between those which regard social and contextual aspects as influential variables on individuals, and those which describe an intertwining between the individual and social. An argument is presented that considerable scope exists for a more complete sociocultural approach to

conceptual change, incorporating notions of inclusive separation and transformative internalisation and externalisation (Valsiner, 1997a, 1998), which to date have not figured in conceptual change theories. Criticisms of the sociocultural perspective (eg Roth, 2008; Vosniadou, Vamvakoussi & Skopeliti, 2008) are discussed and addressed, and a small number of significant empirical studies are examined in order to highlight aspects of the role of peer collaboration in promoting or constraining conceptual change and learning in general. The chapter concludes with a review of the literature on conceptual change in the understanding of acids and bases among upper secondary and tertiary students which highlights the need for additional research, particularly research grounded in theory.

The rationale for the current research study is outlined in chapter 3, in which a general discourse model of conceptual change is developed and described. This model is grounded in sociocultural perspectives, and argues that conceptual change can be regarded as a process of cognitive socialisation whereby an individual becomes a member of a new community through appropriation of the discourse and other cultural tools specific to that community. Both the processes and outcomes of conceptual change are situated in discourse: conceptual change is evaluated through the ability to engage in appropriate discursive practices and the development of change is traced through participation in collaborative discourse and problem-solving activities. Change is perceived as proceeding through the creation of zones of proximal development as participants develop intersubjectivity (Rogoff, 1998) through coordinated and transformative internalisation and externalisation (Valsiner, 1997a, 1998) in the context of structured teaching and modeling. The interdependence of the individual and social is maintained through the use of the notion of inclusive separation (Valsiner, 1998), which posits a distinction between the individual and the context but which nevertheless retains the integrity of the sociocultural whole. Rogoff's (1998) planes of analysis approach is adopted as an analytical framework because it specifically facilitates investigation of the full sociocultural panoply through the ability to foreground specific features against the background of the remaining aspects. The chapter concludes with an outline of the research questions to be addressed in the empirical study.

The primary focus of the empirical study is an intensive investigation of a small sample of first year pharmacy students, however the availability of the entire first year cohort permitted exploration of the characteristics of the population from which the sample was drawn, and the methodology and results of this exploration are reported in chapter 4. A survey covering demographic variables, students perceptions of and attitudes towards chemistry, and prior conceptual understanding of 'Acids and bases' was administered prior to the introduction of the topic in lectures and workshops, and a similar survey (omitting the demographic and attitudinal dimensions) was administered five months after the conclusion of the topic. The purpose behind administering the surveys was threefold: to investigate the general nature of pharmacy students' conceptual understanding of acids and bases on entry to the study, to evaluate the general directions of any change which occurred during the teaching semester, and to evaluate the extent to which the sample selected for more intensive investigation was representative of the cohort. Only limited

conclusions can be drawn from the survey findings, however, because the use of surveys does not provide evidence of students' discursive proficiency.

The methodology for the intensive investigation is outlined in chapter 5. Eleven students, comprising two self-selected workshop groups, agreed to participate and were interviewed on three occasions over a period of 36 weeks in order to trace the outcomes of conceptual change, specifically their ability to engage in appropriate discourse in relation to 'Acids and bases'. The first interview, which took place before the teaching and learning sequence on the topic, established prior conceptual understanding, the second which occurred at the end of the teaching semester identified changes which appeared during the teaching period, and the third five months later after the long summer vacation elucidated those ideas which persisted. Concomitant video recording of classroom interactions was designed to illustrate the processes at work within the groups as they worked together on problems and discursive activities relating to the development of enhanced understanding and contextual discrimination, supported by structured teaching from tutors, one of whom was the researcher. Analysis of student talk within the workshops was complemented by evaluation of their non-verbal behaviours in order to build a more complex description of the group dynamics.

Chapters 6 and 7 complement each other in detailing the results of the intensive study, with chapter 6 foregrounding individual outcomes and chapter 7 foregrounding the interactional processes within the two groups. Chapter 6 traces the learning trajectories of the study participants, focusing on two major dimensions, namely the developments in their understanding of concepts with which they were familiar from chemistry but which carried different meanings in pharmacy, and their learning of novel concepts which were unique to pharmacy. Chapter 7 focuses on both verbal and non-verbal group interactions, and analyses both the quantity and nature of interactional patterns which either promoted or constrained conceptual change learning. Based on both processes and outcomes, one group is identified as the Persistent Change (PC) group, while the other is described as the Transient Change (TC) group. Chapter 6 reveals that individuals within the PC group, despite generally lower academic performance and prior understanding, demonstrated greater development of both new conceptual understanding and contextual discrimination between chemistry and pharmacy than did members of the TC group. Moreover, these developments persisted to a considerably greater extent until the final interview, whereas members of the TC group showed evidence of regression or confusion at this time. The correspondence between the persistence of change and the group of which each participant was a member was confirmed by evidence of stark differences between the group processes, behaviours and dynamics of the two groups as discussed in chapter 7, with quantitative evaluation of the types of speaking turns used within each group providing corroborating evidence of the qualitative differences between them.

The results reported in chapter 6 and 7 are drawn together in chapter 8 which begins with a discussion of the relationships of the findings to the general discourse model of conceptual change which is outlined in chapter 3. Within this discussion, an emergent situated version of the general

model is outlined which specifically describes the relationship between the processes and outcomes identified in the empirical study. The situated version highlights the significance of the nature of group interactions, culture and intersubjectivity in promoting or constraining the creation of zones of proximal development which can lead to eventual cognitive socialisation, and demonstrates the ways in which both group and individual trajectories can be shaped and channeled either towards or away from this desired outcome. The chapter continues with a consideration of the extent to which the findings can be generalised beyond the two small groups who participated, and beyond the classroom context in which the findings were generated, and implications for teaching and methodological issues are discussed together with suggested directions for future research. The concluding section of the chapter discusses the relationship of the current study to previous research on collaboration, particularly highlighting previously unreported complexities in relation to the role of friendship in establishing and maintaining group culture, and outlines the unique and significant contribution of the study to ongoing discussions in conceptual change theory and practice.

CHAPTER 2 LITERATURE REVIEW

The research discussed in this thesis is grounded in a perspective that learning is a social phenomenon which emerges through interaction between individuals engaged in collaborative action and discourse. The thesis draws together theoretical ideas from a range of literatures to create a coherent approach to the understanding of tertiary student learning of scientific concepts which underpin the profession of pharmacy. These literatures can be broadly grouped under the headings of sociocultural theory and conceptual change learning, and the theoretical model which is developed and investigated empirically is a synthesis of ideas which have arisen within these two areas.

This chapter is thus divided into two major sections and reviews the relevant literatures of these two broad research areas. The first section deals with sociocultural theories and approaches to learning and development, and outlines the key concepts and constructs which are important for the theoretical model which is proposed in chapter 3. The second section focuses on conceptual change theory and practice as it has developed historically, including the application of aspects of sociocultural theory, and identifying some of the issues which remain pertinent. The chapter concludes with a brief overview of prior research into student conceptions of 'Acids and bases', which is the specific topic investigated in the empirical study.

2.1 Sociocultural theories and approaches to learning and development

Introduction

This section introduces the major themes within sociocultural theory which are central to this thesis, and which are developed in greater detail in following sections.

Although a number of different perspectives have arisen within the field of sociocultural research (eg. Lave & Wenger, 1991; Valsiner, 1997b; Rogoff, 1998; Wells, 1999b), most acknowledge their historical source in the writings of Vygotsky and his colleagues. Wertsch (1991) and John-Steiner and Mahn (1996) have identified and summarised three essential themes or principles which underpin the sociocultural approach to learning and development as originally proposed by Vygotsky. The first is that all individual development, including the emergence of higher mental functioning, originates from social sources, with the consequence that

every function in the child's cultural development appears twice: first, on the social level, and later on the individual level; first *between* people (interspsychological), and then *inside* the child (intrapsychological)...All the higher functions originate as actual relations between human individuals (Vygotsky, 1978, p.57, author's italics).

The second theme is that human action, on both the social and individual planes, is mediated by cultural tools and signs, including but not restricted to "language; various systems of counting;

mnemonic techniques; algebraic symbol systems; works of art; writing; schemes, diagrams, maps and mechanical drawings” (Vygotsky, 1981, p. 137). These tools are not invented afresh by each individual, but are artefacts which have evolved through an historical process within particular sociocultural contexts, and their function is to mediate internalisation of social knowledge. Differential access to cultural tools has been shown to be a powerful means of directing learning and development (Rogoff & Chavajay, 1995; Nunes, 1999).

The third principle is that the first two themes are best examined through genetic, or developmental analysis, with primary attention paid to the process of learning and development in its social, cultural and historical situation, rather than to its product or outcome. Investigation of process necessarily entails the study of change in a dynamic system, and a focus on the interdependence of all aspects of learning and development, internal and external, personal and social.

These three themes, particularly the third, are encapsulated in Vygotsky’s concept of the zone of proximal development (ZPD): “the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers” (Vygotsky, 1978, p. 86). Within the ZPD, guidance or collaboration is directed towards the development of functions which are still in genesis, with more capable or experienced individuals functioning as sources of social experience and models of the use of cultural tools, for imitation and internalisation by inexperienced or less capable learners. For Vygotsky, the ZPD encapsulated his conception of the relationship between learning and development in that when learning was targeted towards processes which were not yet completely developed in an individual, organised and systematic learning could be a powerful driver of development (Kozulin, Gindis, Ageyev & Miller, 2003). He concluded that “an essential feature of learning is that it creates the zone of proximal development; that is, learning awakens a variety of internal developmental processes that are only able to operate when the child is interacting with people in his environment and in cooperation with his peers. Once these processes are internalised, they become part of the child’s independent developmental achievement” (Vygotsky, 1978, p. 90). The ZPD does not assume unidirectionality however, as the actions of more capable partners are interdependent with those of less capable peers and the setting, creating a complex dynamic system, the elements of which cannot validly be analysed in isolation. Within the ZPD, collaboration between participants is critical, but this collaboration must be characterised by shared thinking, or intersubjectivity (Rogoff, 1998; Mercer, 2000, 2004). A range of approaches to conceptualising the ZPD have been suggested, and a number are outlined in more detail in a later section.

Language is by far the most significant of the tools by which human action is mediated. Social interaction is primarily based on discourse – language-in-use – whereby individuals communicate meaning through the use of situated utterances to an audience, often in a reciprocal or collaborative fashion (Wells, 1999a). Within the ZPD, language plays a significant, although not exclusive, role in the development of shared understandings, and is also often intended by more capable partners

to be used as a model for imitation by less capable partners. From a sociocultural perspective, therefore, evidence for development and learning is to be found in discourse.

Sociocultural theories also focus on ways of describing the process of learning and development in a broader sense, and two major models have been proposed, which are described as 'participation' and 'internalisation'. A participation model posits that learning and development occur through transformation of participation in sociocultural activities (Matusov, 1998; Rogoff, 1998) while the internalisation model proposes a mechanism by which transactions occur between individual and social worlds, and suggests that learning and development are mediated by these transformative transactions (Lawrence & Valsiner, 1993; Valsiner, 1998). Although debate has often ensued between these two perspectives, discussion in a later section argues that tension between them is not inevitable.

Both participation and internalisation models are intended to describe the ways in which learners or novices become part of new communities through involvement in and eventual mastery of social activities which are characteristic of the new community. Thus the processes of socialisation or enculturation are useful in describing how an individual becomes capable of engaging in the practices of the new community, both discursive and non-discursive.

It is important to recognise that the dimensions of sociocultural theory as outlined in the preceding paragraphs are not separate and distinct, but interrelated, therefore the discussion which follows reflects this relationship.

Interdependence of personal and social worlds

As indicated above, fundamental tenets of sociocultural theory are that the individual learner cannot be viewed in isolation from the social, cultural and historical milieu in which learning and development occur, and that social and personal processes are interdependent and mutually constituting (Wells, 1999a, b). This interdependence leads to the occurrence of what Wells (1999a) describes as a "triple transformation" (p. 140) as a consequence of individuals participating jointly in situated activity: transformation of the activity or situation in which the individuals are engaged, transformation of the individuals' knowledge and ability to participate, and transformation of the cultural tools and artefacts which mediate the joint activity. The two major schools of thought identified above, the 'participation' and 'internalisation' models (Matusov, 1998), agree that the individual and social are interdependent but differ in their perceptions of "how the boundaries between self, other and dialogical unit are conceptualised" (Lightfoot and Cox, 1997, p. 7). A review of the arguments surrounding these two models is followed by description of an approach which is suggested as a means of reconciling them.

The participation model

The participation model is favoured by Rogoff and her colleagues (Rogoff, 1992, 1995, 1997, 1998; Rogoff, Baker-Sennett, Lacasa & Goldsmith, 1995; Matusov & Rogoff, 1995; Matusov, 1998), who are particularly interested in the ways by which social practices are maintained and evolve over time. The model involves the notion of an individual “participating in shared endeavours in sociocultural activity” (Rogoff, 1998, p. 689) and developing and changing as a consequence: as the individual’s understanding is transformed, he or she becomes able to play different roles within the activity. The past and future are both seen as involved in the present, which is perceived as an outworking of the former and a means of reaching the latter (Rogoff, 1997). Proponents of this view reject the separation of the individual from the social, suggesting that this creates unacceptable dualisms (Rogoff, 1992; Matusov, 1998) or boundaries (Rogoff, 1998) which undermine the holistic nature of sociocultural activity.

The internalisation model

Internalisation, or “the internal reconstruction of an external operation” (Vygotsky, 1978, p. 56), was proposed by Vygotsky as a means of describing the inherent relationship between internal and external worlds, in particular how the external was transformed to create the internal (Wertsch & Stone, 1985) and how social speech became inner speech (Vygotsky, 1986). As expressed by Leont’ev (1981) “the process of internalisation is not the transferral of an external activity to a pre-existing, internal ‘plane of consciousness’: it is the process in which this plane is formed” (p. 57). Currently the most prominent proponent of this approach is Valsiner (1997a, b, 1998, 2001), who argues in favour of the notion of internalisation and externalisation as reciprocal and transformative processes which describe the bi-directional, dynamic relationship between person and society. He contends that distinctions do exist between individuals and the context in which they are embedded (Valsiner, 1998) and that discounting these distinctions results in an unacceptable fusion of the individual and social (Valsiner & van der Veer, 1993; Lightfoot & Cox, 1997; Valsiner, 1997a; Carelli, 1998). Valsiner (1997a) argues that a focus on internalisation does not create dualisms but dualities, where the latter arise from considering the personal and social as distinct aspects of a dynamic whole. John-Steiner and Mahn (1996) suggest that “internalisation is simultaneously an individual and a social process” (p. 197) in that processes which occur in social practices and interaction are also occurring at the same time in the individual as new understanding is being co-constructed. Chang-Wells and Wells (1993) highlight both the transformative nature of internalisation and the interdependence of individual and social, and Wells (1999b) further points out that externalisation is the means by which individuals contribute to transformation of the understanding by other participants of the nature of the activities in which they are jointly involved, and also potentially to transformation of the culture or community in which the activities are embedded. The arguments proffered on both sides of the debate are briefly reviewed in the next section.

Participation and internalisation as conflicting approaches – boundaries

As suggested above, the primary disagreement between participation and internalisation approaches involves the nature of the interaction between the personal and social worlds, specifically the existence of boundaries. According to Matusov (1998), internalisation implies boundaries between the individual (psychological) and social (activity) planes, between solo and joint activity, and between past, present and future. Proponents of the participation approach (Rogoff, 1992, 1995, 1998; Matusov, 1998) argue strongly that no boundaries separate personal and social, but rather that both are aspects of the larger unit, sociocultural activity. From this perspective, personal and cultural processes are considered to be mutually constituting and therefore inseparable, and learning and development entail transformations of participation in sociocultural activities through collaborative appropriation of social practices. Joint and solo activities cannot be separated because of their mutually constitutive nature, and meaning is not only distributed between participants but across time because “the individual exists in the flow of sociocultural activities” (Matusov, 1998, p. 330). Within this approach, the role of intramental processes is less emphasised, with attention concentrated instead on the publicly accessible sphere of activity. As a consequence, development and learning are seen as processes of becoming successful participants in social practices, with internal mental processes glimpsed only through their expression in concrete action. Through the entry of new practitioners, the social practices themselves are able to undergo transformation, as the newcomers participate in novel ways that are shaped by their participation in other communities, both in the past and contemporaneously. Wells (1999b) also offers a criticism of the mechanistic nature of internalisation as involving both temporal and physical disjunction, whereby the internal is separated from the external and the external precedes the internal chronologically. To avoid these disjunctions he offers the alternative of appropriation, which is described as involving “the gradual construction on the part of the learner of actions equivalent to those manifested in the verbal and other behaviour of others” (p. 117).

Proponents of the internalisation view do not disagree that their approach implies boundaries, because they maintain that there are qualitative differences between individual and social worlds (Valsiner, 1997a) and argue that a failure to maintain the distinction between person and environment leads to the possibility of “fusional reductionism of person to cultural activity settings” (Valsiner & van der Veer, 1993, p. 54), “a social reductionism where the opposites are amalgamated” (Carelli, 1998, p. 358), and the “collapse [of] psychological development onto social contingency” (Lightfoot & Cox, 1997, p. 9). Valsiner (1997a, b, 1998) favours instead the notion of an inclusive separation between person and environment, which maintains a distinction between them without denying their dynamic interdependence. From this perspective, learning and development occur through the processes of internalisation and externalisation which are reciprocal, interdependent and transformative, and which together serve to organise and reorganise person-environment relations. The concept of internalisation has been criticised as promoting a view of the passive transmission of cultural knowledge through internal replication of the external,

however it is usually considered to be a constructive and transformative process (Lawrence and Valsiner, 1993; Wells, 1999b), particularly when considered together with its complement, externalisation. Valsiner (1997a) stresses the bi-directionality of the process, and also the qualitative differences between the personal and social worlds, thus implying the presence of some form of boundary between individual ('inside') and situation ('outside'), without specifying where the boundary is physically located. This boundary is represented as a 'zone' in which internalisation and externalisation processes are intertwined and in which personal meaning is actively constructed by means of interaction between the social and personal (Valsiner, 1997a, Fig 12.1). Bi-directionality is also implied chronologically, since Valsiner suggests that internalisation serves the dual purposes of reorganisation of existing meaning, and enablement of future learning and development. In response to the criticism that the use of internalisation creates unacceptable dualisms (Rogoff 1992; Matusov, 1998), Valsiner distinguishes between dualisms and dualities, where the former are defined as exclusive separations, that is "distinctions that have separated the parts from the whole" (Valsiner, 1998, p. 352), and the latter as distinctions between parts which are included in the whole, or inclusive separations. Thus, for Valsiner, it is not the distinction between parts which is at issue, but rather their inclusion within the system as a whole, and he contends that proponents of the no-boundaries approach view separation purely in exclusive terms. Inclusive separation also favours concepts of personal agency and the relative autonomy of the person from the environment (Valsiner, 1997a), thus permitting a theory of the development of individual differences within a sociogenetic framework (Valsiner, 1997b). Indeed, as Wells (1998) points out, the participation of distinct agentive individuals is essential for the continuing existence of communities of social practice since "without their individual purposes and material bodies – their brawn and brain – there would be no activity at all and no communities of practice" (p. 3).

Participation and internalisation as complementary approaches – planes of analysis

Proponents on both sides of the debate concur that participation in communities of practice is central to shaping the learning and development of individuals, thus it is possible that the differences between them emerge at least partially from differences in purpose and emphasis. Advocates of the participation model adhere generally to a perspective where the maintenance and evolution of social practices is of primary importance, and individual learning and development is regarded as embedded in those practices. Advocates of the internalisation approach tend to place more emphasis on the individual, and particularly on the mechanisms by which the individual becomes a member of a community. Whereas the focus of the participation model is on the development of the ability to participate successfully in social practices, internalisation focuses on semiotic mediation (Valsiner, 1997b) of the appropriation of cultural tools (Leach & Scott, 2003) which enable that successful participation in social practices. Recognition of these differences in emphasis reveals some complementarity between Valsiner's and Rogoff's arguments which is discussed below.

Valsiner's notion of inclusive separation and his model of internalisation and externalisation provide a useful approach with which to study the mechanisms of interdependence between the individual and the social world. In particular, it suggests a means by which unique individual trajectories emerge through participation in shared activities. From a sociocultural perspective, however, the role of the wider cultural and historical context is less obvious in Valsiner's work than in that of Rogoff. She has developed a highly useful framework for the study of the interdependent processes occurring in learning and development, consisting of three planes of analysis, the personal, the interpersonal and the community or institutional (Rogoff, 1992, 1995, 1997, 1998). These planes are not different levels of analysis because they are neither hierarchical nor separate from each other, but each plane focuses on particular aspects of the activity with the other aspects as a necessary and mutually constituting background. The personal plane focuses on individual activity and how participants change as a result of their engagement in the activity, the interpersonal plane focuses on the communication and coordination of activities between participants, and the community plane foregrounds the larger cultural values and practices in which the activity is embedded. The advantage of this approach is that it specifically encompasses all aspects of the sociocultural milieu, but does not require that all aspects are accorded equal weight. Further it avoids analytical over-complexity by permitting a closer scrutiny of the most pertinent aspects of the milieu without ignoring the existence of the others. Further descriptions of this approach as they relate to the research reported in this thesis are included in chapter 3. However, while this model or framework has been extensively used by Rogoff, her emphasis on social practices has resulted in a tendency to focus less on the personal plane than on the other two, and thus she does not offer an explanation of the processes leading to the development of individual differences. Wells (1998) offers a similar criticism of much sociocultural research when he comments that communities and institutions are "often treated as if they existed in a decontextualised realm in which they were independent of any particular individual's participation in them" (p. 3). Valsiner is more interested in the relationship between the personal and interpersonal planes, thus a synthesis of Rogoff's model, which provides a broad perspective, with Valsiner's more process-oriented description of internalisation and externalisation would therefore seem to offer promise in providing a more complete framework for the study of learning and development from a sociocultural perspective. An approach which suggests transformative internalisation and externalisation as mechanisms for transformation in participation is developed further in chapter 3.

The mediational role of tools and signs

Introduction

As indicated earlier, Vygotsky endorsed the notion that learning and development are mediated by the use of cultural tools and artefacts, of which Wells (1998) has distinguished three categories: "material tools and the social practices in which they are employed; representations of these tools and practices...and the imaginative representational structures in terms of which humans attempt to

understand the world and their existence in it" (p. 6). Appropriation of the cultural understandings which are represented and "encoded" (Wells, 1999a, p. 139) by tools and artefacts occurs as learners engage in activities and settings in which the artefacts are used as means of communication and joint activity (Wells, 1999a) and which "fundamentally change the nature of the task, the required processes and the actors" (Renshaw, 2003, p. 361). Wells (1999b) argues that in all of these categories, the central role in the appropriation of culture, the mediation of interactions between individuals and the communication of meaning is played by language. Hasan (2002) further argues that semiotic mediation is most importantly the means by which individuals internalise their experience of living in the world. Halliday (1993) suggests that language is the principal tool involved in learning and that the two emerge together within the developing child since it is "in learning his or her first language through conversations with others that the child takes over the culture's principal means of construing experience" (Wells, 1999a, p. 143). Language is thus simultaneously the method by which knowledge is created from experience, and the means for reflection and construction of theories and models which organise and represent knowledge (Halliday, 1993). The following sections discuss the role of mediation firstly through language and secondly by representational systems, and the significance of the communities in which these mediational systems are embedded.

Semiotic mediation

In sociocultural terms, meaning is appropriated by individuals through transformative internalisation and externalisation as a consequence of their participation in social practices using the cultural tools of the sociocultural milieu, particularly language. Semiotic mediation through language (Hasan, 2002) is therefore central to the communication of meaning and to the development of conceptual understanding. As Wertsch and Stone (1985) have pointed out, the conceptual development of an individual depends critically on the socially and historically evolved meaning systems and linguistic norms of the speech community in which that individual learns and develops. Since, however, internalisation is a transformative process, individuals within similar sociocultural contexts have the potential to construct differences in the meanings that they attach even to the same word, since each individual brings a unique personal history to the situation (Wells, 1998, 1999b). In addition, word meanings change as language evolves, both on the larger timescale of human history, and also within the development of an individual (Vygotsky, 1986).

When considering the mediational role of language it is critical to recognise that language usage must be situated within the context of ongoing dialogue or discourse, since context-free words, phrases or sentences rarely facilitate efficient communication of meaning (Wells, 1998). In relation to discourse, Bakhtin (1986) describes the significance of speech genres which are particular patterns of speaking which structure interactions in recognisable ways such that participants in discourse are able to communicate meaningfully. Halliday (1978) describes discourse as "the exchange of meanings in interpersonal contexts" (p. 2) and emphasises its reciprocal and mutually constituting nature in commenting that "the context plays a part in determining what we say; and

what we say plays a part in determining the context” (p. 3). Hicks (1995) suggests that discourse is never neutral since it is embedded in systems of values, beliefs and social practices. Dialogue and discourse are therefore the activities in which word meanings are communicated, appropriated and transformed: by engaging in discourse, participants in a sociocultural context become involved in a continual process of internalisation and externalisation of speech and thought, through which conceptual understandings and word meanings are inextricably intertwined. Further, as pointed out by Wells (1999b), discourse is dynamic, and thus is not simply an articulation of fixed knowledge or understanding, but is more appropriately described as variable and contingent “strategic moves tailored to the speaker’s assessment of the exigencies of the immediate discursive situation” (p. 105).

Discourse or dialogue of any type, in any setting, is a communicative activity, however the meaning that is actually communicated varies significantly between settings and groups of individuals. Considerable variety is observed even within the relatively narrow range of classroom settings. For example, Lemke (1990) describes the commonly encountered triadic dialogue, in which the teacher initiates an interaction by asking a question with the aim of soliciting the ‘correct’ answer from a student, and concludes with an evaluation of the student’s response. In this mode, the teacher has almost total control over the interaction, and the purpose involves checking whether student answers match those which are expected and accepted by the teacher. In contrast, Wells (1998, 1999b), borrowing from Bereiter (1994), describes a mode known as ‘progressive discourse’ that is designed to mediate collaborative knowledge construction and conceptual development. The primary characteristic of this mode of discourse is a common commitment among all participants to engage in discussions which work towards a satisfactory joint understanding, are based on an examination of evidence, expand the range of propositions, permit critical analysis of beliefs, and build on previous utterances. While any form of discourse can potentially facilitate conceptual change learning and development, both Lemke (1990) and Wells (1998, 1999a) clearly favour those which resemble more closely progressive discourse.

Representational systems

While discourse is of primary importance as a cultural and historical mediational tool, signs also play a critical role, since these are frequently representations of the ‘language’ of particular domains, and appropriation of such systems is fundamental to the process of becoming a member of the discourse community which uses them. At a basic level, written words are signs, since they are representations or images of spoken words which are used to mediate communication in a non-oral form, or to provide records of verbal speech. However other representational systems are also important as mediators of communication, including but not restricted to systems of number, equations, graphs, maps, diagrams, models, pictures, gestures, music, dance, representations of chemical structures, and commonly encountered cultural signs (eg traffic lights, company logos) (Vygotsky, 1981; Nunes, 1999; Wells, 1999a).

Nunes (1999) suggests that mediation by representational signs of both communication and learning has at least three aspects, those of enabling, restraining, and structuring, and demonstrates the striking effects on the processes of calculation which result from representing quantities by written numbers (Nunes, 1993, 1999; Nunes, Light and Mason, 1993). She concludes that representational signs play major roles in the development of mathematical reasoning, and suggests that the same is likely to be true in science, although currently there is only scant evidence to support this hypothesis. Within the domain of chemistry, a myriad of representational systems exist, many of which are dramatic over-simplifications of the phenomena which they are designed to represent, and it is very likely that their use contributes to the development of conceptual misunderstandings, by channelling students' interactions and activities in unproductive directions. However, since the effect of different representations is not a focus of the research reported in this thesis, the specific literature relating to chemical representations is not reviewed.

Socialisation into communities

One of the consequences of learning and development, whether in formal or informal situations, is that the learner is socialised or enculturated into a new community. Socialisation into a community may preferentially involve appropriation of practices and patterns of talking, or may be more targeted towards the appropriation of conceptual understanding or problem-solving. The latter case can be described as cognitive socialisation in that it is intended to develop the novice's cognitive skills or knowledge. As a term, cognitive socialisation does not appear frequently in the literature, and when it does it tends to relate to adult-child interactions. Portes, Cuentas and Zady (2000) use the term to describe how parents across two cultures scaffolded their children's cognitive development through categorisation and design tasks, while Portes and Vadeboncoeur (2002) discuss the significance of socioeconomic status as a mediator of cognitive socialisation. However the concept is also relevant to older learners and enculturation into a professional community of practice, such as that of pharmacy, in that both social practices and the more cognitive aspects of the profession need to be appropriated in order for the novice to become a practising member of the community. Cognitive socialisation is mediated primarily through discourse, although the mediational role of artefacts is also significant.

One of the characteristics of communities is that they have specialised forms of discourse which mediate effective and efficient communication among members of the community but which are often opaque to non-members. Gee (1999) differentiates between discourse (little d) and Discourse (big D) where the former refers to language as it is used and the latter to "language plus other stuff" (p. 17). The 'other stuff' to which Gee refers includes non-language aspects such as actions, interactions, beliefs and values as well as the use of language in socially appropriate ways, at appropriate times, with appropriate people, in appropriate places and using appropriate artefacts. Discourses are characteristic of communities and becoming a member of a community entails appropriation of both the discourse and Discourse such that those who are already members of the community recognise the newcomer as one of them. Individuals are always members of multiple

communities, and each community membership contributes both to the identity of the individual and to his or her emerging trajectories of participation and development.

Socialisation into a new community thus involves the development of the individual's understandings, beliefs and values, behaviours and ways of speaking, and all must coincide before the individual is recognised and accepted as an insider (Gee, 1999). However, appropriation of the characteristic discursive patterns is the primary mediational means of socialisation, because understandings, beliefs, values, and behaviours are grounded in language. Language is thus the primary mediating process by which individuals are socialised or enculturated into a culture or community and by which culture is enacted by current participants and passed on to future participants (Wells, 1999b). Halliday perceived the purpose of language as intended "to explain, within any particular cultural and linguistic community, what people can mean, and how they can use their linguistic resources to do so" (Wells, 1999b, p. 6). However, socialisation by means of semiotic mediation is not a static reproduction of the culture or community. Since each individual is shaped by a multiplicity of interactions within different cultures and communities, each is able to make a unique contribution to any activity in which he or she is involved, thus opening the potential for transformation of the activity and ultimately the social structure in which the activity is situated (Wells, 1999b).

Collaborative learning and intersubjectivity

Introduction

Socialisation or enculturation into a community is not an individual process, but always involves some form of joint action. Similarly, the sociocultural perspective on learning and development accords a central role to collaborative activity. In this section, a brief review of modes of collaboration is followed by consideration of the essential characteristic of collaborative endeavour, namely intersubjectivity or shared thinking.

Collaborative learning

Consideration of the significance of discourse, particularly progressive discourse (Wells 1998, 1999b), leads to an examination of the wider topic of collaboration in learning. Despite some diversity in emphasis, researchers who adopt sociocultural approaches to learning and development invariably highlight the centrality of collaboration, since the sociocultural approach does not consider individuals in isolation from their social milieu (eg Tudge & Rogoff, 1989; Forman & McPhail, 1993; Minick, Stone & Forman, 1993; Tudge & Winterhoff, 1993; Rogoff et al, 1995; John-Steiner & Mahn, 1996; Rogoff, 1998, 2003; Barron, 2000, 2003; Mercer, 2000, 2004; Matusov, 2001; Goos, Galbraith & Renshaw, 2002; Kaartinen & Kumpulainen, 2002; Rojas-Drummond & Mercer, 2003; Leach & Scott, 2003, 2008; Littleton & Whitelock, 2005; Rojas-Drummond, Albarran & Littleton, 2008).

Vygotsky himself introduced the notion in his articulation of the zone of proximal development (page 21), and Davydov (1995) confirms this statement in commenting that “according to Vygotsky, a teacher can intentionally bring up and teach children only through continual collaboration with them and with their social milieu” (p. 17). Rogoff (1998) describes collaboration as a format which encompasses a range of modalities, “including face-to-face mutual involvements such as routine conversation, teaching and tutoring; side-by-side engagements; and participation in shared endeavours without physical co-presence (such as occurs between correspondents, between authors and readers of articles, or in remembered conversations)” (pp. 679-680). She also identifies the quintessential characteristic of a collaborative endeavour as the presence of shared thinking, or intersubjectivity, which is described in more detail in a later section. Barron (2000) suggests that collaboration in problem-solving involves students agreeing upon common frames of reference, resolving differences in perspective and negotiating the parameters of individual and collective activity within the group. She points out that collaboration involves the coordination not only of talk, but also of non-verbal behaviours such as gestures, eye gaze, facial expressions and body positioning.

The most intensively studied type of collaboration is that which Vygotsky identified as being the most critical for learning and development, an asymmetric interaction involving the provision of guidance by an adult or more capable peer to a novice or less experienced individual. Extensive amounts of research have focussed on structured and unstructured interactions between adults (often mothers) and children, although some studies have investigated older novices. Although the focus is generally on guided appropriation by the novice of desired skills, and therefore more expert partners are generally considered best able to facilitate the process, Rogoff (1998) points out that the activities are not exclusively chosen by the experts, and that even very young children are involved in choosing and directing the choice of collaborative activities for their caregivers to engage in with them. This highlights the concept implied by a sociocultural stance that there is a mutuality and reciprocity between expert and novice in the collaborative interaction, rather than a unidirectional transfer of skills to the novice (Goos et al, 2002).

In addition to asymmetric collaborations, it is also of interest to investigate the more symmetric ways in which peers collaborate with each other in the absence of a more experienced guide, since the ways in which partners of approximately equal status and competence interact are less well characterised and likely to be different from expert/novice interactions. Pontecorvo (1993) studied the collaborative process over a three year period in classroom interactions across a number of different domains, and showed that as the classroom became more collaborative, the children were more prepared to share their reasoning and thinking aloud, and to assume a range of different and complementary roles in the discourse, adopting stances which included both agreement with and opposition to other children’s ideas. In a similar vein, Tudge and Rogoff (1989) promote the function of conflict and argument as providing opportunities for discussion of a problem and coordination of a joint solution. The critical feature of such conflict and argument is the extent to which it facilitates the entry of partners into each other’s frame of reference.

Peer collaboration where neither participant is more advanced than the other is also described in a study by Roschelle (1992), in which he identifies convergence in understanding as a result of peer collaboration. This study, which is described in greater detail in a later section of this chapter (page 43), demonstrates the potential of symmetric collaboration for promoting learning and development.

The differential impact of asymmetric and symmetric collaboration is summarised by Tudge and Rogoff (1989), who suggest that differences in the type of activities and learning can explain the observed benefits of adult and peer collaboration. "The benefits appear to vary according to the nature of the task, with peers being more useful than adults when the task primarily involves discussion of issues. Peers may provide each other with opportunities to discuss issues and to manage conversation that is less available in interaction with adults" (p. 30). They suggest that adults are better at helping learners become more skilful and knowledgeable, whereas peer interactions promote freer verbal interactions because of the absence of an authority figure, although they are cautious about the benefits of peer collaboration for children who are not old enough to verbalise their explanations.

Most collaborative learning studies have concentrated on analysing interactions in the interpersonal plane (Rogoff, 1998), although many of them could validly be considered as keeping the personal and/or community planes in the background. However, in an attempt to promote learning about the earth's shape and gravity, Sneider and Ohadi (1998) focused more explicitly on all three planes and were able to demonstrate a significant reduction in the number of misconceptions by an approach that involved students learning not only the justification for currently accepted theories, but also the reasons why other theories were rejected during the course of history. Their approach was effective since it allowed students to see how their ways of thinking were similar to those of earlier scientists, while at the same time learning why those ways of thinking did not always provide adequate explanations of other phenomena.

Adopting a description of collaboration as involving intersubjectivity allows for an expansion of the types of collaboration which are possible, including tacit/passive and regressive collaboration. Tacit collaboration involves participation in a collaborative endeavour by an individual who appears passive because of a lack of verbal contribution, but who is nonetheless engaged in intense observation or listening. Paradise (1996) draws attention to the sociocultural basis of ascribing passivity to one or more participants in an activity, and concludes that closer scrutiny of the interaction may lead to the adoption of the concept of tacit collaboration as a more appropriate description in some cases. Gallimore and Tharp (1990) concur with this approach, suggesting that not all cultures require verbal assistance within the zone of proximal development, and that a number of other modalities, including modelling, have a place in particular cultural manifestations of collaboration.

The preceding discussion has implicitly assumed that the effects of collaboration are uniformly beneficial, or at least not harmful, but this assumption cannot be justified. By reference to a small but significant number of studies, Tudge and Rogoff (1989) argue that interaction does not always lead to development, but that in some cases it can lead to regression, that is, a move from greater to lesser understanding. The crucial element appears to be which partner is the more dominant, with regression favoured when the less skilled partner is more dominant. Their work is a cautionary reminder that while intersubjectivity is crucial to the collaborative process, it should not be unequivocally equated with learning and development. The concept of intersubjectivity is discussed in the next section.

Intersubjectivity

As indicated above, Rogoff (1998) suggests that the presence of intersubjectivity (the sharing of the different 'subjectivities' of participants) is the critical characteristic of a collaborative endeavour. The development of intersubjectivity involves the development of mutual understanding between participants in an activity, usually resulting from some change in the perspective of each, in order to appreciate the perspectives of others and to communicate on common ground. These changes in perspective are thus the basis for changes in thinking and subsequent learning (Rogoff, 1998). Rogoff (1998) further points out that intersubjectivity involves more than simple turn-taking exchanges or use of the ideas of others to increase an individual's personal understanding: it requires joint construction and a blurring of the 'ownership' of particular ideas. Miller (1987) suggests that when intersubjectivity is present, "each participant's thinking becomes more and more an integrative part of what everyone else thinks in the group, and therefore neither the meaning nor the mode of construction of each participant's cognition can be explained as isolated, individual mental entities" (p. 235).

Intersubjectivity is often traced from the writing of Rommetveit, who argued that it was foundational for communication and that an understanding of its 'architecture' was critical to an understanding of how ideas are shared (Rommetveit, 1979). Intersubjectivity has been defined and described in a number of ways, all of which emphasise sharing. Rogoff (1990) defines it as "shared understanding based on a common focus of attention and some shared presuppositions that form the ground for communication" (p. 71). Bonk and Kim (1998) suggest that intersubjectivity pertains to the way in which meaning, values and understandings are shared within a group of people with the resultant construction of a temporary mutual collective reality, and Verba (1994) defines it as "the participants' belief that they are jointly attending to the same aspect of the situation in which they are involved" (p. 127). Matusov (2001) identifies three dimensions of intersubjectivity: a shared focus of attention, a coordinated "space for respectful disagreement" (p. 388), and an opportunity for "caring and practical action" (p. 393). Wells (1999b) describes intersubjectivity as arising from negotiation which involves both agreement and disagreement. Intersubjectivity is achieved primarily through discourse, however non-verbal communication such as body positioning, gaze and gesture is also critical (Kumpulainen & Wray, 2002).

The ideas of Matusov (2001) and Wells (1999b) in the previous paragraph highlight that the achievement of intersubjectivity does not require the existence of perfect agreement between the individuals, but rather that joint understanding of the task and its goals create a common ground for initiating coconstruction of a solution, and that participants enter into each other's frame of reference (Tudge & Rogoff, 1989; Mercer, 2000). Indeed, using examples from research into children's learning about states of matter, Mortimer and Wertsch (2003) point out that participants in conversation may actually resist the perspective of others, particularly when it contradicts their theories of how the world functions.

Mercer and his colleagues have developed a slightly different approach to the notion of intersubjectivity which they term 'thinking collectively' or 'interthinking' (Wegerif, Mercer & Dawes, 1999; Mercer, 2000, 2002, 2004; Rojas-Drummond & Mercer, 2003; Mercer & Littleton, 2007). This approach has much in common with intersubjectivity but differs subtly. It is similar to intersubjectivity in that interthinking emphasises joint activity and mutuality: it is defined as "the joint, coordinated intellectual activity which people regularly accomplish using language" (Mercer, 2000, p. 16) and described as the way that humans use language both to make mutual sense of experience and to change individual thought into communal thought and action. Further, it is grounded in the common knowledge of the participants, and can be created through both agreement and conflict. It differs in that intersubjectivity is generally considered as a state which arises as a result of socially mediated activity, whereas collective thinking is a process in which participants use language to create and engage in social activity (Mercer, 2000).

In summary, intersubjectivity or interthinking occur when discourse participants share meaning through the use of language supplemented by non-verbal modes of communication. On the other hand, misconceptions or conceptual misunderstandings arise when different participants differ greatly in their understanding of the meaning of particular words. This notion is further examined in the review of conceptual change literature. Achievement of intersubjectivity is critical for the creation and emergence of zones of proximal development, which are discussed in the next section.

Zone of proximal development

As suggested earlier, the concept of the zone of proximal development (ZPD) encapsulates many central aspects of the sociocultural approach. According to Valsiner and van der Veer (1993), the ZPD is significant because it is one of a very small number of ideas which can assist in conceptualising how the future emerges from the present and how development occurs in the interdependence of the personal and social. The term was introduced by Vygotsky as a descriptive metaphor in his study of children's emerging capabilities (Valsiner & van der Veer, 1993), but a full exposition of its meaning and implications was never published because of his early death (Wells, 1999b), and later researchers have since redefined and extended the concept in a variety of directions. Winegar (1988) suggests that three distinct adaptations of the ZPD concept can be identified: an assessment model which focuses on comparisons of the performance of children in

solving problems alone and with adult guidance, a learning approach which focuses on the ways that children's learning is enhanced through interactions with adults or more capable peers (Wells, 1999b), and a development model which is embedded in the more theoretical aspects of developmental psychology. The first model thus emphasises a dynamic rather than static assessment of both learning and learning potential and is classified by Wells (1999b) as the "zone defined by the difference between a child's test performances under two conditions: with or without assistance" (p. 313). The second introduces the metaphor of scaffolding (Wood, Bruner & Ross, 1976) whereby the adult supports the emergence of new capabilities in the child and can be defined as "the lower and upper bounds of the zone within which instruction should be pitched" (Wells, 1999b, p. 314). The third approach has resulted in the extension of the ZPD concept beyond Vygotsky's original formulation (Valsiner & van der Veer, 1993), and in this sense, Wells (1999b) points out that the ZPD – as it is used – is not a fixed construct, but is rather an example of a cultural tool which has been applied in a range of contexts, and which has therefore undergone considerable modification in the process. Although Vygotsky used the concept in a number of different contexts (van der Veer & Valsiner, 1991) related to the "process of construction of the future structure of the functions on the basis of the present experience of the child" (Valsiner & van der Veer, 1993, p. 44), recent research has tended to focus on the ZPD as a means of illustrating the environment within which learning and development are intended to occur.

Valsiner and van der Veer (1993) have suggested five historical advancements or extensions of Vygotsky's theories of the ZPD. They identify Wertsch's primary contribution as extending the concept to incorporate semiotic mediation of psychological functions, thus linking Vygotsky's ideas of the ZPD to internalisation (Wertsch & Stone, 1985). Cole and his colleagues emphasised the significance of the cultural activities which guide children's development through participation, and described the ZPD as a place in which culture and cognition mutually create each other (Cole, 1985). Rogoff's notion of the child as a cultural apprentice (Rogoff, 1990) whose participation in cultural activities is guided by a more capable other places the ZPD as the setting in which such guided participation occurs (Rogoff, 1995). A fourth extension is identified with a Yugoslav research tradition in which the ZPD is viewed as a useful mechanistic description of internalisation and also as a metaphor for the social resources available to a child within the learning environment. Finally, Valsiner's notion of systems which constrain or channel future learning and development is identified: the Zone of Free Movement which includes all of the possibilities for activity and development at a particular point in time, and the Zone of Promoted Actions which encompasses those activities which are selectively promoted or favoured by the context at that time (Valsiner, 1987). Similarly, Wells (1999b) has traced the development of the concept through its role in assessment and instruction to looking at the processes of semiotic medication and internalisation, and consideration of the role of the teacher and 'significant other'. The general conclusion from these descriptions is that the range of possible interpretations and applications which have been proposed have enriched the concept beyond its original formulation, particularly "by emphasising the holistic nature of the learning that takes place in the ZPD and by making clear that it involves not simply speech but a wide range of mediational means, and not simply dyads in face-to-face

interaction but all participants in collaborative communities of practice” (Wells, 1999b, p. 330). Renshaw (1998) goes even further to suggest that “the ZPD is more than a social space within which skills, strategies and knowledge are acquired. The ZPD is a space that enables communities to be established and identities to be transformed” (p. 88).

However, most researchers working with the concept of ZPD are less concerned with specifying strict definitions than in applying it. Broadly considered, the ‘modern’ ZPD is “an interactive system within which people work on a problem which at least one of them could not, alone, work on effectively” (Newman, Griffin & Cole, 1989, p. 61), and it is uniquely created in the course of each specific activity or setting (Tudge & Winterhoff, 1993). Chaiklin (2003) describes it as “an interaction on a task between a more competent person and a less competent person, such that the less competent person becomes individually proficient at what was initially a jointly accomplished task” (p. 41). Frequently the ZPD involves asymmetric collaboration between a more experienced or capable partner and a learner or group of learners (Tudge & Winterhoff, 1993), although peer collaboration can also lead to the creation of a ZPD (Roschelle, 1992; Pontecorvo, 1993; Goos et al, 2002). Its formation is characterised by the existence of intersubjectivity and semiotic mediation (Wertsch & Rogoff, 1984), and the nature of the interactions which create it relies on the unique developmental histories of the participants (Newman et al, 1989). Sociocultural mediation may be facilitated by any type of tool, however discourse usually figures most prominently in published accounts, particularly those relating to older learners, and much attention has been paid to linguistic and functional analysis of the utterances of individuals within the interaction. Newman et al (1989) suggest, however, that discourse in the ZPD is often indeterminate, with utterances serving multiple functions, and Kumpulainen and Mutanen (1999) emphasise the need to locate even functional analysis of discourse within the situated context of the interaction. Mahn and John-Steiner (2002) emphasise the importance of considering affect in the creation of a ZPD, and focus particularly on the opportunities which are available for participants to offer each other both confidence, and “mutual respect, trust and concern” (Wells, 1999b, p.333). At the same time, however, ZPDs necessarily involve the presence of “difference between the partners” (Renshaw, 1998, p. 88) since this condition creates the possibility of contest and challenge of individuals’ existing ideas or practices, without which development is not possible.

The difficulties in reaching consensus on the notion of the ZPD illustrate an important point about sociocultural theories. Within a sociocultural milieu, a concept such as the ZPD with its range of historical interpretations is unlikely to achieve a single meaning, since the meaning attributed to it by individual researchers emerges from their prior understanding. Further, as Wells (1999b) has argued, the ZPD is employed as a cultural tool by researchers in social, cultural and historical contexts other than the one in which it was developed by Vygotsky, and therefore its use in these different contexts has led to modifications relevant to the context.

Conclusion

Sociocultural theories and approaches offer an authentic basis for understanding and investigating learning and development as it occurs in both everyday and school settings. Recognition of the fundamental interconnectedness of all aspects of the sociocultural milieu focuses attention on interactions between participants in collaborative activity as mediated by cultural tools and situated in historically evolving practices. Sociocultural ideas are becoming important in a range of approaches to learning, including conceptual change, which is reviewed in the following section.

2.2 Conceptual change

Introduction

Over the past decade, a number of important publications have traced the historical development of conceptual change research both theoretically and empirically (Schnotz et al, 1999; Limón & Mason, 2002a; Sinatra & Pintrich, 2003a; Vosniadou, Baltas & Vamvakoussi, 2007; Vosniadou, 2008a). Vosniadou (2007a, 2008b) describes the foundations of conceptual change as arising from the history and philosophy of science, specifically Kuhn's (1962) description of the ways that scientific thinking has developed, and outlines how his ideas have been adopted under the notion of conceptual change in the distinct fields of developmental psychology and science education (Vosniadou 1999, 2008b; Mason, 2007). In this section, a broad review of the field is presented, focusing particularly on the development of scientific conceptual understanding through formal instruction and encompassing the major theoretical schools of thought. A brief description of the origins of conceptual change learning as an idea is followed by an outline of the classical model proposed in 1982, and developments which focus primarily on conceptual change learning as an individual phenomenon. The significance of considering social and contextual dimensions is then discussed, leading to an evaluation of the extent to which current approaches can be legitimately classified as consistent with sociocultural theories. A review of a select number of general studies of relevance to the current research is complemented by consideration of research which has been carried out on conceptual change learning within the specific chemistry topic area of acids and bases.

The origins of conceptual change theory

Together with other philosophers of science Kuhn (1962) challenged the view that scientific theories could be considered as sets of logical axioms which changed only through expansion as additional or anomalous information became available. He argued in favour of paradigms: coordinated clusters of beliefs, assumptions and practices which defined the prevailing views of science at particular points in history. From this perspective, additional information which was anomalous to the prevailing paradigm created a crisis which was resolved, not through an expansion but a revolution in thinking, or a paradigm shift. Kuhn argued that concepts were

embedded in these paradigms, and that when a paradigm shift occurred, it was accompanied by changes in these concepts. Although the concepts sometimes retained their names, they were significantly different within the new paradigm because they were “embedded in a different theory, [had] different interconnections to other concepts and [applied] to different phenomena” (Vosniadou, 2008b, p. xiv).

Science educators have traditionally viewed conceptual change as a process whereby initial student misconceptions are replaced by scientifically correct conceptions, and the analogy of the sequential revolutions in scientific thinking has been used extensively. Following a brief discussion of ideas about the nature of concepts, the next section describes the original model, which was based upon and emphasised cognitive aspects.

The nature of concepts

To understand and interpret the nature of conceptual change, it is first useful to explore the nature of ‘concept’ itself, although there is by no means general consensus on the definition (diSessa, 2008). For most of the history of conceptual change research, concepts have been regarded essentially from a cognitive perspective (alternative sociocultural approaches are described in a later section), and a number of approaches to understanding the concept of concept have been proposed, each however consistent with concepts as “abstract constructs that intervene between the biological substrate – the brain – and behaviour” (Säljö, 1999, p.83). Klausmeier (1990) described an individual’s concept of something as a mental construct, unique to that individual, consisting of organised information about the phenomenon which provided the individual with a means of discriminating between it and other phenomena. He also used the term to describe the societally accepted meaning of the word (or words) by which experts named the phenomenon. Pines (1985) defined a concept as a “package of meaning” (p. 108), invented by the individual, which provided a means of organising the individual’s world. Concepts were not regarded as static entities, but changed and developed as the individual matured (Pines, 1985; Klausmeier, 1990), and they did not function in isolation as independent entities, but were encompassed in conceptual frameworks or networks (Roth, 1990; Pines, 1985). Concepts were considered to vary across a continuum from concrete to abstract in nature (Pines, 1985; Klausmeier, 1990), and to possess different meanings when employed for different purposes and in different contexts (Pines, 1985). Concepts were represented by words, which were symbols used to name them and communicate them to others (Klausmeier, 1990), and ‘handles’ which were used to hold on to (grasp), think about and manipulate them (Pines, 1985), although it was acknowledged that the significance of a word lay not in the word itself, but in the meaning that the word conveyed. Ferrari and Elik (2003) suggest a useful definition of concepts as categories with specific sets of features and properties which are sufficient to identify members of the relevant category (diSessa & Sherin, 1998; Entwistle, 2003). Alternative approaches focus on probabilistic theories which utilise prototypes or exemplars rather than sets of features, theory-based approaches which perceive concepts in more elaborate terms than prototypes, and relational approaches which identify concepts as they are connected with other

concepts (diSessa & Sherin, 1998). Ferrari and Elik (2003) use a definition of concept as the smallest unit of thought, while diSessa (2008) defines a smaller, sub-concept element which he describes as a phenomenological primitive.

Despite the variety, concepts have generally been regarded as cognitive phenomena, and thus the early conceptual change theories focused on cognitive changes.

The classical approach

The original cognitive model of conceptual change learning, which became known as the classical approach (Vosniadou, 2007a; Vosniadou et al, 2008), was proposed by Posner et al (1982) and refined a decade later (Strike & Posner, 1992). Development of this model was stimulated by research into students' scientific misconceptions and alternative conceptions (Driver & Easley, 1978; Wandersee, Mintzes & Novak, 1994), and it aimed to provide a "well-articulated theory explaining or describing the substantive dimensions of the process by which people's central, organizing concepts change from one set of concepts to another set, incompatible with the first" (Posner et al, 1982, p. 211). The model was based on Piaget's notion of cognitive schemes which undergo progressive modification and development through the process of equilibration (Driver et al, 1994), and was based on the assumption that the way science is learned by an individual is analogous to Kuhn's description of the way scientific paradigms change during the course of history (Posner et al, 1982; Pintrich, Marx & Boyle, 1993).

The fundamental assumption behind the model was that the learner's current concepts and knowledge were critical in the acquisition of new understandings: that is, conceptual change learning occurred in the context of concepts already possessed by the learner. In some cases, these concepts were adequate to deal with new information that was presented, in which case the learning occurred by assimilation of the new material into an existing structure. In other cases, the new information was in cognitive conflict with existing concepts, and so a replacement or reorganisation of the existing basic conceptual structure was necessary, usually labelled accommodation. Most of the work on conceptual change learning focused on this latter form, although Bliss (1995) argued that both assimilation and accommodation were integral parts of the process of equilibration, and neither occurred in pure form without the other.

Posner et al (1982) focused on two aspects of accommodative conceptual change, namely the reasons behind change and the process by which it occurred. With respect to the former, they suggested that four preconditions must be fulfilled in order for change to occur. The *sine qua non* was that the learner must perceive his or her existing conceptual understanding to provide an inadequate or unsatisfactory explanation of new material which is presented, or a new situation which is encountered. This perception of inadequacy was regarded as the stimulus for exploration of alternative concepts. However, in order for a new concept to be considered as a viable alternative, it must meet the requirements of intelligibility, plausibility and fruitfulness. In other

words, the individual's existing knowledge must be sufficient to allow the learner to grasp the meaning of the new concept in some way, by identifying or constructing a coherent mental representation or theory. The new concept must also possess the potential to resolve problems which cannot be solved by the old concepts, and it must not contradict other knowledge, in particular the fundamental beliefs and assumptions of the individual. Finally, the new concept should suggest to the learner possibilities of application and extension beyond the immediate context, and should seem capable of providing adequate explanation of a wider range of phenomena and situations.

With respect to the process of change, Posner et al (1982) proposed five features associated with the individual's existing concepts which critically governed progress and direction, and which influenced the selection of a new or revised concept. These features were described collectively as the individual's conceptual ecology, and consisted of anomalies (situations where existing knowledge was inadequate), the types of analogies and metaphors with which the learner was familiar, the nature of what constituted an adequate explanation (Perkins & Simmons, 1988), fundamental beliefs about the nature of science and the world, and other existing knowledge in similar and different fields. Pintrich et al (1993) added that the idea of a conceptual ecology was based on the assumptions that concepts existed in interrelated networks and that a change in one concept would inevitably lead to the need for changes in other concepts as a result.

The stimulus to conceptual change was thus seen to be dissatisfaction with pre-existing conceptual understanding, brought about by an encounter with anomalous data. However the stimulus by itself was not sufficient to bring about conceptual change, since revision of a fundamental conceptual understanding is not a simple task, and the learner is likely to attempt other strategies to resolve the problem brought about by the anomaly. Such strategies may include attempting to assimilate the knowledge into pre-existing conceptual structures, resolving the conflict by compartmentalising the knowledge, ignoring the existence of anomalous data completely or rejecting it as erroneous or irrelevant. Alternatively, the learner may delay consideration of the anomaly, in the hope that it will make sense at a later date (Posner et al, 1982; Chinn and Brewer, 1993).

Although initially widely accepted, and utilised throughout the quarter century since its introduction (Champagne, Gunstone & Klopfer, 1985; Wang & Andre, 1991; Magnusson, Templin & Boyle, 1997; Diakidoy & Kendeou, 2001; Biemans, Deel & Simons, 2001; Palmer, 2003; Hovardas & Korfiatis, 2006; van Haften, 2007), this model of conceptual change learning was subject to criticism both by other workers and by the authors themselves in the light of further research. In a later revision of the model (Strike & Posner, 1992) several additional features were incorporated into the model although without challenging or invalidating its basic premise. These largely focused on the nature of the conceptual ecology, and on the nature and generation of misconceptions, and set out to correct a perceived over-reliance on rationality. Later developments criticised further aspects of the model including the nature of change and the processes which occur

to bring it about, and the failure to consider learner motivations and beliefs or the effect of the environment and instruction in shaping change.

Vosniadou (2007a) has recently traced these theoretical developments and has offered a re-framed approach to conceptual change in learning and instruction (Vosniadou et al, 2007) which takes account of many of these developments and which appears to have considerable contemporaneous support. She concludes that

the re-framed approach to conceptual change is a *constructivist, domain-specific* approach that avoids many of the criticisms of earlier attempts to account for the process of conceptual change with learning and development. First, the focus is not on misconceptions as unitary, faulty conceptions, but on an intricate knowledge system consisting of different domain-specific areas organised in complex *theory-like* structures. Second, a distinction is made between naïve explanations, based on everyday experience and lay culture, and those that result from learners' attempts to synthesise new, scientific information with existing knowledge...Third, this theoretical position is a constructivist one. It can explain how new information is built on existing knowledge structures and provides a comprehensive framework within which meaningful and detailed predictions can be made about the knowledge acquisition process that can guide instructional interventions...The re-framed approach to conceptual change takes into consideration *socio-cultural factors*. It does that by considering as its *primary unit of analysis* the individual participating in rich socio-cultural activities, without, however, denying that knowledge can be acquired and stored in memory in some form...Last, conceptual change is considered not as the replacement of an incorrect naïve theory with a correct one, but rather as an opening up of the conceptual space...creating the possibility of *entertaining different perspectives* and different points of view. (Vosniadou, 2007a, pp. 11-12, emphasis added)

The following sections elaborate upon the developments which have led to this re-framing, particularly but not exclusively those highlighted in the above quotation, and offer additional possibilities together with a critique of the approach as described. The discussion can be divided broadly into two parts, the first describing developments which focus primarily on the individual either alone or within specific contexts, and the second recognising the individual as part of the broader sociocultural environment.

Theoretical developments 1: Conceptual change learning as an individual phenomenon

Introduction

Most approaches to conceptual change learning continue to regard the individual as the primary unit of analysis, notwithstanding that the individual may be engaged in a particular context and influenced by a range of sociocultural factors. In this section, theoretical developments which retain the assumption of conceptual change learning as primarily an individual cognitive phenomenon are discussed in the first part, and the role of the learner in shaping conceptual change, including consideration of learner perspectives, motivations, epistemologies and belief systems is discussed in the second.

Cognitive conceptual change

Modification of the classical approach initially involved a critique of its underlying assumptions, and subsequently a reconsideration of the nature of concepts, and thus of the ways in which they could be perceived as changing. The following section outlines the initial challenges to the model, followed by developments and issues relating to the understanding of the nature of concepts and conceptual content.

Challenges to the metaphor of paradigm shift

One of the earliest challenges to the classical approach revolved around its assumption that science learning by an individual could be regarded as corresponding to the development of scientific paradigms during the course of history (Posner et al, 1982; Pintrich et al, 1993; Tyson, Venville, Harrison & Treagust, 1997). Duschl and Gitomer (1991) argued that the latter process was somewhat unpredictable, with aims, theory and methodology changing at different rates and in different ways, rather than the smooth and rational process implied by Posner et al (1982). Basing their argument on an analysis of the way science progressed, and also on the perceived lack of success in actually achieving conceptual change learning, Duschl and Gitomer (1991) argued for a piecemeal, rather than holistic, process of conceptual restructuring. They suggested that simply presenting new concepts, without addressing the procedural knowledge necessary to evaluate theories and evidence, was unlikely to be successful. On the other hand, learning how theories in science were generated, revised, altered and replaced could provide students with a model of how changes might occur in their own thinking. Implicit in this model was the assumption that learning science should be less about embracing science knowledge and more about positioning learners to take the next step in their own learning.

Caravita and Halldén (1994) additionally challenged the metaphor of the science learner as a scientist. They pointed out critical differences between the two in terms of freedom of choice of material to be studied or learned, willingness to offer explanations in the case of uncertainty, attitude towards failures or setbacks, and attitudes towards the role of peers. Further, they argued against the learner's awareness of cognitive conflict as the stimulus for conceptual change, but instead asserted that cognitive conflict was often not even recognised consciously until it had been resolved. Their arguments were persuasive, and most contemporary researchers would agree that the paradigm shift metaphor of conceptual change learning is neither helpful nor valid.

Derivative theories and models

The appropriateness of the metaphor was not the only aspect of the original approach which was challenged. Demastes, Good and Peebles (1996) expressed significant concerns about the extent to which Posner et al's (1982) model had been applied. They argued that it had by that stage, fourteen years after its appearance, reached a stage in its evolution where it had been applied beyond its

validity and that it needed to be compressed into its bounds of applicability. They concurred with Posner et al's (1982) original claim that the model was only intended to be applied to major conceptual change learning, but they further suggested that it was too narrow to encompass all ways in which even major conceptions underwent change. From their observations, Demastes et al (1996) proposed four patterns of conceptual change which addressed this last issue: cascade change where change in one basic component of the conceptual ecology resulted in a cascade of changes in related concepts; wholesale change where a fundamental prior conception was completely discarded and replaced by a new one; incremental change where a new concept was initially assimilated and then gradually accommodated; and dual constructions where two mutually incompatible conceptions were held by the same individual, possibly because the learner was unaware of any cognitive conflict. They claimed that incremental change and dual constructions were outside the scope of Posner et al's (1982) model, and suggested that individual students would exhibit different patterns of change on different occasions. The work of Demastes et al (1996) presaged both the focus on mechanisms of change and the notion of contextual discrimination which are addressed further in later sections.

The structure of concepts: 'theory-like' or 'knowledge in pieces'

As indicated earlier, Vosniadou (2007a) suggested that a re-framed approach to conceptual change learning involves "an intricate knowledge system consisting of different domain-specific areas organised in complex theory-like structures" (p. 11). However, in a more recent review of the current state of conceptual change research (Vosniadou, 2008b) she suggests that the question of whether students' conceptions are best described as 'theory-like' or 'knowledge in pieces' remains a critical issue. diSessa (2008) concurs, describing it as ironic that consensus should still not have been achieved about such a central issue as the fundamental nature of concepts within a research tradition that focuses on their change.

Most conceptual change researchers have tended to adopt the theory-like approach, either explicitly or implicitly, where theory is defined as "a structure consisting of a relatively coherent body of domain-specific knowledge that is characterised by a distinct ontology and a causality and can give rise to prediction and explanation" (Vosniadou, 2008b, p. xv). A theory-like approach has been adopted to explain the conceptual change learning observed in physics (eg. McCloskey, 1983), biology (eg. Carey, 1991, 1999; Carey and Spelke, 1994; Inagaki & Hatano, 2008) and astronomy (eg. Vosniadou & Brewer, 1992, 1994; Vosniadou, 1994, 2002, 2008b) among many other examples.

As a prominent proponent of the theory-like approach, Vosniadou (1994) draws a distinction between specific theories and the larger framework theories that underpin them. Central to the notion of framework theories is that knowledge, particularly naïve knowledge, is not fragmented, but organised in coherent and relatively stable patterns which are based on and constantly confirmed by everyday experiences in the world (Vosniadou et al, 2008). These naïve framework

theories are resistant to change because they provide robust explanations and predictions of observable phenomena, and contrast significantly with the often counter-intuitive concepts embedded in the different explanatory frameworks suggested by science. Naïve frameworks are thus regarded as a source of persistent misconceptions, and a range of instructional approaches have been designed with the aim of restructuring and changing them into the more accepted scientific versions. Specific theories, on the other hand, are sets of beliefs about the behaviour of specific physical objects, which are less resistant to change because they are not grounded in fundamental presuppositions which provide a relatively coherent explanatory system for everyday experience. Change in framework theories usually proceeds in gradual stages rather than as an abrupt abandonment of prior convictions (Vosniadou & Brewer, 1992, 1994; Blown & Bryce, 2006; Vosniadou et al, 2008; Inagaki & Hatano, 2008), and often includes intermediate stages of incomplete change which Vosniadou (1994) describes as the formation of synthetic mental models. Change can occur either through ‘instruction-induced conceptual change’ (Vosniadou et al, 2008; Inagaki & Hatano, 2008) or the more spontaneous conceptual change which accompanies children’s natural learning and development as they grow older (Vosniadou, 2008b).

An opposite approach is, however, proposed and cogently argued by diSessa (1988, 1993, 2006, 2008) who favours a ‘knowledge-in-pieces’ approach. In essence, diSessa considers that there are significant weaknesses and omissions in the theory-like approach which can be plausibly addressed by considering knowledge as a collection of a large number of elements at a sub-conceptual grain size, “smaller and more numerous than scientific concepts” (diSessa, 2008, p. 38). These elements were originally described as phenomenological primitives or p-prims (diSessa, 1993), and are regarded as being recognised, cued and activated in particular circumstances to create identifiable relational structures, or concepts, which pertain to those circumstances. Thus the genesis of misconceptions is construed as the assembly of inappropriate relations between elements which in themselves are not incorrect or invalid (diSessa, 1988, 2008). From this perspective, concepts can also be deconstructed into their constituent elements, which has the dual advantages of illuminating the processes by which the concept emerges and suggesting instructional approaches which can guide students towards structural relationships which create more accurate scientific concepts.

Some attempts have been made to reconcile these different perspectives, although consensus is not readily apparent. Basing their evaluation on a reinterpretation of diSessa’s p-prims, Vosniadou et al (2008) have suggested that their framework theory approach is not inconsistent with diSessa’s knowledge in pieces, although diSessa (2008) generally considers that the two approaches are mutually exclusive. Taber (2008) takes an inclusive approach in arguing that frameworks and knowledge-in-pieces are both part of the “‘apparatus’ of an individual’s cognitive structure” (p. 1035) in that students use well-developed conceptual frameworks when these are available in a particular context, but that they generate explanations *in situ* when no pre-existing framework is present. Brown and Hammer (2008) have proposed a complex systems approach which they regard as able to draw together both framework theory and knowledge in pieces approaches such that “the differences in diSessa’s and Vosniadou’s models mostly disappear” (p. 135), and they further argue

that this approach is consistent with discourse perspectives on conceptual change learning. However description and application of this complex systems approach has been restricted to the domain of physics, and further discussion in the literature would therefore be necessary in order to explore its more general utility.

Types of concept

In addition to debate about the nature of concepts as either elements or complex structures, White (1994) and Tyson et al (1997) suggested that different types of concepts exist, and that some types are more likely than others to lead to the development of strongly held naïve conceptions which resist change. Lawson (1994) defined two distinct types of scientific concepts, namely descriptive concepts and theoretical concepts, where the former possessed characteristics which were open to observation, and the latter could not be directly perceived.

The most prominent proponent of this approach is Chi, who with her colleagues (Chi, Slotta & de Leeuw, 1994; Chi & Roscoe, 2002; Chi, 2005, 2008) argues in favour of three primary types of concept, and categorisation as a mechanism for learning. All concepts were originally considered as belonging to one of three ontological categories: matter, processes or mental states (Chi et al, 1994), although these have been subsequently revised to entities, processes and mental states (Chi, 2008). Within each category, subcategories are arranged in a hierarchical manner to form a set of three distinct “trees”. From this perspective, assigning a concept to a particular category allows a student to make inferences about the concept beyond the immediately observable: for example, categorising a robin as a bird infers the property that robins lay eggs because birds lay eggs. Further, the meaning of a concept is determined by the category to which it is assigned, and conceptual change is the process of reassignment of the concept from one category or subcategory to another. Major conceptual change occurs when a concept moves from one category to another (eg from matter to processes), and minor conceptual change occurs when the move is only at the level of subcategory (eg from one type of matter to another).

Later work has refined and developed these ideas, and proposed reasons for the differential robustness of misconceptions, some of which appear to be relatively easy to change and others very resistant. Chi (2008) identifies three grain sizes of misconceptions: false beliefs, flawed mental models and miscategorisation, and suggests that the third is the most resistant to change. False beliefs are described as relatively straightforward errors, for example believing that the heart is responsible for oxygenating blood or that all blood vessels have valves. These beliefs are regarded as the easiest to change through refutational instruction (Guzzetti, Snyder, Glass & Gamas, 1993; Chi & Roscoe, 2002). Flawed mental models are described as organised collections of beliefs about a phenomenon which are coherent but incorrect (Chi, 2008), and which lead to consistent but invalid explanations or predictions. Examples of flawed mental models include a single-loop model of the circulatory system in place of the physiologically correct double-loop (Chi & Roscoe, 2002) and the synthetic mental models of the earth described by Vosniadou and Brewer (1992, 1994).

These models could be successfully transformed but the transformation requires the revision of multiple beliefs, and potentially involves extended periods of time, depending on the relative prevalence of correct and incorrect beliefs that comprise the model. Correction of the miscategorisation of concepts, on the other hand, requires the learner to shift the concept from an inappropriate category to the correct one, with a concomitant and difficult reassignment of the properties of that concept. For example, two commonly encountered and strongly persistent misconceptions in physics arise because students frequently categorise force and heat as entities, when they are in reality processes. Chi (2008) argues that these concepts are resistant to change because the different categories are characterised by mutually exclusive properties (for example entities are composed of substances whereas processes occur) and a shift between two categories requires the learner to revise the fundamental assignment of these properties, many of which have been built up intuitively from observations of the world and from everyday conversations.

The role of the learner

In parallel with the criticisms of cognitive dimensions of the classical approach, researchers also suggested that the approach was over-reliant on rationality in that it ignored the role of the learner in his or her own learning (Strike & Posner, 1992; Pintrich et al, 1993). This section outlines aspects of that role which have been suggested as important in shaping conceptual change learning in science education. A consideration of the learner's perspective on ideas that are labelled misconceptions is followed by discussion of motivational and epistemological issues, culminating in a brief overview of the notion of intentional conceptual change.

The learner's perspective on concept meaning

Two implicit assumptions underlying approaches to conceptual change learning that focused on the cognitive were identified by researchers who used the learner's prior conceptions, rather than accepted scientific concepts, as a starting point. Firstly, it was generally assumed that naïve concepts about scientific phenomena, which were often labelled 'misconceptions', were primarily constraints to learning the correct version (Vosniadou, 2008b) because students attributed 'incorrect' meanings. Secondly, it was assumed that learners placed intrinsic value and importance on the scientifically acceptable explanation. However, these assumptions have been seriously challenged by researchers who have approached the area of conceptual change learning from the perspective of the learner.

Dekkers and Thijs (1998) developed an argument against the validity of the first implicit assumption in their investigation of learners' prior conceptions. They suggested that use of the term 'misconception' and a concomitant focus on the negative aspects of prior knowledge was counterproductive for the promotion of conceptual change learning. Instead they suggested that a more fruitful approach was to attempt to ascertain meaning from the learner's perspective. Using as examples the terms 'motion' and 'force', they demonstrated that when learners used a word which had a particular scientific meaning, they were actually referring to a different concept or

phenomenon from that to which the word applied in the scientific context. The novelty of this approach was that it concentrated on what the learner meant by use of a word, rather than attributing to the learner an erroneous conceptual understanding based on the scientific meaning. They suggested that attempts to provoke cognitive conflict were often likely to be unsuccessful, since the learner did not necessarily attribute the same meaning as the teacher, and data which was anomalous from the teacher's perspective may have been consistent with the learner's understanding. Indeed, some learners may not even have recognised that competing concepts existed, because "students do not feel a need to differentiate between concepts in the same way that scientists would" (p. 42). As a consequence they argued that conceptual change teaching should be targeted towards ascertaining what the learner meant when using a term and developing that meaning in appropriate and productive directions.

A similar argument was presented from the knowledge in pieces perspective by Smith, diSessa and Roschelle (1994), who concurred with the view that misconceptions were more than simply mistakes to be corrected, and suggested that they were frequently inappropriate collections of otherwise productive knowledge elements. Conceptual change learning was therefore described as a process of "knowledge refinement" in which "old ideas can combine (and recombine) in diverse ways with other old ideas and new ideas learned from instruction" (p. 147).

The views of Cobern (1996) were perhaps the most critical of the rationality of the classical conceptual change model. He suggested that it oversimplified the issues in disregarding the learner's value system which may not have included scientific modes of explanation and thinking. Moreover, he suggested that the philosophy behind the model was that of the superiority of scientific ways of viewing phenomena over other ways, a proposition which was not universally accepted, and he foregrounded the importance of an individual's worldview in providing a lens through which all concepts, scientific or otherwise, are viewed. Cobern criticised science education as being overly concerned with teaching science knowledge rather than scientific understanding, and assuming that understanding would automatically follow once the knowledge was acquired. Quoting Burbules and Linn (1991) he surmised that:

Students rarely see a relationship between the science they learn in school and the science problems they encounter in everyday life. This narrowness is attributable not only to the generally recognised difficulty of transferring knowledge from one domain to another, but also to an active belief on the part of the students that 'school knowledge' represents a distinct and special category of learning, separate from the commonsense solutions they develop in real-life contexts (p. 588).

He concluded that in order for science learning to be regarded as relevant, educators therefore needed to take account of the underlying assumptions of learners about the functioning and behaviour of the world. Pintrich (1999) expanded upon this conclusion, and suggested that the goal orientations, epistemic beliefs, values, interests, and self-efficacies of learners all played their parts in facilitating or hindering conceptual change learning. Sinatra and Mason (2008) concurred, and added the importance of affect and emotion. These ideas are addressed in the following sections.

Motivational factors

In a significant contribution to the conceptual change literature, Pintrich et al (1993) highlighted the hazards of assuming that learning was solely a rational or 'cold' process, and suggested that conceptual change learning was hindered or enhanced by "personal, motivational, social and historical processes" (p. 170). While acknowledging that a purely cognitive model might be sufficient in controlled experimental settings, they advocated a classroom-based investigational approach which incorporated both student motivational beliefs and the influence of classroom context on both cognition and motivation as important for explaining why conceptual change learning was differentially achieved.

They identified two general motivational factors as potential mediators of the process of conceptual change learning and as a framework for selection of particular cognitive and metacognitive strategies, namely the learner's reasons for choosing to do a task, and beliefs about performance of the task. The former included aspects such as learning and social goals, the perceived importance of the task and level of interest in it, and the latter included beliefs about ability and capacity to perform the task (self-efficacy), and about the level of control that could be exercised over behaviour or outcomes of performance.

Learning goals were perceived as influential on the extent and quality of conceptual change learning in that students who adopted a mastery approach were more likely to engage at a deeper level with academic tasks than those who adopted a performance approach (Pintrich, 1999). Social goals within the classroom context were also important, in that a desire to impress others, or to make or maintain friendships could impact upon levels of engagement with the material to be learned. The importance of the task itself was related to its utility value for the student and the extent to which the student was interested in the material (Andre & Windschitl, 2003). Self-efficacy was construed as providing either affordances or constraints to conceptual change learning, and control beliefs were suggested as a mediator of intentional learning (Bereiter, 1990). Pintrich et al (1993) also pointed out that not only were these individual factors important in themselves, but that interactions between them also contributed to the conditions which either favoured or hindered conceptual change learning. They suggested that future work needed to take these aspects into account in both investigating conceptual change learning and designing environments in which it might be promoted. Later research has concurred with this conclusion and motivational factors have been incorporated into the work of a number of conceptual change researchers (eg. Schnotz et al, 1999; Limón & Mason, 2002a; Linnenbrink & Pintrich, 2002, 2003; Andre and Windschitl, 2003; Sinatra & Pintrich, 2003a; Sinatra, 2005; Vosniadou, 2008a; Murphy & Alexander, 2008; Sinatra & Mason, 2008).

Sinatra and Mason (2008) suggest that affect and emotion are also expected to play a role in promoting or constraining conceptual change learning, but indicate that the complexity of the

constructs themselves result in complicated relationships, with positive and negative affect able to act as either affordances or constraints under different circumstances.

Epistemic motivation, beliefs and conceptual change

As defined by Sinatra and Mason (2008), epistemic motivation “refers to motivations that are not focused on the self but rather on knowledge as an object” (p. 565), while Vosniadou (2007b) and Murphy, Alexander, Greene and Edwards (2007) propose that the term ‘epistemic beliefs’ be used “to denote individuals’ beliefs about knowledge” (Vosniadou, 2007b, p. 99, Hofer & Pintrich, 1997). Both notions therefore draw attention to the learner’s beliefs about and attitudes towards the nature of knowledge, and thus to the ways in which these beliefs might facilitate or constrain change. A disposition of active open-mindedness in thinking is regarded as likely to lead to acceptance of new and sometimes counter-intuitive ideas, and students who believe that knowledge is simple, certain, static and handed down by authorities are less likely to undergo conceptual change than students who hold beliefs about knowledge as complex, uncertain, evolving and derived from reason (Qian & Alvermann, 1995; Windschitl & Andre, 1998; Mason, 2000, 2003; Mason & Gava, 2007; Sinatra & Mason, 2008).

Intentional conceptual change

Consideration of the preceding ideas together with Bereiter’s notion of the intentional learner (Bereiter & Scardamalia, 1989) led to the emergence of the notion of intentional conceptual change as a means of exploring the active intentions of the learner in shaping conceptual change learning (Sinatra & Pintrich, 2003a). In contrast to unintentional conceptual change which occurs without the active volition of the learner, intentional conceptual change is regarded as being under the control of a goal-directed learner and involving “conscious initiation and regulation of cognitive, metacognitive and motivational processes” (Sinatra & Pintrich, 2003b, p. 6). Linnenbrink and Pintrich (2003) and Limón (2003) suggest that three prerequisites are necessary before intentional conceptual change is possible. Firstly, the learner needs the metacognitive awareness that a need to change exists, and of what change is necessary. Secondly, the learner needs the volition to change, in that change is directed towards a desired personal goal, and thirdly the learner needs to possess the ability to self-regulate the change process through planning, monitoring and evaluation of their progress. Conceptual change learning can and does take place in the absence of intention (Vosniadou, 2003) but a number of studies have demonstrated that a conscious intention to learn improves the likelihood (Andre & Windschitl, 2003; Hatano & Inagaki, 2003; Hennessey, 2003; Mason, 2003).

Summary

Approaches which focus on individual cognition and those which incorporate the role of the learner have elucidated many critical aspects of the process of conceptual change and provided a rich

description of the multiple ways in which learning through conceptual change can be considered. Although considerable diversity remains on many issues, the significance of the learner as an individual is not in dispute. However, the individual is not isolated from the context in which learning occurs. The following section outlines the ways in which context has been described in relation to concepts and conceptual change, particularly with respect to the need for replacement of 'misconceptions'.

Theoretical developments 2: The significance of context for conceptual meaning

The identification of dual constructions by Demastes et al (1996) highlighted an emerging theme that learning need not necessarily entail replacement of an old concept by a new one, and Tyson et al (1997) argued that strongly held prior conceptions were more frequently retained, at least in some fashion, than completely extinguished. Taber (2000, 2001) demonstrated the existence of multiple overlapping coherent scientific frameworks relating to chemical bonding which helped to make sense of the concept for a college student over a two year instructional period. Linder (1993) argued that the critical element was context, and suggested that "conceptual change depiction of learning should be extended to include conceptual fitting based on context" (p. 293). In other words, learners have at their disposal a range of alternatives, and the validity or legitimacy of any one alternative is governed by the context in which it is applied. Even within the domain of science, alternative conceptions are sometimes necessary, since light can be regarded as behaving either as particles or waves, depending on the context. Linder (1993) described the range of alternatives as conceptual dispersion, and suggested that teaching should focus on assisting learners to develop the discernment necessary to apply the appropriate element from this dispersion in any given context. The equivalent term used by Spada (1994) was "multiple mental representations", and he also described learning as development of the ability to discriminate between complementary conceptions which are applicable to separate contexts.

Driver et al (1994) described a similar perspective using the term "parallel conceptual schemes" and introduced the notion of a conceptual profile including both scientific and commonsense explanations of phenomena. Commonsense explanations are regarded as valid in a particular context if they are adequate for interpretation of the phenomenon within everyday culture, and for guiding action. The notion of conceptual profile was further developed by Mortimer (1995) who suggested that there are two critical stages in the learning process, namely the acquisition of a new element in the conceptual profile, and the achievement of consciousness by the learner of his or her own profile. Mortimer thus explicitly outlined the contribution of metacognitive processes to the modification of conceptual comprehension, with cognitive conflict perceived as providing the necessary stimulus to both of these stages.

Current researchers have recognised the significant role of context in the investigation of conceptual change, and would acknowledge that non-scientific explanations using everyday

language are not necessarily counter-productive provided that they are used in appropriate contexts. However the approaches described in this section have traditionally regarded context as an external factor which influences individual behaviour, for example “a context is a frame that surrounds the event being examined and provides resources for its appropriate interpretation” (Halldén, 1999, p. 63). Thus although the role of context has been endorsed, further theoretical considerations are necessary in order to describe a sociocultural approach to concepts and conceptual change. Earlier sections of this chapter have outlined the sociocultural notions of semiotic mediation and the interdependence of the individual and social, and these are discussed in the next section in relation to science learning and conceptual change.

Theoretical developments 3: Towards a sociocultural approach

Introduction

Approaches to science learning which are grounded in sociocultural perspectives have been proposed by a number of authors but a succinct summary was expressed by Lemke (2001) who suggested that a sociocultural perspective involves “viewing science, science education, and research on science education as human social activities conducted within institutional and cultural frameworks” (p. 296). He argued that all aspects of the sociocultural milieu at all scales of analysis are significant: social interactions between individuals which are embedded in larger scale communities and institutions, cultural sense-making tools which characterise these communities and institutions, and all forms of human activity and time scales. Human activity is semiotically mediated by cultural tools, primarily language-in-action, but also systems such as visual and mathematical representations. Critically, he foregrounds the functions of language rather than its linguistic or grammatical aspects (Lemke, 1990), such that it is perceived as a culturally situated means of mediating interaction and sharing meaning among members of a particular community (Gee, 1990). The key concept described by Lemke is ‘talking science’ (Lemke, 1990), a process of discursive socialisation involving the use of extended talk among learners and teachers in which scientific ideas and relationships can be communicated and developed. Roth also used the notion of talking science as a means of learning science (Roth, 2005), and further introduced the perspective of discursive psychology (Roth, 2008) which focuses to an even greater extent on talk as both the “context/terrain and tool of human activity” (p. 35) in that it “not only establishes and maintains the topic, but also establishes and maintains the activity in which participants talk about a particular topic” (p. 35).

Focusing more directly on conceptual change, a significant point made by Mortimer (1995) is the role of language in mediating the way individuals move between everyday and scientific domains, and the necessary use of the language of everyday life even in a scientific context. Thus, semiotic mediation through discourse is critical for the development of a sociocultural approach to conceptual change learning and is discussed in the next section. This discussion is followed by an outline and critique of particular conceptual change approaches which have been described as

sociocultural, some validly, and others which are more appropriately termed social influence (the notion of social influence is discussed in this later section). Significantly, these approaches are all characterised by a focus on theory, and the lack of empirical research in support of theory was an important stimulus for the research which is described in this thesis. Finally the role of collaboration in conceptual change learning is briefly considered.

Conceptual change learning and semiotic mediation through discourse

As described previously, within the cognitive tradition, general consensus exists that concepts are essentially mental constructs located within the minds of individuals, however consideration of conceptual change as semiotically mediated requires a reconceptualisation of the nature of concepts. Säljö (1999) argues that concepts are more appropriately viewed as discursive phenomena, and as semiotic tools for making and communicating sense and meaning between individuals and within communities. Concepts are not described as constructs, patterns or representations unique to an individual, but rather as “repositories of human sense-making capacities and activities” (p. 81) which represent “modes of understanding reality, communicative traditions and social practices that have evolved over long periods of time” (p. 90). Givry and Roth (2006) define conceptions from a sociocultural perspective as “publicly displayed forms of meaning-making talk” (p. 1087). Roth (2008) particularly criticises the mentalist notion of concepts, rejecting any attempts to construct models which are “inside a person’s head” (p. 37) and therefore invisible, and suggesting that conceptual understanding is best viewed as an emergent phenomenon which becomes publicly available through talk. These are critical distinctions, since they portray conceptual knowledge as socially distributed rather than located in individual minds. Conceptual change learning then becomes less a matter of learning new pieces of knowledge and incorporating them into an individual’s mental model than a process whereby “individuals are socialised into patterns of thinking, and into the concrete practices that go along with these patterns, which provide them with perspectives and resources that have been cultivated by others and that are made for action in specialised settings” (Säljö, 1999, p. 90). This socialisation occurs through learning to participate with increasing expertise in those discursive practices characteristic of particular institutions or communities as individuals engage in coordinated patterns of speaking. Foundations of this approach are found in Driver et al (1994) who point out that individual understanding is constructed through talk and activity such that “making meaning is thus a dialogic process involving persons-in-conversation, and learning is seen as the process by which individuals are introduced to a culture by more skilled members” (p. 7). Discourse is also highlighted by Inagaki and Hatano (2008) who suggest that conceptual change learning can be enhanced by group discussions and interactions, where the availability of a range of perspectives can lead to the recognition of inconsistencies or conflicts in understanding, and generation of possible solutions.

As indicated in an earlier section of this chapter, sociocultural theories are traced back to the writings of Vygotsky, and thus it is important to consider his approach to the development of conceptual understanding. According to Karpov and Haywood (1998), Vygotsky perceived

important differences between concepts developed spontaneously by children as they experienced the world and scientific concepts which were formally taught in schools. The former resulted from “generalisation and internalisation of everyday personal experiences” (p. 28), whereas the latter involved the internalisation of notions derived from the generalisation of the experiences of humanity through history. Vygotsky argued strongly against the principle that children should be required to learn science by rediscovering those explanatory laws which had already been discovered, and accorded primary significance to “initial verbal definition” (Vygotsky, 1986, p. 148) in promoting the development of scientific concepts. Thus the foundations of a Vygotskian sociocultural approach to the learning of scientific concepts involves the initial modeling of appropriate ways of articulating those concepts within the relevant scientific community as a resource for transformative internalisation and externalisation by learners.

Sociocultural and social influence approaches

Preceding discussions about the role of the individual and context in conceptual change learning have identified critical and important features of the process, and sociocultural approaches do not seek to contradict all of these notions directly. What sociocultural theory provides is the capacity to analyse the individual and social in dynamic intertwined interaction, rather than as independent influences upon each other. Further, the unit of analysis is not regarded as the individual as was common in cognitive approaches, nor “the individual participating in rich socio-cultural activities” as suggested in Vosniadou’s reframing (Vosniadou, 2007a, p. 12), but is broadened to encompass a range of ideas based on either aspects of the sociocultural milieu, or discursive practices.

A number of researchers have proposed approaches to conceptual change learning which are consistent with sociocultural principles. Kelly and Green (1998) articulate as a theoretical framework a set of premises involving the use of cultural tools (including discourse), socially distributed and constructed meaning, and participation in culturally valued practices on the basis of which conceptual change can be evaluated. The framework, however, makes no reference to mechanisms or processes of conceptual change and therefore is problematic in its application. Sociocultural approaches to learning, including by means of conceptual change, have also been proposed by Säljö and his co-workers (Bliss & Säljö, 1999; Wyndham & Säljö, 1999; Ivarsson, Schoultz & Säljö, 2002). In relation to conceptual change, their specific focus is on use of physical tools rather than discourse (Ivarsson et al, 2002) and they regard “cognition as the use of tools” (p. 85) which are appropriated through engagement in social and cultural practices. Their framework is clearly consonant with sociocultural theory, however the mechanism of tool use appropriation is not clarified and it is unclear how individual conceptual change emerges from situated tool use. Further, empirical research based upon these approaches is lacking and it is therefore difficult to evaluate the applicability of these theoretical sociocultural frameworks.

However, much of the recent research into conceptual change, particularly in the domains of science learning, focuses on context in such a manner as to meet the criterion of social influence

rather than sociocultural. Social influence approaches (Guzzetti, 1998; Pozo, Gómez & Sanz, 1999; Halldén, 1999; Pintrich, 1999; Vosniadou, 1999, 2003; Limón & Mason, 2002b; Pintrich & Sinatra, 2003) treat context as an independent variable which exerts an influence on the individual (dependent variable), whereas the sociocultural perspective emphasises their interdependence and mutual co-constitution. Within sociocultural approaches the individual and the context remain distinct but are inclusively separated (Valsiner, 1998) and develop by coevolution.

That a social influence approach underpins the majority of contextually situated approaches to conceptual change learning is indicated by the expressions used in their theoretical formulations. In the following examples, the italics are added to highlight the critical wording.

Limón and Mason (2002b) claimed that “the social and cultural nature of the *contexts* in which the change of individuals’ conceptions is desired to occur seems to *play an essential role*” (p. xv). Pozo et al (1999) focused on “the contextual *variables* that *influence* the activation pattern of both alternate and scientific theories” (p. 163). Vosniadou (1999) suggested that “a theory of conceptual change learning needs to provide a description of the internal representations and processes that go on during cognitive activity, but should also try to relate them to external, situational *variables* that *influence* them.” (p. 11). Later, she suggested that “a full theory of conceptual change needs to provide information about the following four *variables*” which included “the educational settings in which science education takes place” and “the broader social and cultural environments in which students live and learn” (Vosniadou, 2003, p. 380). Halldén (1999) favoured the definition of context as a “*frame* that surrounds the event being examined and provides *resources* for its appropriate interpretation” (p. 63). In his account of the relationship between motivation and conceptual change, Pintrich (1999) referred to “classroom *contextual factors*” and commented that “the development and activation of different goal orientations is assumed to be situated in the classroom context and *influenced by features* of the context” (p. 35). Pintrich and Sinatra (2003) concluded that “intentional conceptual change is directed by individual personal goals and regulated by an individual’s strategies and actions. This suggests a fairly individual and internal psychological model of intentional conceptual change. At the same time, it seems clear that *contextual factors* cannot be ignored in our models” (p. 438). In arguing for the possibility of resolving cognitive and sociocultural perspectives on conceptual change, Alexander (1997) commented that “the frameworks and models espoused by many researchers...cannot exist without recognition of the thoughts and reflection of the mind or without consideration of the *sociocultural influences* that exist in the world outside the mind” (p. 67).

In comparing sociocultural and social influence approaches, Pressick-Kilborn, Sainsbury and Walker (2005) concluded:

By continuing to emphasise the ways in which context is detached from participant, and individuals are influenced by and reflect learning contexts, these social influence viewpoints contrast with the sociocultural perspectives of Valsiner (1998), Wells (1999) and Matusov and Rogoff (1995) in which individuals mutually constitute contexts, rather than being influenced by or reflecting them. In considering conceptual change...from a sociocultural perspective, we need to be able to maintain a focus on interdependent aspects

of the context by considering the situated individual, inclusively separated within the sociocultural milieu (pp. 40-41).

Other conceptual change approaches have been described which are marked by some features of a sociocultural perspective, although taken as a whole they cannot be described as either sociocultural or social influence. A discourse approach is outlined by Greeno et al (1998) who suggest that evidence for conceptual change learning can be found in changed discursive practices, however their approach is not entirely consistent with a sociocultural perspective. Their model of conceptual learning/change uses student talk as a means of elucidating changes in conceptual structures, which is a cognitively-based approach. In addition, the theoretical bases for their two major constructs are poorly compatible in that they adopt a participatory explanation of learning (sociocultural) and a cognitive model of concepts: "we take learning to be participation in (one or more) discourse communities, we believe that it is in the discourse of these communities that we need to look for conceptual learning...concepts are considered as ways of organising more detailed information, thus supporting easier access to specific material" (p. 443).

Collaboration and learning

Although distinctions therefore exist between social influence and sociocultural approaches, both clearly acknowledge the central role of collaboration in mediating conceptual change, thus it is relevant to consider some of the findings from collaborative approaches to learning. Barron (2000, 2003) indicates that reviews of collaborative learning suggest, on average, that group work provides better overall learning outcomes than individual work (Johnson & Johnson, 1981; Cohen, 1994; Stevens & Slavin, 1995; Webb & Palincsar, 1996). With respect specifically to conceptual change learning, some success has been reported for peer collaboration, however the evidence in favour of positive outcomes is far from unequivocal. Two examples of particular relevance to the current conceptual change study are evaluated in the following section, together with a further example which focuses more broadly on affordances and constraints to collaborative learning in general.

Peer collaboration and conceptual change learning

Basili and Sanford (1991) investigated the effect of collaborative learning on the extent to which students changed their conceptions in a range of chemistry issues from "flawed" to scientifically acceptable. The learning environment included two group activities, an unstructured discussion of each student's response to a series of questions designed to elicit scientific misconceptions, and the joint production of a concept map which was handed in for grading. Conceptual change learning was assessed by comparison of pre- and post-intervention test results and analysis of audiotapes of the group sessions. The written tests required students not only to answer factually but also to explain their reasoning, and different gradings were given based on the correctness of both answer and reasoning. The collaborative learning group showed a statistically significant decrease in misconceptions and an increase in correct conceptions compared to the control group, however an

analysis of the verbal interactions did not indicate a strong correlation with group behaviours. The authors concluded that, although they did not give specific directions about how the groups were to structure their interactions, leaders emerged in each group and the group leadership styles had a major impact on the learning within the group. They therefore suggest that students should be trained in group leadership strategies with emphasis on the importance of the leadership style. In addition, they found that students' imprecise use of scientific terminology, often based on everyday usage of the same words, impeded development of conceptual understanding. As a result, students were unable to see that their conceptions were different from the scientific ones. This is in line with the suggestion of Dekker and Thijs (1998) that the problem is one of interpretation rather than misconception, and that the appropriate strategy is to "distinguish between the *meanings* of the words the student uses" and "*not...to assume that a student's meanings of the words are the same as [the scientific] meanings of those words.*" (p. 40, authors' italics). Perhaps, therefore if Basili and Sanford (1991) had analysed the contextual significance of student verbalisations, a different relationship or pattern may have been evident. In addition, some form of expert scaffolding (rather than simply feedback from peers who held similar conceptions) may have allowed students to re-examine their conceptions and perhaps encouraged them to differentiate more precisely between everyday and scientific meanings.

Collaborative, convergent, conceptual change

Roschelle (1992) describes what he terms convergent conceptual change in his study of student learning about velocity and acceleration using a computer simulation program. His proposal is that "convergent conceptual change is achieved by using conversational interaction in the service of conceptual change" (p. 243) using as evidence his observation that through taking turns in conversation a pair of students collaboratively co-constructed concepts and arrived at a convergent understanding. He contends that this process can occur despite the limitations of imprecise, and often unscientific and ambiguous terminology on the part of both students, provided that in the process of conversation, the students construct a shared meaning of terms, and therefore a shared understanding of the concepts. He claims that this comes about because particular comments are interpreted in the situated context of a dialogue, an assertion which is consistent with Wells' sociocultural approach. The case study described in detail in this paper provides some evidence for this assertion, but the applicability is somewhat limited by the fact that fewer than 50% of the students in the wider study of which this case was a part achieved either convergence or conceptual development. Again, it may be that the addition of a more capable peer or guide would have provided more effective scaffolding for student pairs than each other, in that the more capable person may have been able to guide students in more productive directions. In emphasising convergence to a meaning shared between two students (who are by definition novices in the discipline) rather than to the accepted public bodies of scientific knowledge which students are expected to appropriate, Roschelle also unfortunately underplays the importance of developing appropriate scientific discourse, thus limiting the applicability of his findings. Nevertheless, he

demonstrates the significant potential that collaborative learning may have in promoting conceptual change, despite the difficulties in harnessing it most effectively.

Patterns of collaboration

Although not specifically defined in terms of conceptual change, the findings of Barron (2000, 2003) are significant in identifying patterns of collaboration within small groups which are likely to be more or less productive for learning in general. In a study of collaborative problem-solving in mathematics by school children, Barron (2000) identified characteristic patterns of discourse in two groups, one of which was considerably more successful in problem-solving than the other. These characteristics are summarised in Table 2.1.

The more successful group...	The less successful group...
...documented their findings more frequently	...documented their findings less frequently
...generated more correct ideas in discussion	...generated fewer correct ideas in discussion
...repeated ideas generated by their peers	...repeated their own ideas
... responded to suggestions with acceptance, a request for clarification or elaboration	...tended to ignore the suggestions of others, and to reject proposals as frequently as to accept them
...was characterised by equality of participation	...was more likely to be dominated by one individual
...displayed coordination of talk	...showed evidence of poorer coordination of the expression of ideas

Table 2.1: Patterns of discourse displayed by two groups of primary school children when solving mathematical problems (Barron, 2000)

Barron summarised the outcomes and processes observed within the less successful group as containing “evidence of struggles of control, failure to understand one another, repeated attempts at explanation, rejections of that explanation (even when invited), self-focused talk, admissions of confusion” (p. 425) and leading to a competitive nature for the exchanges. Some participants were primarily focused on achieving their own solutions rather than contributing to a collective answer. On the other hand, the more successful group was characterised by interactions which were described as “seamless, coordinated and relationally comfortable” (p. 428). Further, Barron identified the extent of mutuality, joint attention and shared task alignment as markers of coordination, where mutuality refers to the extent to which discussion allows all participants to contribute and be heard, joint attention refers to common engagement with an artefact (a centre of coordination) such as the task description or problem-solving resource, and shared task alignment refers to the extent to which participants act together in engaging with the task. Differences between the groups with respect to these markers are summarised in Table 2.2.

The more successful group...	The less successful group...
... paid attention to each other's articulations and accorded them value by taking them seriously	... frequently ignored or rejected contributions from others
... used an artefact (workbook) as a centre of coordination, and jointly attended to the mutually agreed documentation of solutions	... turned the workbook into "contested territory" (p. 430) which was appropriated by individuals for their own purposes
... displayed greater joint attention, and when attention was split it was easily regained	... was characterised by split attention and a perception that attempts to create joint attention were primarily disruptions to individual work
... focused their interactions on solving the problem together	... generally advocated individual solutions which were not taken up by others
... worked synchronously on the same aspect of a problem	... often unknowingly worked on different aspects of the problem
... adopted and fluidly interchanged complementary roles in the process (eg idea generator, discussion monitor, scribe)	... rarely adopted complementary roles

Table 2.2: Markers of coordination displayed by two groups of primary school children when solving mathematical problems (Barron, 2000)

Although these findings have been presented here as separate aspects of discourse and behaviour, Barron (2000) pointed out that all of them were interrelated in creating conditions for productive or less productive problem-solving, and concluded that that her findings captured "the multiple planes of activity and interpersonal goals that can co-occur in the context of collaboration" (p. 431). She further concluded that students' interpersonal capabilities could usefully be developed in order to enhance their potential for taking notice of and respecting the contributions of others, their ability to use strategies which result in a common focus, and their likelihood of remaining engaged with the task through periods of confusion and misunderstanding.

Barron (2003) extended these findings and conclusions to identify three key aspects of productive collaboration. Firstly she suggested that coordination and management of joint attention between participants is critical for collaborative problem solving because joint attention allows for the creation of a shared problem space (Roschelle, 1992). Maintenance of joint attention can be difficult when students are attempting simultaneously to develop their own understanding and to comprehend what their peers are saying and doing, but her findings reinforced its fundamental importance for problem solving and learning. Secondly she highlighted the essential and complementary actions of speakers and listeners in establishing joint attention, pointing out some of the barriers that were created within her study when one or more participants were too self-focused and thus prevented other participants' ideas from being considered. Thirdly she identified the role of interpersonal relationships in creating affordances and constraints to the development of joint attention and shared problem spaces:

Collaboration might productively be thought of as involving a dual-problem space that participants must simultaneously attend to and develop: a *content space* (consisting of the problem to be solved) and a *relational space* (consisting of the interactional challenges and opportunities). The content space and relational space are negotiated simultaneously and can compete for limited attention (p. 310, author's italics).

Her findings illustrated a number of relational difficulties within less successful groups which hindered collaborative engagement in the problem and thus hampered learning, and she suggested that shared interests, personal histories, knowledge, goals and commitment towards work were more facilitative. Importantly, she suggested friendship as a critical mediator of productive collaboration in that friends had been shown to interact more productively by means of more extensive talk which elaborated and extended the ideas of their friends. Friendship was also posited to mediate more effective collaboration through familiarity with ways of thinking and personal histories, and through increased motivation to work harder.

Significance of these studies

These empirical research studies illuminate a number of aspects relevant to the research described in this thesis. Firstly, the chosen examples involve intensive investigation of small student groups, which is the methodology used in this thesis, and which Barron (2003) has suggested is very useful for providing "detailed portraits of collaborative interactions that are missing in studies that look for patterns across many groups" (p. 312). Secondly, they focus on student meaning-making through discursive interactions, either in the broader context of collaborative problem-solving or in the specific case of conceptual change learning. Thirdly, they identify patterns of talk and behaviours which correlate with more or less productivity and suggest some strategies for addressing the less productive ones, and fourthly they highlight the difficulties for students in achieving meaning, discursive practices and solutions to problems which are appropriate to a particular community without assistance from some form of support, structuring or modeling. Thus they identify and describe some aspects of pertinence to a sociocultural study of conceptual change learning involving the development of proficiency in the discursive practices of the pharmacy community through collaborative discussion and problem-solving within small student groups. However, empirical research into conceptual change learning grounded in an integrated framework of sociocultural principles is currently lacking, and the research reported in this thesis seeks to redress this lack.

Issues that remain

As suggested above, few approaches to conceptual change can be clearly identified as based on sociocultural theories, and this is one of the issues which remain in relation to conceptual change learning, together with the lack of evidence to support these socioculturally based theories. Other issues include criticisms of the "radical expression of sociocultural theory" (Vosniadou et al, 2008, p. 24), and the need for methodologies which generate data which can be used for investigating

theories of conceptual change (Mayer, 2002). The latter two issues are outlined in the following sections.

Criticisms of the sociocultural approach

While accepting that sociocultural theories have a role in identifying relevant practices, contexts and tools for thinking, Vosniadou et al (2008) have recently advanced specific criticisms of the sociocultural approach to conceptual change learning as they currently perceive it. They suggest three major shortcomings, all of which are regarded as a rejection of important cognitive aspects, namely that sociocultural theories are characterised by a reluctance to acknowledge the role of the active individual in processing ideas, a denial of the objectification of knowledge and thus of the possibility of transfer between situations, and a rejection of the notions of constructs and representations such as mental models.

Further, Roth (2008) introduces a discursive psychological perspective on the nature of conceptions which he contrasts with both cognitive and sociocultural approaches. He argues that both current theories involve reductionism of “all phenomena of thought and reasoning, mind and memory” (p. 36) either to “social explanations as socioculturally and culturally-historically formed” or to “events happening in the brain” (p. 37). Thus sociocultural theories posit learners as “cultural dopes” (p. 37) and cognitive theories treat individuals “as if their mental models or conceptions *determined* their (discursive, practical) actions” (p. 37, author’s italics). These are contrasted with the discursive approach which suggests that new understandings “*emerge from* rather than *are determined by* the contextual particulars of societal forms of activity and specific social situations” (p. 36, author’s italics). He further suggests that the unit of discourse analysis is a “turn pair” (p. 38), suggesting that a speech act is “completed in and through the performance of the next person” (p. 38). This is consistent with Wells’ (1998, 1999b) notion of progressive discourse where exchanges constitute the unit of analysis.

These criticisms are important because they highlight the difficulties of resolving perspectives which are widely divergent. In later sections of this chapter, a counter to these criticisms is presented which proposes that reconciliation is not impossible if additional aspects of sociocultural theories, such as inclusive separation and the reciprocal and transformative nature of internalisation and externalisation are considered.

Methodologies

A difficulty which has been long recognised in conceptual change research is that of evaluating whether conceptual change has actually occurred, thus methodologies which provide relevant data on learning outcomes and processes are critical. Herrenkohl & Guerra (1998) suggest that “learning is a process to be accounted for in the context of the actual community and not in individually administered examinations alone” (p. 435), a perspective consonant with sociocultural theory. Most

reported studies, however, use pre- and post- test outcomes to garner evidence of the existence of conceptual change outcomes, despite the frequent demonstration that student test results are not necessarily reliable evidence of conceptual understanding (Gil-Perez & Carrascosa, 1990; Garnett et al, 1995; Kelly & Green, 1998; Dekker & Thijs, 1998). These examples highlight the need for eliciting students' articulations of their own thinking in a situation not abstracted from the problem and not construed by the student as a 'test' which calls for a known-to-be-preferred answer. Pintrich and Sinatra (2003) discuss the strengths and shortcomings of different methodologies including self-report questionnaires, interviews and observations, and conclude that there is a need for multiple methods "in order to capture aspects of both individual internal processes and the role of context" (p. 436). A means of situating both the processes and outcomes of conceptual change learning is suggested in a later section of this chapter.

A way forward

The preceding discussion has highlighted two major issues regarding the way to move forward in conceptualising conceptual change learning. Firstly, conflict remains between approaches based on individual and cognitive perspectives and those which are founded on sociocultural principles; secondly, currently used methodologies are inconsistent with collecting data appropriate for evaluating discursive change from a sociocultural perspective. These two dimensions are addressed in the following sections, and the approach which underpins this thesis is then introduced as a means of offering a productive way of moving forward.

Resolving the impasse between individual and social perspectives

Alexander (2007) argues that resolving this particular impasse is either unnecessary or impossible, suggesting that the divide is too wide because "it remains a seeming impossibility for those who keep thinking solely within the confines of one's mind or for those whose world does not allow for conceptualization, truth, or mind" (p. 72). However a number of other authors are more sanguine about the possibility, and have offered suggestions for ways of bringing together individual and social perspectives on conceptual change. Greeno and van de Sande (2007) suggest building a 'bridge' between cognitive and situated perspectives using 'bridgeheads' on either side. On one side is the distributed nature of knowledge and cognition with learning as participation, and on the other side the theory of information structures and processes. Murphy (2007) proposes that both sociocultural and cognitive elements act as catalysts for conceptual change and focuses on students' epistemic beliefs and the role that they play in contributing to the change process. In considering acquisition (individual perspective) and participation (sociocultural perspective) metaphors for learning, Vosniadou (2007c) suggests that there is no essential contradiction between them, "but rather that knowledge can be acquired through participation in sociocultural activities" (p. 62), and advocates a softening of the boundaries between the two perspectives by eliminating the need for a divide between internal and external representations of concepts. Mercer (2007) argues that sociocultural researchers do not necessarily deny the idea of scientific knowledge as

something that can be acquired and changed, and suggests that the strict dichotomy between purely cognitive and purely situative approaches is neither helpful nor reasonable. He concludes that “it is quite possible for us to move forward on the basis that an important catalyst for conceptual change is dialogue, but for us also to maintain that conceptual change is ultimately a matter of cognitive reconstruction and not merely the acquisition of membership of a community of discourse” (p. 77).

Perhaps the most clearly reasoned approach is offered by Leach and Scott (2003, 2008) who address criticisms such as those outlined above by Vosniadou et al (2008) and expand upon how individual and sociocultural perspectives can be drawn together within the learning of science. They argue that there is great value in understanding the prior knowledge brought by students to the science classroom and in recognising that this knowledge has emerged from engaging in the language or discourse of the communities in which they have participated to that point. They do not disregard intramental structures, but view them as arising through internalisation of conceptual tools, including language, which are initially encountered in the social plane. In accord with Vygotsky and Valsiner, they do not perceive internalisation as a direct transmission process, but rather one in which the individual interprets the socially available tools and ideas, and comes to a personal understanding. They conclude that

The view of science learning that we are developing here brings together the social-interactive and personal-sense-making parts of the learning process and identifies language as the central form of mediational means on both intermental and intramental planes. It draws upon sociocultural approaches in conceptualizing learning in terms of developing a new social language, and in identifying epistemological differences between social languages. It draws upon individual views in clarifying the nature of the learning demand as learners make personal interpretations of the social language of science (Leach & Scott, 2003, p. 103).

Sfard (1998) offers further insight into the relationships between individual and sociocultural perspectives in her discussion of the dangers of focusing exclusively on either acquisition or participation as a metaphor for learning. She describes the cognitive traditions as favouring the former, and the more social perspectives as favouring the latter. Through an evaluation of both approaches, however, she proposes that neither metaphor is complete in itself and concludes that both metaphors have their place; because they are metaphors, neither corresponds precisely and sufficiently to reality, and aspects of both offer useful ways of thinking about learning.

Sfard (1998) thus appears somewhat pessimistic about the possibilities of reconciling individual and social perspectives, while Leach and Scott (2003, 2008) appear more optimistic. The suggestion of Leach and Scott (2003, 2008) that individual and social perspectives are not incompatible is congruent with the approach outlined in this thesis, but this thesis offers a more comprehensive approach by incorporating the crucial concepts of transformative internalisation and externalisation and inclusive separation (Valsiner, 1998) to address the criticisms of both Vosniadou et al (2008) and Roth (2008) as outlined previously. This notion is explained in more detail in a later section.

New methodologies

A consequence of considering sociocultural approaches to conceptual change as essentially discursive in nature is that the means of evaluating the extent and quality of change and the processes which promote or constrain this change must also be discursive. Lemke (1990) highlights this clearly when he contrasts the social nature of classroom learning with the individual testing of knowledge. Herrenkohl and Guerra (1998) argue that assessment of learning continues to be dominated and rewarded by student reproduction of ideas which have been presented by the teacher, whereas a more appropriate approach would be to conduct assessment in the context of the authentic activities of a community.

The approach adopted in this thesis

Both issues identified in the preceding paragraphs are addressed in the research reported in this thesis. Firstly the reconciliation of individual and sociocultural perspectives is addressed by regarding the individual as inclusively separated (Valsiner, 1998) within the sociocultural milieu, thus continuing to recognise that the individual is distinct but interdependent. Specifically the role of prior knowledge as an important mediator of the process of conceptual change learning is recognised as critical. Secondly, the methodology is situated within the discourse of students as they engage in classroom activities, with evidence for both the outcomes and processes of conceptual change sought in this discourse. These ideas are developed in detail in chapter 3, but a brief outline follows which particularly addresses the criticisms outlined above.

Firstly, Vosniadou et al's (2008) criticisms are addressed by specifically focusing on the individual learner, and following learning trajectories which are simultaneously shaped by prior experience and participation in the learning activities described in the research. The individual is considered as distinct from the context, but not independent of it; rather the individual and the social are considered as inclusively separated (Valsiner, 1998) and co-constitutive. The activity and agency of the individual is emphasised through the transformative nature of internalisation and externalisation, which are postulated as the mechanisms by which the social interacts with the individual. Roth's (2008) criticism of the socioculturally situated learner as a cultural dope is also addressed through the latter, particularly his suggestion that sociocultural theories posit talk as a "neutral means for reading out and making public what is in the speaker's head" (p. 35). Specifically, the use of transformative externalisation contradicts the notion that talk is an exact reflection of something that exists as a mental construct; further it is capable of explaining the discursive psychological phenomenon whereby "participants talk about scientific phenomena even when they have never talked or thought about them before" (Roth, 2008, p. 34).

Methodologically, this thesis extends and complements approaches such as those of Ivarsson et al (2002) (tool use) and Greeno et al (1998) (discourse), through employing discourse as evidence for both outcomes and processes. Appropriation of discursive tools, and their use in mediating

communication of meaning, are investigated by considering conversations between participants, both in interviews and in classroom activities. Evidence for conceptual change learning is sought not in written tests but in situated talk, and changes in discursive patterns are perceived as emerging from participation (Roth, 2008). This thesis thus not only represents an important contribution to the development of sociocultural theories of conceptual change, but it also offers practical and authentic methods for conducting empirical research which are consistent with sociocultural theoretical underpinnings.

2.3 Conceptual change in 'Acids and bases'

The final section of this chapter focuses in detail on prior research into conceptual change learning in the topic of 'Acids and bases', with which the empirical study described in this thesis is concerned. The studies described in this section are descriptive only, since no theoretical orientation was apparent in any of the investigations reported. Most published research has focussed on the dual aims of identifying the major misconceptions held by students on entry to a course or unit of study, and of ascertaining whether conceptual change was subsequently achieved through the use of particular teaching strategies. A range of investigative strategies has been employed, including interviews, questionnaires, observations, tests, examinations, and concept maps; teaching interventions have included conceptual conflict strategies, practical exercises, collaborative concept mapping and group problem solving. A summary of this research is included in Appendix A.

Despite the variety in methodology, and the use of students from a number of different countries, with a diverse range of ages and levels of experience, a number of conceptual difficulties have been consistently reported. Many students had trouble in identifying substances other than those used in science classrooms as acids and/or bases, with the latter more problematic than the former (Cros, Maurin, Amoureux, Chastrette, Leber & Fayol, 1986; Cros, Chastrette & Fayol, 1988; Ross & Munby, 1991; Vidyapati & Seetharamappa, 1995; Toplis, 1998). Many students used definitions which included physical and functional aspects such as taste, feel and corrosiveness, in addition to the more scientific Arrhenius, Bronsted-Lowry or Lewis descriptions (Hand & Treagust, 1988, 1991; Toplis, 1998), and where they were used, considerable confusion was displayed between the three different scientific definitions (Cros et al, 1986, 1988; Vidyapati & Seetharamappa, 1995). The concepts of strength and concentration were frequently confused with each other (Schmidt, 1991; Banerjee, 1991; Botton, 1995; Nakleh, Lowrey & Mitchell, 1996), and particular difficulty was experienced with the term 'neutralisation' (Cros et al, 1986, 1988; Hand & Treagust, 1988, 1991; Vidyapati & Seetharamappa, 1991; Ross & Munby, 1991; Nakleh & Krajcik, 1993; Botton, 1995; Schmidt, 1991). Many students were uncertain about the pH scale (Cros et al, 1986, 1988; Ross & Munby, 1991; Schmidt, 1991; Banerjee, 1991; Zoller, 1996) and the meaning of equilibrium constants in general (Banerjee, 1991; Banerjee & Power, 1991; Zoller, 1996). More recent studies with students at the University of Sydney suggested that the concept of strength, and

the relationship between strength, pH, pKa and concentration were problematic (Read, George, Masters & King, 2004, 2007; Yeung, Schmid & George, 2007).

Changes in understanding brought about as a result of teaching interventions, where reported, were not dramatic, and the majority of authors concluded that the students' misconceptions were extremely difficult to change (Cros et al, 1986, 1988; Hand & Treagust, 1988, 1991; Banerjee & Power, 1991; Toplis, 1996; Zoller, 1996). This view was endorsed in a review of students' alternate conceptions in chemistry (Garnett et al, 1995), and several explanations for the prevalence of stable misconceptions were proposed, namely:

the use of everyday language in scientific contexts, over-simplification of concepts and the use of unqualified generalised statements; use of multiple definitions and models; rote application of concepts and algorithms; students' preconceptions from private world experiences; overlapping similar concepts; and inadequate prerequisite knowledge (Garnett et al, 1995, p. 92).

de Vos and Pilot (2001) suggested a more fundamental reason for student confusion about acids and bases. They reviewed the history of the development of ideas about the topic and identified six 'layers' which were apparent in chemistry textbooks over a fifty-year period during the twentieth century. These layers are more appropriately described as historical and semantic contexts, where the textbook descriptions of acids and bases reflect the scientific thinking of the period. The authors suggest that each successive layer or context was added without replacement or modification of the previous layer, and that the differing assumptions underlying new theories created poorly coherent textbooks which contributed to conceptual confusion for both teachers and students. Particularly problematic were the terms 'acid', 'base', 'strong' and 'weak', as well as the nature of acid-base reactions and the role of water as both solvent and acid/base.

Whilst these explanations are pertinent, they are not sufficient, since many of the studies suffered from philosophical and methodological shortcomings which contributed significantly to the relatively low success rates reported. In addition, as suggested previously, no clear theoretical basis was apparent for these studies, which further hampered interpretation of the findings. The research reported in this thesis, on the other hand, is grounded in a clearly articulated theoretical framework, with methodology which is consonant with theory, thus it provides significantly greater explanatory and interpretive potential.

A recent study (Roche, 2007) has reported promising results for pharmacy students in an American university where a specific series of classes emphasising the fundamental principles of acid-base chemistry was associated with high performance levels in an end-of-semester examination and good retention of this performance after six months. The key element in the teaching sequence appeared to be a comprehensive handout which set out the critical principles and worked examples, and which focused on making connections between concepts. However the evaluation of both conceptual change and its retention was based solely on solving problems in examinations, and no indications were provided of prior knowledge in the area. It is thus difficult to assess the extent to

which students' conceptual understanding was enhanced by the teaching, although the author reported the receipt of two unsolicited emails from students suggesting that they were able to use appropriate acid-base principles in another subject.

A number of research gaps and limitations have been highlighted in this review of the literature, demonstrating that considerable scope clearly exists for investigation of conceptual change learning in relation to 'Acids and bases' which is grounded in sociocultural theory and which focuses on the development of discursive proficiency and discrimination between the domains of chemistry and pharmacy. Both a lack of theoretical underpinnings and the focus on the notion of replacing misconceptions within previous investigations clearly highlight the significance of the research reported in this thesis which both investigates the prior understandings of first year pharmacy students about the chemistry concepts of acids and bases, and develops a sociocultural approach to the description of both the processes and outcomes of conceptual change. Importantly, the adoption of a sociocultural perspective shifts the emphasis from treating students' ideas as misconceptions to acknowledging the different ways of talking about concepts in different contexts and situations, and thus validates the diverse means of communicating meaning adopted by students under different circumstances. Further, the theoretical framework provides a means of analysing and interpreting both the processes and outcomes of conceptual change learning in acids and bases, rather than simply describing them, and allows a more rational and evidence-based approach to the design of learning environments in which conceptual change learning might be promoted.

2.4 Conclusion

This chapter has reviewed key concepts of sociocultural theories and historical developments in approaches to conceptual change learning, and presented an argument for the development of a model of conceptual change learning grounded in sociocultural principles which can be investigated empirically using appropriate methodologies. While acknowledging that conceptual change research has increasingly recognised the significance of context in influencing learning, and has employed approaches which have been described as sociocultural, it is argued that few authors have fully appreciated the interdependence of the individual and social which is fundamental to sociocultural theory, and thus that a need exists for a new approach which offers both theoretical validity and appropriate methods of empirical study. Critical sociocultural notions include those of the inclusive separation of individuals within contexts, discursive mediation of intersubjectivity and transformative internalisation and externalisation, the creation of collaborative zones of proximal development, and cognitive socialisation into communities. Within conceptual change theories, the central notions involve the conceptualisation of 'concepts' as socially distributed means of making and communicating meaning, and the embedding of evaluation of both the processes and outcomes of change in discourse. This thesis draws together these two sets of ideas and develops a discursive sociocultural model of conceptual change which represents a unique and powerful means of understanding how learning is facilitated and constrained. A detailed rationale for the study and a

description of the model which is proposed as the framework and explanation of conceptual change learning are outlined in chapter 3.

CHAPTER 3 A DISCOURSE MODEL OF CONCEPTUAL CHANGE: DESCRIPTION AND RATIONALE

3.1 Introduction

As outlined in chapter 2, research and theoretical development in conceptual change learning has begun to acknowledge the social nature of thinking and learning and the significance of context in shaping learning outcomes (Sinatra, 2002). Use of cultural tools, both discursive (Kelly & Green, 1998) and physical (Ivarsson et al, 2002), and participation in culturally valued practices (Kelly & Green, 1998) have been proposed as means of exploring conceptual change, and Karpov (2003) has argued for the critical place of structured teaching in the development of scientific concepts. Further, Mayer (2002) has suggested that the most significant challenges for research into conceptual change are describing *mechanisms* which are theoretically grounded, and *methodologies* which are able to provide data as evidence of those theories. There is, however, a critical need for an approach which addresses these notions in an integrated rather than fragmentary manner. Such an approach is outlined in this chapter, which describes a sociocultural discourse model of conceptual change learning, focussing on both processes and outcomes, and highlighting the interdependence of the individual learner with the milieu in which learning takes place.

The model is used in an investigation of conceptual change learning relating to specific aspects of chemistry and pharmacy among first year university students in Australia. The investigation includes discourse in the context of both classroom interactions and individual interviews, and follows learning trajectories for a period of eight months in order to evaluate both the processes and outcomes of conceptual change.

This chapter is divided into two sections. The first section outlines the critical requirements of any model of conceptual change, and proposes in general terms how a discourse model is able to fulfil these requirements. The second section describes the rationale for the specific model which is proposed, and indicates how aspects of this model will be used in the current empirical research study of conceptual change in the scientific domains of chemistry and pharmacy.

3.2 A discourse model of conceptual change

Any model of conceptual change learning is required to provide plausible and integrated explanations of the three major dimensions of the phenomenon, namely the nature of concepts, the mechanisms and processes by which they change, and the means by which the evidence for change is evaluated. The discourse model proposed in this chapter is grounded in the notions that concepts are fundamentally discursive in nature, and that change can be perceived as a process of cognitive socialisation operating at the level of both individual understanding and community participation. Cognitive socialisation is considered to take place as concepts are firstly appropriated through

transformative internalisation as a result of participation in appropriate activities, and subsequently externalised in situated discursive practices which are recognised and accepted as valid by central participants in a community of practice. From a sociocultural perspective, the model further argues that learning is fundamentally social and that both the processes and outcomes of learning are shaped by the interdependence between individual and context. A brief overview of the means by which this discourse model of conceptual change meets these criteria is followed by a more extensive exposition of the details.

The nature of concepts – discursive tools

Central to the discourse model of conceptual change is the notion that concepts are considered to be discursive tools whose primary functions are to mediate communication of meaning and facilitate individual and collaborative activity (Säljö, 1999; Harré & Gillett, 1994; Roth, 2008). They are seen as having evolved from ongoing social practices and experiences within communities of practice, and as therefore being socially, spatially and chronologically distributed. The ways in which concepts are used and communicate meaning within a specific community can be considered to constitute the collective discursive practices – the discourse – of the community, and these practices customarily characterise and distinguish that community (Gee, 1992; Hicks, 1995; Mercer, 2000). Discursive practices can be manifested in a range of ways, including spoken and written verbal language, and specialised representational systems (Nunes, 1999). Within the broad domain of science, in which the current model will be applied, such specialised representational systems commonly include mathematical notations, chemical symbols and equations, abbreviations and acronyms, graphical representations and other types of diagrams, although other systems are also possible (Wells, 1999b). The collective discursive practices of a community can therefore be seen as encompassing all of the means by which language and representational systems act as tools for mediating the communication of meaning, and facilitating collaborative activity.

Evidence of change – discursive proficiency

A perception of concepts as discursive tools for mediating communication and facilitating collaborative activity leads to the reformulation of conceptual change as a process of cognitive socialisation through which an individual learns to engage in the discursive practices of a specific community of practice by developing skills in the use of these tools. Evidence that change has occurred is sought in the extent to which an individual is accepted as a valid participant in the community (Gee, 1999), is able to communicate meaningfully using the discursive practices of the community (Mercer, 2000), and is able to engage in collaborative activity with more mature members of the community. Conceptual change is therefore manifest when an individual learns to participate meaningfully in the discursive practices which characterise the community, and this learning is accompanied by increasing levels of intersubjectivity between the learner and more central participants in the community. Within the broad scientific domain, learning of scientific

concepts leads to development of fluency in ‘talking science’ (Lemke, 1990) using both verbal and written language, and specialised representational systems (Nunes, 1999).

Mechanisms and processes of change – cognitive socialisation

As argued above, conceptual change can be perceived primarily as a process of cognitive socialisation which involves learning the discursive practices of a specific community and using them appropriately. From a sociocultural perspective, learning is regarded as a fundamentally social process in that all individual development originates from social sources. Conceptual change learning thus involves the individual appropriation of socially distributed discursive practices: as Wells (1999b) puts it, “the construction on the intra-mental plane of the discourse practices that are first encountered on the inter-mental plane of activity-related social interaction” (p. 319). The proposed discourse model utilises the notions of transformative internalisation and externalisation (Valsiner, 1998) to explain the mechanisms associated with appropriation (Leach & Scott, 2008). These reciprocal processes are described in more detail in a later section but can be broadly explained as the movement of socially available concepts from extrapersonal to interpersonal, and the subsequent emergence of these concepts after some form of transformation or reinterpretation within the interpersonal world. Appropriation takes place as individuals engage in transactions within multiple overlapping and evolving zones of proximal development (Newman et al, 1989). These zones are constructed through collaborative exchanges in the classroom involving peer learners and teachers (Wells, 1999b), the latter providing structured teaching and modeling of relevant discursive practices for learners to appropriate through transformative internalisation. Subsequent exchanges between learners (either between themselves or with teachers) provide opportunities for the former to practice and test their learning. This structured teaching and modeling is designed to shape the trajectories of conceptual change in ways that result in learners being cognitively socialised into discursive practices which are recognised by the community, rather than idiosyncratic discursive practices which may develop as a result of unguided collaboration. Externalisations by the learners provide both evidence of conceptual change and further opportunities for the development of intersubjectivity.

In order for internalisation and externalisation to occur, the individual learner must be engaged in some form of contextualised social activity, and the nature of the context will be critical in shaping the trajectories of change. In accord with a sociocultural perspective, the proposed discourse model considers context as an inclusively separated whole (Valsiner, 1998) in order to maintain and emphasise the interdependence of the individual learner and all other aspects of the zone of proximal development. An inclusively separated context perceives the individual and all other aspects of the environment to be mutually constituting, rather than mutually influencing. Mutual constitution allows a distinction to be made between different parts of the context, but views the relationship between the constituents as dynamic and evolving along interdependent trajectories of change. From both a theoretical and analytical perspective, Rogoff’s planes-of-analysis approach

supports the notion of inclusive separation by providing a means of selectively foregrounding specific aspects of the context against the background of the context as a whole (Rogoff, 1998).

3.3 The specific model: broad overview

The discourse model of conceptual change outlined in this chapter encompasses two major propositions. Firstly, conceptual change is perceived from a sociocultural perspective as a process of learning and beginning to participate more centrally in the discursive practices of a particular community, which can be regarded as a form of cognitive socialisation. Secondly, this process is seen to be facilitated by provision of opportunities to engage with both peers and more central community members in authentic activities. The model addresses Mayer's (2002) challenges by outlining a *mechanism* for conceptual change founded on transformative internalisation and externalisation (Valsiner, 1998) and utilising evidence generated from *methodologies* which capture both the processes and outcomes of change, and it provides a strong theoretical framework for the design of curricula and learning activities which are able to enhance student learning.

The model is grounded in sociocultural principles and notions of discursive practices. Concepts are regarded as discursive in nature (Säljö, 1999), and as essentially social constructs which are used as communicative tools. Conceptual understanding is situated within the social and cultural practices of particular communities, and the ability to communicate meaningfully with other members of the community constitutes evidence of that understanding (Gee, 1990). Concept learning (conceptual change) is similarly embedded in sociocultural practices, and individual development emerges through collaborative participation in authentic discourse and cultural practices. This participation promotes the development of intersubjectivity (Rogoff, 1998; Gee, 1999) since the learner is able to experience both relevant social resources for internalisation, and evaluation of the aptness of personal externalisations. Conceptual change is semiotically mediated through the reciprocal processes of transformative internalisation and externalisation (Valsiner, 1998), and results in the development of contextual discrimination between different situated meanings. Structured teaching and modeling of appropriate discourse and practices form a critical part of the learning process (Karpov, 2003), but must be complemented by the provision of opportunities for the learners to engage in the practices and discourse in meaningful ways (Lemke, 1990). From this perspective, the characteristics of the learning environment are critical in shaping the trajectories of the zones of proximal development which evolve within the classroom interactions, and the learning which occurs as a consequence. The outcomes of conceptual change include identification with a new community or discourse, or an increased centrality of participation in its practices, particularly its specialised discourse and representational systems, validated through recognition and acceptance by more central members of the community (Gee, 1992, 1999). Both processes and outcomes of conceptual change are considered from individual and interpersonal perspectives, using a multiple planes of analysis approach (Rogoff, 1998) to demonstrate their mutual co-constitution and interdependence. These characteristics of the model are outlined in greater detail in the following section.

The model provides an analytical and interpretive framework for the conduct of empirical research into both the processes and outcomes of conceptual change learning in the present study, which investigates the patterns of conceptual change within a cohort of first year pharmacy students at the University of Sydney. The impetus for this study arose from observations over a number of years that a significant percentage of students experienced difficulties with the concepts of 'acid' and 'base' as used in the pharmacy community, and frequently used discursive practices which were relevant to the chemistry community rather than pharmacy. This lack of contextual discrimination appeared to constrain meaningful communication between these students and more central participants in the pharmacy community, although many students were successful in formal examinations relating to these concepts. The discourse model of conceptual change provides a framework for evaluating evidence for change, and a means of exploring the processes which afford and constrain change, in the context of an instructional design encompassing both structured teaching and collaborative student participation in discursive practices.

3.4 The model: detailed description and rationale

The discursive nature of concepts

A sociocultural approach to conceptual change is founded on the notion that concepts are embedded in social practices as "repositories of human sense-making capacities and activities,...sediments of human experiences" (Säljö, 1999, p. 81) and are therefore distributed across communities and time. Concepts are therefore regarded as discursive tools which have evolved from shared activities and experiences, and which can be used to facilitate the communication of meaning. This discursive approach contrasts with the more mentalistic understanding of concepts favoured in the cognitive tradition, where concepts are considered to be possessed by an individual and shared with others (Ferrari & Elik, 2003). Moreover, concepts are not static means of categorising objects and experiences, but are flexible tools which enable and facilitate situated action, both individual and shared: as Harré and Gillett (1994) suggest, "applying a concept to something enables me to act in ways that otherwise I could not" (p. 41). They cannot be applied uniformly in all circumstances, but are used differently in different situations, and their meaning must be renegotiated in each different setting (Säljö, 1999). Thus concepts are fundamentally discursive in nature; as sense-making tools they mediate the communication of socially and historically situated meaning, and facilitate collective activity (Wells, 1999b, p. 295). Conceptual change occurs as individuals appropriate these tools for their own use in communication and activity, and are cognitively socialised into a new community of practice (Sfard, 1998).

As argued earlier, discursive tools and practices include both verbal language and specialised representational systems such as systems of number, equations, graphs, diagrams, pictures, abbreviations and acronyms, gestures and other non-verbal depictions, representations of chemical structures, and commonly encountered cultural signs. These different systems focus attention

differentially on specific aspects of conceptual meaning, and channel activities and interactions in particular directions (Nunes, 1993). Since these tools are highly diverse in nature and function, the meanings which are communicated through the use of different representations may vary significantly between individuals as they internalise specific aspects of the representation which may be peripheral to their socially accepted purpose.

In the current study, the discursive nature of concepts is foregrounded by structuring the classroom learning activities in such a way as to encourage students to engage in spoken discourse as an essential part of the process of solving problems in a collaborative fashion. Emphasis is primarily placed on verbal communication within conversational exchanges, rather than competence in answering written examination questions. Written material is used as supporting documentation, but the focus is on talking rather than writing. Although within the domains under study many specialised representational systems are common, and it is very likely that their use contributes to the channelling of students' interactions and activities, and to significant differences in the communication of meaning, the mediational significance of these representational systems is not specifically evaluated in this study.

Cognitive socialisation

As argued in the previous section, concepts are more appropriately viewed as discursive phenomena, and as semiotic tools for making and communicating sense and meaning between individuals and within communities (Säljö, 1999) rather than primarily mental constructs. This is a critical distinction, since it locates conceptual knowledge not in the individual mind, but within the social practices in which individuals participate. In addition, regarding concepts as discursive tools and resources permits a focus on their function and use (Mercer, 2000), rather than on their definition. Conceptual change then becomes less a matter of learning new pieces of knowledge than a process of socialisation into patterns of thinking, speaking and acting which have developed and evolved historically, and which are designed to communicate meaning in particular circumstances and settings (Säljö, 1999). This cognitive socialisation occurs through learning to participate with increasing expertise in those discursive practices characteristic of particular institutions or communities (Barron, 2000; Mercer, 2000), and a sociocultural conceptual change model must therefore focus on situated discourse as the source of evidence for both the processes and outcomes of change and cognitive socialisation.

In the current study, the situated discourse of students is investigated in two contexts: individual interviews with the researcher in which opportunities to engage in authentic discourse are specifically provided; and formally scheduled workshop sessions, in which students participate in collaborative activities with assistance from tutors. These activities include both conceptual discussions and problem solving. Both contexts permit an evaluation of the processes of conceptual change in addition to the outcomes; of particular interest are the types of interactions which characterise, mediate, afford and constrain conceptual change.

Context and situated conceptual understanding

A critical consequence of regarding concepts as discursive tools which mediate communication of situated meaning is that meaning is not constant, but differs between contexts. Context is doubly significant within the conceptual change model, because concepts are located in social and cultural practices which are by nature highly context-sensitive since they have originated and evolved within a specific community of practice and reflect idiosyncratic aspects of that community's activities. The meanings attributed to these practices are often unique to the specific community, and collaborative activity may be restricted to members of the community because outsiders are unable to recognise the nature or purpose of the community practices.

A comprehensive definition of context is problematic, since many sociocultural and historical dimensions combine to produce different breadths of context, from the individual to the institutional (Rogoff, 1998), from the immediate to the evolutionary, and across widely divergent cultural traditions. The model outlined in this chapter focuses on two major dimensions of context, and a third aspect which serves as a point of contact between the first two. The former of these two dimensions focuses attention on the situated nature of conceptual understanding, while both are necessary for an explanation of the emergence of individual understanding as outlined in a later section.

The first dimension of relevance is the community of practice (Mercer, 2000), in particular the "modes of understanding reality, communicative traditions and social practices that have evolved over long periods of time" (Säljö, 1999, p. 90). Communities are characterised by particular behaviours, attitudes, values, goals, relationships, representations and patterns of discourse which are accepted by the members of the community as appropriate, and which are accorded meaning and salience as they are embedded in the situated customs or traditions of the community (Gee, 1999). Membership of the pharmacy community encompasses individuals who are registered to practice as pharmacists, together with individuals who are engaged in activities which complement and support those of registered pharmacists. Students enrolled in degrees which can lead to registration as pharmacists are granted peripheral affiliation with the community, in the sense that free membership of professional organisations is offered to them, and they are required to undertake placements in authentic clinical settings during their university study. As a consequence, students are progressively socialised into the community over a long period of time before their professional qualifications entitle them to full and central membership, and the process of becoming a pharmacist is considered to begin at the commencement of formal study¹.

The second dimension of context involves the interpersonal interactions which occur between unique individuals within a formal learning environment over a limited instructional timeframe in a

¹ It is appropriate to acknowledge that a significant proportion of students enter the degree with prior experience within the pharmacy community, and can therefore be considered to have commenced their journey towards full participation before commencement of their tertiary studies. At the University of Sydney, students are required to undertake their first clinical placement in the second week of their first year of study.

particular location. These interactions primarily involve discourse, but also involve social and relational aspects which can serve to guide the direction of the interactions. Affordances and constraints at this level of context, such as the availability and utilisation of learning resources, the physical environment (for example, the arrangement of furniture, the ambient temperature, the time of day and relationship to other scheduled classes), and the physical and emotional status of participants, are also capable of channelling the direction of the discourse and thus the learning of participants. In the current study, interpersonal relationships between participants have been established to different extents before commencement of the study; these have considerable potential to shape the social functioning of each small group, and, as a consequence, the extent to which intersubjectivity is achieved through discourse.

The third aspect of context, the classroom, serves to interweave the other two dimensions, by providing an environment in which beginners learn to use the socially accepted discursive tools of the community of practice by engaging in interpersonal interactions with peers and tutors. As described in a later section, the classroom is also the milieu in which zones of proximal development are created and evolve.

From the perspective of community of practice, development of conceptual understanding involves learning and eventual mastery of the discursive practices which are accepted and validated for use by members of that community. This frequently involves learning to use words which are commonly encountered in other contexts, but which are intended to communicate specific and different meanings within the community (Mercer, 2000). For example, terms such as *force* and *motion* are common in everyday dialogue, but have precise meanings in the physics community which are often incongruent with commonsense usage (Mortimer, 1995; Dekkers & Thijs, 1998; Säljö, 1999). Further, as with physical tools, language can be used to mediate the achievement of different purposes. In a domestic context, *vacuum* may refer to a household appliance used to remove dirt from carpets or to a container which keeps drinks at a constant temperature, while to a physicist a vacuum refers to a relative or absolute lack of air which can be used to address a range of theoretical and practical problems (see for example scientific journals such as *Vacuum*). Conceptual meaning and understanding are therefore strongly situated within particular communities of practice, and mediate different types of activities which serve the specific purposes of those distinct communities (Säljö, 1999).

The existence of distinct discourse communities has implications for the communication of meaning within and across communities, and also for the ways in which misconceptions are considered. Within the community, meaning is often communicated in ways which are clearly apparent to members, but which are not at all transparent to outsiders. Students, as initial outsiders, are unlikely to recognise, and attribute appropriate meaning to, the characteristic discourse patterns to which they are exposed (Mercer, 2000). When unfamiliar terms are introduced, this is liable to lead to considerable confusion on the part of the student/outsider, who may be forced to construct an idiosyncratic meaning which is not aligned with the accepted community norms, and as a

consequence, communication is hindered. On the other hand, when familiar terms are used in a new context to communicate different meaning and mediate the solution of different types of problems, the student is likely to apply existing understanding and discourse, with the result that communication is again hindered. In this situation, the student's understanding may be labelled as a misconception, which according to the traditional conceptual change model must be replaced with the correct version. The discourse model avoids the use of terms such as *misconception*, but rather emphasises the need for the outsider to be cognitively socialised into patterns of meaning and discourse characteristic of the new community and context (Driver et al, 1994).

The empirical study focuses on conceptual differences between two related, but distinct, communities of practice, those of chemistry and pharmacy. More specifically, chemistry is considered to be those parts of the discipline which are routinely learned by students in secondary and early tertiary studies, while pharmacy is considered to be the pharmaceutical sciences which underpin the professional practice of registered pharmacists. Whilst by no means the only area of difference between chemistry and pharmacy, this investigation focuses on the topic of 'Acids and bases', for three primary reasons. Firstly, this topic has been identified as a source of student conceptual confusion over a number of years; secondly, it is a foundational topic for much of the pharmaceutical and pharmacological science that underpins the professional practice of pharmacy (Roche, 2007). Finally, within this topic, a number of terms are used with similar meanings in the two communities, while other terms differ significantly between the two communities, and in general the two communities are interested in solving different types of problems. The two communities are not identical to any of the contexts or layers described by de Vos and Pilot (2001) (page 52), however the problematic meaning of the terms acid, base, strong and weak that they describe is very pertinent to the current study. The major similarities and differences are detailed in chapters 4 and 6, but the following brief outline encompasses the key issues.

Within the chemistry community, the terms *acid* and *base* are usually intended to refer to aqueous solutions of acidic and basic chemical compounds, often inorganic (for example, hydrochloric, nitric, acetic and sulphuric acids; sodium, potassium, calcium and ammonium hydroxides), and the major emphasis is on how these chemical compounds behave in aqueous solution, particularly how they influence the pH of the solution. Chemistry textbooks tend to focus on numerical problems relating to pH and concentration, and on the derivation and application of balanced equations involving reactions between acidic and basic species in water (eg Russell, 1992; Daintith, 1996). The contextualised meanings of the terms acid and base in chemistry thus mediate the solution of these problems and the use of these equations to explain and predict chemical observations. In the context of the pharmacy community, however, the primary purpose in using the terms acid and base is to classify drugs and other pharmaceutical compounds on the basis of the presence of specific organic functional groups within their molecular structures. These functional groups are significant in contributing to the pharmacological mechanism of action of drugs, their behaviour in dosage forms, their ability to penetrate into different parts of the body, and the processes underlying retention or elimination from the body (Nogrady, 1988; Florence & Attwood, 1998;

Ansel, Allen & Popovich, 1999; Aulton, 2002; Sanson, 2009). The focus in teaching pharmacy is therefore on assisting students to identify relevant functional groups in molecular structures, and to deduce both the state of ionisation in specific circumstances and the effect of that state of ionisation on drug behaviour (Roche, 2007). The contextualised meanings of the terms acid and base in pharmacy thus mediate a qualitatively different type of problem from those in chemistry.

Emergence of community membership and individual understanding – ‘talking science’

As outlined in the previous section, the sociocultural conceptual change model is contextualised in two major dimensions, community of practice and interpersonal classroom interactions, and emergence of individual understanding can be considered within each of these dimensions.

An individual becomes a member of a particular community of practice through learning to participate effectively in its social and cultural practices (Sfard, 1998; Rogoff, 1998), particularly its specialised discourse (Gee, 1999; Mercer, 2000). Membership of a community is inferred when an individual behaves in ways appropriate to the community, and authorised members of the community or insiders (Gee, 1999) accept that individual as a member. Northedge (2002) argues that effective participation is inferred when the individual “can produce utterances accepted as valid by community members” (p. 262). Community membership therefore entails the development of a situated identity which is both individually enacted and socioculturally recognised (Gee, 1999).

This situated identity develops through a process of enculturation (Rogoff, 1998), which can be viewed as the emergence of individual understanding and communicative competence through immersion in authentic discursive and cultural practices. These practices are resources for individual development, and are appropriated through transformative internalisation and externalisation as they are used as tools for thinking, talking and acting in interaction with others (Wells, 1999b). The processes associated with appropriation, namely internalisation and externalisation, are discussed in a later section.

Within the localised instructional context, however, opportunities to engage directly in authentic practices are limited, and the classroom becomes a simulated or surrogate learning environment which can be designed to mimic community practices to a greater or lesser extent. Full community membership is unlikely to be attained solely from classroom learning (Lave & Wenger, 1991), however the latter can be used to provide students with opportunities to practice authentic discourse in collaboration with their peers and the teacher.

The application of the conceptual change model in the current study is to the learning of scientific concepts, therefore the process of talking science (Lemke, 1990) becomes the key to learning authentic discourse as part of the process of enculturation. Talking science is a process of cognitive

socialisation by means of which the learner gradually makes sense of science, and of the world from a scientific perspective. It is more than simply a matter of knowing the vocabulary of science, and more even than knowing definitions of scientific terms.

Definitions try to give a sense of the meanings of words, but to speak and understand, to write or read, you need to find the meanings of whole phrases and sentences, and not just of words. When words combine, the meaning of the whole is more than the sum of its separate parts. To get the meaning of the whole, you need to know more than the meaning of each word: you need to know the relations of meaning between different words. A student may know the definitions of “electron”, “element” and “orbital”, but that does not mean he or she could use those words together in a sentence correctly, or say how their meanings relate to each other. To do so requires additional knowledge: knowledge of how these words are used in talking science (Lemke, 1990, p. 12).

Northedge (2002) further argues that meaning cannot initially be found by learning definitions because definitions are in themselves devoid of meaning unless they are embedded in some form of discourse. He contends that definitions can even act as constraints on learning if the individual cannot satisfactorily relate them to the discursive context in which they are framed: under these circumstances the definition of a term can be a replacement for understanding its meaning and use if the definition is presented in a decontextualised manner, separated from its discursive frame of reference. Learning to talk science according to Hicks (1995) involves learning both its discourse genres and the means of creating and maintaining semantic links between participants and artefacts.

Talking science is therefore seen as a matter of inferring the intended meaning of an utterance, which usually requires that the utterance be embedded in a discussion or conversation (Wells, 1998; Gee, 1999). Therefore individual conceptual understanding emerges as the learner participates in discursive activities within the classroom which are designed to facilitate the use and practice of appropriate scientific language (Driver et al, 1994; Hicks, 1995). Interpersonal and group interactions lead to the construction of shared or collective ways of talking and thinking, which can then be differentially appropriated by each of the participants (Wells, 1999b). The collective discourse of a group of learners is likely to mirror only partially that which is accepted by the relevant community of practice, since it is constructed by a group of peripheral participants or outsiders, and is likely to develop idiosyncratic features unique to that particular group, which may not be congruent with desired conceptual change outcomes (Roschelle, 1992). However with appropriate modeling by a teacher, particularly in the context of activities which are meaningful for the learner (Wells, 1999b), the appropriation of this collective discourse provides the participants with resources for further learning and therefore forms an important part of the overall process of cognitive socialisation and enculturation.

Enculturation into the community of pharmacy involves learning to distinguish not only between everyday and pharmacy discourse, but also between pharmacy and chemistry patterns of meaning as outlined in a previous section of this chapter and in chapters 4 and 6. The differences between the discourse practices of these two communities are often subtle but critical. Most first year pharmacy students are relatively adept at talking science since the majority have a strong background in science, particularly in chemistry. The challenge in this setting is to provide an

environment where they can learn to talk pharmacy, and develop the ability to discriminate between two related but distinct communities of practice.

The notion of talking science, or in the current study talking pharmacy, extends and expands the discussion in the previous section relating to the differences in situated meaning of the terms acid and base in chemistry and pharmacy. As Lemke (1990) has pointed out, learning definitions of terms is not sufficient for an understanding of their meaning, nor does it guarantee that an individual is able to use the terms appropriately in a sentence or conversation – or in application to problems. First year pharmacy students have generally had extensive opportunities to use the situated meanings of acid and base in solving chemistry problems, and can be considered at least peripheral participants in the chemistry community. In order to be socialised into the pharmacy community, they must additionally develop discourse which is recognised and accepted as valid by more central community members. The studies reported in this thesis are carried out in situations which involve the use of authentic discursive practices, as far as is practical given the constraints imposed by the institutional setting. This is achieved by investigating activities designed to encourage students to talk pharmacy in relation to the topic area of ‘Acids and bases’, supported by appropriate physical tools, and relevant representational systems including chemical abbreviations, drug structures and equations. Since this is a classroom study, exigencies of the curriculum mean that little interaction is possible between students and practicing pharmacists, therefore the process of enculturation through discourse and the potential for development of a situated identity as a pharmacist are necessarily preliminary. However the learning environment is carefully structured to encourage the construction of shared discourse within small student groups through inclusion of workshop activities requiring collective discussion and problem-solving. Both teacher-guided and peer discourse is facilitated by the physical structure of the learning environment (primarily the arrangement of the room). Tutors who are themselves central participants in the pharmacy community of practice actively teach and model appropriate discourse in their interactions with students, specifically highlight the different purposes behind the discourse patterns of the two communities of chemistry and pharmacy, and validate student use of accepted discursive practices. As the students engage in these collaborative activities, it is anticipated that individual understanding will begin to emerge; this will be evaluated both in the classroom and through the individual interviews conducted throughout the study.

Semiotic mediation – transformative internalisation and externalisation

Consideration of conceptual change learning in science through talking science highlights the role and significance of semiotic mediation, and focuses attention on the processes by which an individual is socialised by appropriation of the collective discourse. These processes have not been well articulated in previous models of conceptual change, and their articulation has been identified as critical to the evolution of theory (Mayer, 2002). Vygotsky used the concept of internalisation as a means of explaining the semiotic mediation of learning and development (Vygotsky, 1981), however considerable debate has ensued about its meaning and usefulness (chapter 2). The current

model employs the notions of transformative internalisation and externalisation (Valsiner, 1997b, 1998) in order to describe and explain the processes by which individual conceptual understanding and discursive proficiency emerge from participation in social and cultural practices. The directional and transformative nature of internalisation and externalisation are also fundamental to maintaining an inclusive separation of the personal and social worlds (Lawrence & Valsiner, 1993; Valsiner 1997b, 1998) and highlighting the role of active personal agency in individuals' interactions with their environment.

The reciprocal and transformative processes of internalisation and externalisation describe movement of collective discourse or conceptual understanding from the extrapersonal or social world to the intrapersonal world, the reorganisation of the individual's relationship with the world, and the consequent emergence of aspects of this reorganisation in further interactions (Valsiner, 1997b). Internalisation is a process in which "semiotic material is 'brought over' from the social domain into the personal domain. This process involves the person's active construction of personal meaning systems" (Valsiner, 1997b, p. 245). Externalisation is the counter-process, which often occurs immediately (Valsiner, 1997b), in which "once-social-become-personal material (ie external-made-internal-material) is injected back into the social environment" (Lawrence & Heinze, 1997, p. 47). These reciprocal processes are active and constructive (Valsiner, 1997b), involving a metamorphic incorporation of sociocultural resources into an individual's self-construct (Lawrence & Valsiner, 1993), the reconstruction of the individual's unique personal meaning systems, and the externalisation of these changed personal meaning systems through some form of action which results in a reorganisation of immediate relationships with the social world. As Valsiner (1997b) points out, these processes assume and maintain a qualitative difference between the personal and social worlds, thus avoiding the reduction of individual subjectivity to a purely social phenomenon. At the same time, however, these distinct worlds are regarded as inclusively rather than exclusively separated within the whole (Valsiner, 1998). Inclusive separation describes a system where the parts are clearly distinguishable from each other and interact with each other in particular ways, while still maintaining the integrity of the system as an integrated whole (Valsiner, 2001). Inclusive separation describes the relationship between participants and the field of participation as one of dynamic interdependence and mutual constitution, while exclusive separation eliminates the whole by disconnecting the parts from each other and from the totality. The notion of inclusive separation permits an exchange between personal and social, since they are distinguishable from each other, but embeds the exchange within a "dynamic feed-forward loop" (Valsiner, 1997b, p. 247) which mediates ongoing development of all parts of the field of participation.

Transformative internalisation and externalisation therefore provide a means by which both the "*sociogenetic origins* of human intrapsychological functions" and "the *relative autonomy* of the person's intrapsychological processes from their immediate interpersonal (social) contexts" (Valsiner, 1997a, p. 288, author's italics) can be explained. The notion of inclusive separation allows simultaneous maintenance of distinctness and mutuality, and explains how the individual

both contributes to, and learns from, social activity which is mutually constituted by all relevant parts of the field of participation.

The notion of a bi-directional exchange between the social and the personal suggests the existence of some form of boundary zone in which internalisation and externalisation processes are intertwined in the present time and in which active, constructive personal meaning systems enable interaction and development. According to Valsiner (1997b), it is in this boundary zone that the reciprocal processes meet, and in their interaction produce a range of results, some of which are potentially predictable and some of which are novel and surprising. In this way he is able to posit a mechanism which explains the constructive and idiosyncratic nature of internalisation and externalisation as one where the social is not imprinted on the individual, but interacts with the individual's existing understanding and contributes to the development of a unique learning trajectory.

Valsiner further points out that the importance of externalisation is not limited to its essential role in the constructive exchange between the personal and social. Acknowledgement of externalisation is critical in a technical sense (Valsiner, 1997a) since it provides the only means of investigating intrapsychological or intramental processes. An individual's thinking and mental processes are not available to anyone other than the individual, and any action – whether verbal or non-verbal – which is intended to reveal these processes to others involves externalisation (Valsiner, 1997a). In other words, any analysis of learning and development – or indeed any intrapersonal process – is dependent on the externalisation of what has been internalised: “intramental processes are only accessible if their externalisation is the target of investigation” (Valsiner, 1997a, p. 304). Similarly, Winegar (1997) points out that only externalisation is observable, and inferences can be drawn about internalisation only through observation of longitudinal acts of externalisation. This notion is consistent with the sociocultural interpretation of concepts as discursive tools of sense-making and communication (Säljö, 1999): transformative internalisation of the social use of these tools is followed by externalisation in the context of ongoing activity and the evidence of conceptual change is located in the externalisations of the participants as they develop increasing facility in the use of these discursive practices. Further, these processes illuminate a plausible mechanism for cognitive socialisation by linking intramental cognitive restructuring to the social context which provides the necessary impetus and momentum, and by explicitly focussing on feed-forward as a means of sustaining dynamic change. It is important to point out that externalisation is not a direct copy of what has been internalised, since externalisation is also transformative (Wells, 1999b), however it nonetheless provides useful and critical insight into the intrapersonal world.

In the current study, the notions of transformative internalisation and externalisation provide the basis for developing the data collection and analysis processes. Rather than focussing on written evidence to support the occurrence of conceptual change, a conversational emphasis has been chosen, in order to permit analysis of the externalisations of different participants in the context of both interactions with peers within workshop sessions and interviews with the researcher.

Interpretation of these externalisations, specifically the ability to distinguish between the pharmacy and chemistry contexts when engaging in discussion, and the use of language appropriate to the context, provides the basis for evaluating the presence and extent of conceptual change within the current model. In keeping with Winegar's (1997) argument in favour of the evaluation of longitudinal changes in externalisations, the time frame of the study is sufficient to allow an investigation of the persistence of any changes. Written representational evidence, including material produced during interviews, is used in support of spoken externalisations, but is not the major focus of the study. It is acknowledged that the use of written representations is critical to the overall development of community membership, however the current investigation was not intended to study this aspect in depth.

Further, an appreciation of the ongoing feed-forward nature of internalisation and externalisation underpins the choice and structuring of workshop sessions as the learning environment under investigation. The two hour duration of these sessions permits students to engage in extended discussion of the concepts and the problems to be addressed, and the activities themselves are chosen to stimulate this discussion. The classroom is arranged to facilitate small group interaction, with students grouped around tables such that all members of a group can engage in direct eye contact with each other. Groups are self-selected in order to allow students to work with peers with whom they feel comfortable, thus promoting a non-threatening social context, and are limited to a total of six participants so that all have the opportunity to contribute.

Collaborative learning and intersubjectivity

Transformative internalisation and externalisation provide an explicit mechanism for understanding the ways in which collective and individual meaning are exchanged and evolve through ongoing discourse, and are thus central to the notions of collaborative learning and intersubjectivity. Discourse or dialogue of any type, in any setting, is a communicative activity, however what is communicated varies significantly between settings and groups of individuals. Wells (1998) describes "progressive discourse" (p. 8), which is designed to promote collaborative knowledge construction and conceptual development. The primary characteristic of this mode of discourse is a common commitment among all participants to engage in discussions which work towards a satisfactory joint understanding, are based on an examination of evidence, expand the range of propositions, permit critical analysis of beliefs, and build on previous utterances. This commitment may be explicit, tacit, or even indirect, but is critical in distinguishing between collaborative learning endeavours and those which simply involve individuals working contemporaneously on a common task.

The current model proposes that conceptual change is promoted by collaborative learning, and that activities in which the participants engage collaboratively are likely to lead to some form of conceptual change. Collaboration is a central aspect of sociocultural approaches to learning and development, since sociocultural theories do not consider individuals in isolation from their social

milieu. Rogoff (1998) describes collaboration as a format which encompasses a range of modalities, "including face-to-face mutual involvements such as routine conversation, teaching and tutoring; side-by-side engagements; and participation in shared endeavours without physical copresence (such as occurs between correspondents, between authors and readers of articles, or in remembered conversations)" (pp. 679-680). In the current study, collaboration is primarily evident in group discussion and coordination of problem solving. Hatano & Inagaki (1991) explore the processes by which collective discourse facilitates the development of conceptual understanding, and identify the seeking of clarification, challenging of others' utterances and coordination of distributed discourse as critical aspects of conceptual development.

Rogoff (1998) also identifies the essential characteristic of a collaborative endeavour as the presence of shared thinking, or intersubjectivity. Mercer (2000, 2004) uses the terms 'interthinking' and collective thinking with similar, although not identical, meanings. Intersubjectivity pertains to the way in which meaning, values and understandings are shared within a group of people with the resultant construction of a temporary mutual collective reality (Bonk & Kim, 1998), and is described by Verba (1994) as a belief by the participants that they share a common perception of the situation in which they are engaged. In considering intersubjectivity, it is not essential for perfect agreement between the individuals to exist, but rather that joint understanding of the task and its goals create a common ground for initiating coconstruction of a solution, and that participants enter into each other's frame of reference (Tudge & Rogoff, 1989). Indeed the existence of different perspectives within the group is likely to be beneficial in providing opportunities for discussion of the problem and co-ordination of joint activities to solve it. It is not assumed that the individual is an undifferentiated part of the whole, but that the individual contributes his or her own perspective to the collective shared reality in an inclusively separated manner.

In the current model, it is hypothesised that the nature of intersubjectivity and the extent to which it develops is closely related to the quality of the progressive discourse and cycles of internalisation and externalisation, and that the degree and nature of conceptual change mirrors to some extent the degree and nature of intersubjectivity developed within each participant group. Groups which display a greater commitment to developing a joint understanding are likely to produce more externalisations and thereby contribute to the collective resources for internalisation, thus creating the potential for a greater degree of shared meaning. However, it is also possible that high levels of intersubjectivity may act on occasion to hinder conceptual change. In situations where agreement is very readily obtained, existing discursive patterns may be simply reinforced rather than challenged (Roschelle, 1992), and off-task activities relating to shared experiences outside the classroom context may create diversions. As a consequence, cognitive socialisation may be constrained by particular instances of intersubjectivity which lead either to distraction from the topic, or to a minimisation of differences in perspective amongst the participants which reduces the range of social resources available for transformative internalisation.

As previously described, the learning environment in the research study is structured to facilitate collaboration in learning, in that groups are self-selected to enable established social relationships to be maintained and strengthened, and the activities are designed to promote discussion of problem-solving strategies and outcomes.

Zone of proximal development

As outlined in a previous section, the processes of contextually situated internalisation and externalisation are critical in mediating learning and development, and within the discourse model of conceptual change they constitute the mechanisms by which zones of proximal development (ZPD) are created and maintained. As described in chapter 2, the term ZPD was originally used as a cultural tool by Vygotsky to describe the relationship between instruction and development (Chaiklin, 2003), but the concept has been modified by later researchers to encompass the notion of a situation within which learning and development are intended to occur. The ZPD as used in educational contexts can be broadly defined as a space within which individuals collaborate on activities which they cannot successfully complete alone (Newman et al, 1989); it is uniquely created in the course of each specific activity or setting (Tudge & Winterhoff, 1993) through tool-mediated interactions between participants in the activity (Wells, 1999b) and involves transformations of understanding, behaviour and identity.

This definition of the ZPD is useful as a means of considering the milieu within which concept formation and change occur. Each interactive system is constituted by the individuals involved, with their varied personal histories and trajectories, together with the physical, social, cultural and historical environment. In classroom learning, the ZPD is not the classroom itself but the activities occurring within it, and the classroom acts as a source of both affordances and constraints to the learning which occurs within the ZPD. A ZPD may be asymmetric (Tudge & Winterhoff, 1993) in that it involves participants of different centrality of membership of a community of practice, or more symmetric (Pontecorvo, 1993) and involving participants of a similar standing (Tudge, 1990; Forman & McPhail, 1993).

Within the ZPD, interactions are primarily mediated by discourse (Wells, 1999b), including language and other representational systems, and learning occurs as individuals engage in transformative internalisations and externalisations of the discourse in collaborative action. The activities within a classroom designed to promote conceptual change can be formulated in such a manner as to encourage talking science (Lemke, 1990), thereby providing the participants with the opportunity to construct a collective scientific discourse which can be uniquely appropriated by each learner (Wells, 1999b).

The notion of the ZPD is a useful tool for the study of conceptual change from a sociocultural perspective, since it focuses attention simultaneously on many relevant aspects of the process. As Valsiner and van der Veer (1993) have pointed out, however, the concept as usually employed

suffers from a number of drawbacks, most notably a functional inability to illuminate the processes of internalisation and externalisation which are at work in the emergence of new conceptual understanding. Within the current model, these latter processes are explicitly highlighted, thus enhancing the utility of the ZPD as a conceptual tool or framework. The use of the ZPD also enriches the description of Rogoff's (1998) planes of analysis model, by highlighting those characteristics of the interpersonal plane which have the potential to provide a favourable environment for conceptual change learning.

The empirical research study reported in this thesis is underpinned by the notion that learning is occurring within multiple overlapping zones of proximal development, however the detailed characterisation of these zones is not a specific focus of the analysis.

Structured teaching and modeling

Newman et al (1989) have suggested that discourse within the ZPD is often indeterminate, and in an earlier section of this chapter it was proposed that groups of learners who are at best peripheral participants in a community of practice are likely to construct shared ways of thinking and talking which have features unique to the particular small group rather than to the community. This is especially likely in the classroom, where contact and opportunities to engage in dialogue with community members is minimal. Roschelle (1992) describes the achievement of convergence between pairs of students as they collaboratively co-construct conceptual understanding and shared meaning in relation to a physics task, but points out that this often results in imprecise, unscientific and ambiguous terminology. As a consequence, students may not necessarily develop discursive patterns which would be validated and accepted by the community, although they may develop tools which serve their own purposes and those of their peers. In order to facilitate cognitive socialisation through the appropriation of discursive tools which are both useful and valid for use within the community, the conceptual change model incorporates as a critical feature specific teaching and modeling of the concepts and ways of speaking which are considered appropriate within the community (Wells, 1999b). The ZPDs which are created within the classroom are thus characterised by a mixture of symmetric and asymmetric collaboration.

This approach is consistent with Vygotsky's doctrine of scientific concepts (van der Veer & Valsiner, 1991; Karpov & Haywood, 1998; Wells, 1999b; Karpov, 2003). Vygotsky related the creation of a ZPD to formal schooling: "to create the ZPD, that is, to engender a series of processes of internal development we need the correctly constructed processes of school teaching" (Vygotsky, 1933/1935, p. 134, cited in van der Veer & Valsiner, 1991, p. 331). Karpov (2003) points out that Vygotsky specifically regarded formal school instruction as critical in the learning of scientific concepts, in contrast to the spontaneous concepts which children learn through everyday experience. From a discourse perspective, children develop ways of describing and representing their experiences which communicate meaning to their peers but which are often idiosyncratic. While spontaneous concepts provide a foundation for the learning of scientific

concepts, the latter cannot generally be discovered through personal exploration since they are socioculturalhistorical constructs emerging from a wide range of human experiences (Karpov & Haywood, 1998; Karpov, 2003) in society – in other words, practices which have evolved in specific scientific communities. Dekkers and Thijs (1998) concur with this view and suggest that teaching is critical in highlighting differences in the meanings communicated by the use of particular words. Vygotsky accorded a primary role to “*initial verbal definition*” (Vygotsky, 1986, p.148) in the development of scientific thinking, and promoted well-organised instructional processes as the means by which scientific concepts could be acquired, developed and used. Karpov (2003) develops Vygotsky’s contention and argues in support of the effectiveness of appropriately structured teaching and modeling in promoting learning. He describes studies by Russian followers of Vygotsky which suggest that the learning of spontaneous concepts is fundamentally different from the learning of scientific concepts. The former involves comparisons and generalisations about the characteristics of a class of objects, and often results in misconceptions when the generalisations are not based on significant or essential characteristics. The latter occurs through exposure to a more systematic presentation of the salient characteristics of a phenomenon, often complemented and organised by some form of specialised representational systems. The use of structured teaching thus affords the development by learners of tools and discursive practices which facilitate their participation in scientific communities; Karpov (2003) argues that such participation is more often hindered when teaching is based on the notion of learners attempting to discover scientific concepts for themselves.

Teachers are able to demonstrate by example, ask leading questions, suggest initial steps to a problem solution (Chaiklin, 2003), reformulate expressions, request elaborations, summarise discussions and model appropriate discursive practices in the context of meaningful activities (Wells, 1999b). Northedge (2002) argues that the teacher’s primary role is to facilitate collaborative meaning making, and that teaching should initially involve engaging students in familiar discourse, followed by guided excursions into the new discursive practices. These excursions comprise teaching and learning activities which create zones of proximal development within which teachers and students are able to engage in discourse more aligned with the discursive practices of the new community than the students are currently able to manage without support. Northedge argues that teachers’ roles within the ZPDs are multifaceted, including coaching, modeling accepted discursive practices, interpreting student meanings, and elaborating and reformulating their discursive endeavours.

By extension, the proposed conceptual change model adopts the stance that students do not spontaneously develop discursive practices which have evolved within a community over time without relevant teaching which models it. In other words, structured and explicit teaching is critical in facilitating cognitive socialisation. This aspect is approached in the current study in three main ways. Firstly, initial verbal definition (Vygotsky, 1986) is provided in the form of articulation of the new discursive practices in lectures (the lecturer is the researcher) with written reinforcement in the course notes which support the lectures and workshops. Secondly, the learning environment

includes learning activities which are designed and structured so as to promote the formation of zones of proximal development involving the potential for both symmetric and asymmetric collaboration. In this way, students are encouraged to attempt the discursive practices of the new community in ways which are meaningful for them. Thirdly, the teaching is carried out by teachers who are able to engage in and demonstrate discourse which is characteristic of the two relevant communities of practice – chemistry and pharmacy. In addition to specifically indicating the areas of conceptual difference between them, lecturers and tutors actively and intentionally carry out the roles suggested by Northedge (2002) in their interactions with students. This explicit coaching, modeling, interpreting, elaborating and reformulating is critical in providing the resources for transformative internalisation and evaluating student externalisations in comparison to community norms. Teachers within the tertiary learning environment need not necessarily be members of the communities themselves (although in the case of the current research study they are), but should be familiar with their discursive practices and able to use them appropriately and effortlessly in interactions with students. The study further allows comparisons to be made between student discourse in the presence and absence of teachers, and an evaluation of the effect of expert assistance on subsequent student interactions and discourse.

Conceptual change outcomes

An important consideration in the articulation of a conceptual change model is the means by which change is identified. As outlined previously, in learning to talk science, individuals learn to participate in the discursive practices of the science community, and their externalisations (including talk) provide evidence on the basis of which already accepted members of the community decide whether to recognise the individual as a legitimate member of the same community. Evidence for conceptual change is therefore situated in the community, and encompasses the identification of appropriate contextualised tool use. This sociocultural approach contrasts with other perspectives on conceptual change outcomes, which have tended to focus on demonstrating a change in performance in abstracted assessments such as written tests of competence or knowledge to provide evidence of conceptual change (eg. Fast, 1999; Huddle, White & Rogers, 2000; Zeilik & Bisard, 2000; Diakidoy & Kendeou, 2001; Edens & Potter, 2003; Roche, 2007).

Support for the use of discursive evidence for conceptual change is found in the work of Lemke (1990), Hatano and Inagaki (1991) and Herrenkohl and Guerra (1998). Lemke (1990) is particularly concerned about the lack of consistency between learning and assessment in science classrooms. He points out that “despite all we know and acknowledge about the social nature of classroom learning, we still test students under conditions in which social skills become irrelevant...classroom learning is social; classroom testing is individual” (p. 80). Herrenkohl and Guerra (1998) contend that despite all the evidence supporting the notion that students learn by active involvement in tasks that promote learning, opportunities to engage in active practice and discussion of concepts are not widespread. Further, they argue that assessment or evaluation of

learning has traditionally focussed on the recitation or reproduction of answers to teacher questions, either verbally through teacher-student exchanges in school classrooms, or in written form through formal tests and examinations. Given a perspective on learning focussed on demonstrating the ability to participate in culturally valued and relevant activities, they argue that “learning is a process to be accounted for in the context of the actual community and not in individually administered examinations alone” (p. 435). Hatano and Inagaki (1991) describe a number of studies in which group discussion provides evidence of both the challenging and enhancement of student conceptual understanding.

These authors therefore support the contention that legitimate evidence for learning, including conceptual change learning, must include data other than that generated by individual written or verbal testing. The current model approaches this through the use of individual and collective discourse in which cycles of internalisation and externalisation are promoted, and the student patterns of discourse are evaluated in terms of those used and accepted by members of the pharmacy community.

In this model, therefore, conceptual change is perceived as operating at the level of both individual understanding and community participation. Change has occurred when the individual is both capable of participating more appropriately in the discursive practices of the relevant scientific community, and able to identify when it is pertinent to do so. This capability is evaluated and validated by reference to the discourse of the community as demonstrated by more central participants. Further, the capability must be maintained for a reasonable period following instruction: in other words, change needs to be persistent in the context of authentic activity for it to be considered genuine and not simply an artefact of examination preparation. The need for persistence is in accord with Winegar’s (1997) comment that internalisation can only be inferred “from *longitudinal* changes in externalisation” (p. 31, emphasis added).

In the current study, conceptual change is inferred when students explicitly differentiate between chemistry and pharmacy in discussion about acids and bases, and when they are able to communicate using discursive patterns which are appropriate to the context. The development of these patterns is investigated by means of an interview immediately following the teaching semester, and the persistence of any changes is evaluated through a final interview five months later, after a long summer vacation. Conceptual change outcomes are also identified as they emerge in and from classroom discussions involving students and teachers.

Interdependence of individual and social

The preceding discussion has outlined conceptual change as a cognitive socialisation process involving interactions within a social environment which leads to the emergence of personal understanding and discursive competency, which in turn allows an individual to participate more effectively in the practices of a specific professional community. It is thus possible to identify three

dimensions of interest to an investigation of the processes and outcomes of conceptual change: the developing individual, the interpersonal interactions which occur within the environment, and the community of practice itself. Rogoff's (1998) planes of analysis model has previously been suggested as a framework for analysis and interpretation of the data, however it can also be used as a theoretical framework for consideration of the interdependence of individual and social in conceptual change learning. This model is particularly apt because it maintains and illustrates the notion of inclusive separation as described by Valsiner (1998, 2001). Within this model, Rogoff suggests the existence of three planes: the personal, interpersonal and community or institutional. The personal plane focuses on how individuals change through their participation in an activity, and how such participation prepares them for subsequent engagement in associated activities. The interpersonal plane focuses on the ways in which activities are communicated and coordinated between individuals in order to facilitate or constrain particular types of participation, and the community plane focuses on institutional practices and cultural values which have developed over time. These planes are always present but it is possible, and indeed useful, to keep one at a time in focus in the foreground, with the others considered as background. Rogoff (1992) describes these planes using as analogy the interdependence of organs in a body, which can be studied by focussing on each one separately, but the function of the whole cannot be inferred without reference to the backgrounded whole. Similarly the role of parent cannot be defined in isolation from the role of child – the roles are mutually defining and neither exists or has meaning in the absence of the other. Highlighting or foregrounding one plane serves the purpose of focussing temporary attention on the contributions of that plane, but meaning is lost if the foregrounded plane is separated from its background. In other words, attempting to understand interactions between individuals is meaningless without a consideration of the ways in which each individual develops during the course of the interaction, and without examination of the interaction against its cultural and historical backdrop. The planes are not seen as being identical with levels, in the sense that one is not considered to be higher or lower than another; the emphasis is rather on bringing into focus one plane in the foreground for the purpose of closer scrutiny, with the others in the background. Within these planes, particular processes occur and interrelationships exist which facilitate the functioning of the system. With respect to the personal plane, Rogoff suggests the operation of a “personal process by which, through engagement in an activity, individuals change and handle a later situation in ways prepared by their own participation in the previous situation” (Rogoff, 1995, p. 142). From a discourse perspective, this process corresponds to transformative internalisation and externalisation of the social practices in which the individual is engaged. With respect to the interpersonal plane, Rogoff describes “the system of interpersonal engagements and arrangements that are involved in participating in activities...which is managed collaboratively by individuals and their social partners in face-to-face or other interaction” (p. 146). The interpersonal plane is thus constituted by the situated tool-mediated activities in which individuals interact and engage in appropriate discursive practices. With respect to the community or institutional plane, she uses the metaphor of apprenticeship to signify the community process whereby part of the purpose of active participation by individuals is the development of more mature participation by those members

who are initially less experienced. This plane therefore corresponds to the social and cultural practices, including discursive practices, which constitute a community of practice.

From a theoretical perspective, this approach provides a framework which permits an exploration of the evolution and development not only of the individual, but also of the activities in which the individual is engaged. Moreover, the planes of analysis model provides a means of exploring changes in community practices over time, where developments on both the personal and interpersonal planes are gradually incorporated into the social and cultural norms of the community as it evolves. Development in all three planes can therefore be conceptualised as proceeding along trajectories which are mutually interdependent yet distinct.

In the current study, the major focus is directed towards the changes occurring within the personal and interpersonal planes, since the timescale of the study is insufficient for observation of any changes on the community plane. Moreover the participants cannot be considered central community participants even by the end of the study and are thus unlikely to influence any of its core practices.

The use of Rogoff's approach also addresses an analytical challenge common to all sociocultural researchers – that of maintaining both sociocultural integrity and clarity in relation to descriptions of the mutual constitution and coevolution of individual and social processes in conceptual change learning. Both processes and outcomes of conceptual change are specifically analysed on the personal plane through the use of individual developmental/learning trajectories derived from analysis of classroom behaviours and individual interviews, and on the interpersonal plane through analysis of group interactional dynamics as observed in the classroom and verbalised through interview responses. On both planes, multiple behavioural aspects both spoken and non-spoken are evaluated, and the interdependence of individual and social is demonstrated through interweaving descriptions of the personal and interpersonal planes of analysis to provide evidence in support of the model.

3.5 Research questions

The discourse model of conceptual change outlined in this chapter is a unique approach to the mechanisms and results of learning, and the empirical research study is designed to investigate its utility as a theoretical, analytical and interpretive framework. Specifically, the following questions underpin the study:

1. What evidence can be found for the presence of conceptual change learning in the context of novices studying introductory pharmaceutical concepts and terminology in the formal university setting?
 - To what extent do students learn and use pharmaceutically accepted patterns of discourse?

- To what extent do students develop the ability to discriminate between contexts and use patterns of discourse which are appropriate to the setting?
 - How persistent is any conceptual change which is identified?
2. How is the process of conceptual change learning mediated?
 - What types of interactions occur within small student peer groups in formal workshop settings?
 - In particular, what are the characteristics of student discourse?
 - How do these interactions and discourse practices act as affordances or constraints on conceptual change learning?
 - How do interactions between students and tutors act as affordances or constraints on conceptual change learning?
 - What relationships exist between the nature of the externalisations by participants, the intersubjectivity achieved and conceptual change outcomes?
 3. What, if any, are the implications for curriculum design and delivery?

These questions were addressed primarily in the intensive study described in chapter 5, however investigation of the entire cohort, which constituted the population for the specific context in which the study was situated, was also undertaken in order to ascertain both similarities to and differences from the findings of previous investigations, and to evaluate the possibilities of generalising the results of the intensive study to the rest of the cohort. Both the methodology and findings of the population study are described in chapter 4.

CHAPTER 4 POPULATION STUDIES

4.1 Introduction

This chapter outlines investigations carried out with the entire population of first year Pharmacy students at the University of Sydney. Although the primary focus of the research study was an intensive investigation of a small sample drawn from the population (chapter 5), investigation of the entire cohort was considered appropriate for two primary reasons. Firstly, as summarised in chapter 2, previous research has highlighted specific conceptual difficulties experienced by students with this topic. Conduct of a study with elements similar to those already reported, but in a different population, afforded the opportunity for comparison with this previous work. Secondly, since the sample selected for more intensive study was chosen for convenience rather than as necessarily representative, the availability of cohort statistics permitted evaluation of the extent to which the sample reflected the demographics, attitudes and conceptual understanding of the population. This correspondence is important in validating the generalisation of findings beyond the sample.

The sociocultural perspective which underpins this investigation suggests that aspects of the setting were likely to have played a significant part in shaping student responses, therefore contextual details of the data collection process are highlighted where relevant.

In order to allow comparisons with the most closely related research, a survey containing a range of item types was designed and administered to the population. Both closed (multiple/choice and true/false) and open (free response) items were included since they probe different aspects of conceptual understanding. A number of items were taken directly from prior studies, while others were modified on the basis of difficulties encountered by previous cohorts of pharmacy students at the University of Sydney and the specific discourse of pharmacy. Data relating to attitudes towards chemistry were included to provide insight into students' interest, confidence and perceptions of the relevance of chemistry. Demographic data were also collected to permit evaluation of the characteristics of the cohort, particularly in terms of prior exposure to chemistry and language background, since these two dimensions were considered to be significant influences on conceptual understanding as manifest in discursive practices.

4.2 Context for the study

The study was conducted with a first year cohort of 190 Pharmacy students at the University of Sydney in 2001. All students were enrolled in the Bachelor of Pharmacy degree, a four-year full-time program delivered primarily face-to-face. The immediate setting of the study was a compulsory unit of study, Introductory Pharmaceutical Science (IPS), offered in second semester of first year, which was designed to introduce students to important concepts underpinning the science of pharmacy. All students in the study were attempting the unit for the first time. A major topic

within this unit, 'Acids and bases', had been associated with significant difficulties in previous student cohorts as outlined in chapter 3. This topic included 10 hours of lectures and 6 hours of small group activity, and comprised approximately 25% of the unit. Lectures were given once only, however the cohort was divided into four groups for small group activities. The researcher was both unit coordinator and sole lecturer; small group activities were facilitated by two tutors, of whom the researcher was always one. The researcher had eight years' experience in teaching and coordinating this unit.

Students gain entry to the Bachelor of Pharmacy through one of two routes. The majority of successful applicants enter through a state-wide competitive performance-based selection system which is open to Australian and New Zealand citizens, and Australian permanent residents. Applicants may have completed secondary education only, in which case their application is based on secondary achievements, or have completed a minimum of one year of full-time tertiary study, the results of which form the basis for entry. All successful applicants are also required to reach a predetermined standard in an independently administered test of verbal and quantitative reasoning. Competition for places is high with the result that entrants generally require performances that place them amongst the top 7-8% of tertiary applicants in the state.

Additional places are available for international students, who apply individually for entry. Different criteria are used to evaluate these applications, although academic merit is central. Achievement of a specific standard in an international test of English language skills (IELTS) is required together with evidence of results in either secondary or tertiary education which are comparable to those gained by successful local applicants. They are not required to complete the test of verbal and quantitative reasoning.

4.3 Data collection methodology

Instrument

As outlined earlier in the chapter, a survey instrument was developed to probe conceptual understanding of 'Acids and bases', based on both findings from prior published research and significant conceptual difficulties experienced by previous pharmacy students as identified by the researcher. The focus of the survey was on probing perceptions of acid/base characteristics, the significance of specific parameters (pH and pKa), and conceptual understanding of strength/weakness. A range of item types (multiple choice, true/false and short answer) was used in order to test factual recall, application and interpretation of concepts, and contextual discrimination (Tables 4.4 and 4.5, Appendix B).

The instrument also included items relating to demographics (Table 4.2, Appendix B) and perceptions of chemistry (Table 4.3, Appendix B). Since the cohort entering pharmacy has traditionally been diverse in terms of age distribution, language background and prior university

study, these items were important descriptors of this diversity. Of particular relevance were the items relating to the extent of exposure to tertiary level chemistry, and the language which students considered as their primary tongue. Students with extensive experience of university chemistry would be expected to have greater familiarity with the discourses of the science community than those with more limited experience, while the complexity occasioned by the coexistence of everyday and scientific discourses would be magnified for students for whom a language other than English was their primary communication tool.

Approval for administration of this instrument was obtained from the Human Ethics Committee of the University of Sydney. All procedures were carried out in accordance with the approved protocols.

Initial survey

The full instrument was administered during the fourth last week of first semester 2001, approximately two months prior to commencement of Introductory Pharmaceutical Science. The majority of students were concurrently learning about 'Acids and bases' in a chemistry unit of study, the exceptions being those students who were exempt from this unit on the basis of prior study. Students completed the survey as the first activity of a scheduled two-hour tutorial class, with thirty minutes allowed for its completion. An academic colleague uninvolved in the study was responsible for administration and collection of the forms; he reported that the time allocation appeared to be appropriate.

Final survey

A modified version containing a subset of the items was administered during the second week of first semester 2002, approximately five months after completion of Introductory Pharmaceutical Science and ten months after the initial survey. Demographic information was omitted in this version, as were a number of conceptual understanding items which analysis of the initial survey had indicated were peripheral to the focus of the study. The format and wording of retained items were identical to those of the initial survey. The cohort, however, was not identical to that which completed the initial survey, although the overlap was approximately 80% and all students had completed Introductory Pharmaceutical Science within the previous two years. Survey completion took place during a whole-class lecture in Medicinal Chemistry 2A, a compulsory second year unit which builds on much of Introductory Pharmaceutical Science including 'Acids and bases'. A small amount of revision of the concepts covered in Introductory Pharmaceutical Science had been provided to the students prior to their completion of the survey.

4.4 Analysis

Tabulated data can be found in Appendix B, and a summary of the important findings is outlined below.

Demographic data, attitudinal variables, multiple choice and true/false responses

These data were tabulated as percentages and are presented in 'Results' and Appendix B.

Short answer responses

A coding scheme was developed and applied to the analysis of written responses to three key conceptual understanding items: 'List the major characteristics of acids/bases' (Table 4.5a), 'What is meant by the pKa of an acid/base and what information does it provide?' (Table 4.5b) and 'What is the difference between a strong acid/base and a weak acid/base of the same concentration?' (Table 4.5c). All responses to these items in both the initial and final surveys were coded by the researcher using a combination of *a priori* categories and categories which emerged from the data. These categories were then grouped to provide a more general level of classification as outlined in the 'Results' section and tables (Appendix B).

Frequency distributions were compiled and the results are presented in 'Results' and Appendix B.

4.5 Results

In order to provide contextual detail for the conceptual understanding findings, pertinent descriptive data are presented initially in this section. Response rates were analysed to estimate the validity of assuming the data to represent a population, and the demographic and attitudinal data were included to provide a general description of the relevant characteristics of that population. The conceptual understanding data were then analysed against the background of these descriptive data. All tables are included in Appendix B.

Response rates

The initial survey achieved a very high response of 96% (Table 4.1), which validates use of the data to describe the cohort of first year pharmacy students as a defined population. The high response rate is likely to be attributable primarily to the mode and timing of administration, in that it was distributed during a tutorial at which attendance was closely monitored, and was therefore maintained at close to 100%. Further, students were given ample time to complete the survey in a room with comfortable seating and air temperature, and the tutorial activities were delayed until thirty minutes after the usual commencement time.

Logistical restrictions on the administration of the final survey ten months later resulted in a significantly different context for completion compared with the initial survey, which is likely to have contributed to a reduced response rate. The final survey was conducted during the following academic year, and therefore the original cohort could not be easily contacted. A best possible match was made with Medicinal Chemistry 2A, in which 155 of the original cohort of 190 were enrolled (82%) together with an additional 38 students who had completed Introductory Pharmaceutical Science prior to 2001. The survey was therefore administered during a Medicinal Chemistry lecture, however the lack of attendance monitoring at lectures appeared to promote greater absenteeism in comparison to the initial survey. As Table 4.1 indicates, the overall response rate for the final survey was approximately 78%, or 150 responses. Of these, between 120 and 126 represented responses from students who had also completed the first survey. Given that the maximum number of students able to complete both surveys was 155, this represented an effective response rate of between 77% and 81%.

Demographic data

The majority of students were in their first year of university, having completed secondary studies the previous year, therefore the age distribution was weighted in favour of 17 to 19 year olds (74%) (Table 4.2). However a significant minority (31%) had completed some tertiary study, ranging from one to ten years. Many individuals in this group (74%) brought significant prior experience of university level chemistry, with 49% claiming more than 100 hours of formal teaching. The sociocultural conceptual change model described in chapter 3 relies on student ability to differentiate between chemistry and pharmacy discourse concerning acids and bases, therefore the wide range of exposure to the discourse of chemistry within the cohort was of importance.

Gender distribution was heavily biased in favour of females (Table 4.2): this was consistent with recent trends within the Bachelor of Pharmacy degree enrolment profile.

The relative proportion of local (89%) and international (11%) students (Table 4.2) was also consistent with recent enrolment profiles, although the trend is towards gradually increasing international numbers. Students who completed studies within and outside Australia were potentially exposed to different chemistry content, teaching modes and discourses, thus increasing the diversity of backgrounds within the cohort.

Of particular import for a discourse model of conceptual change was the data relating to language background. A large proportion of students (45%) reported that English was not their primary tongue, while 71% reported that a language other than English was spoken at home (Table 4.2). The most common primary languages were Chinese (including Cantonese and Mandarin), Arabic and Vietnamese. The multilingual nature of the cohort therefore added an extra dimension to the discourse complexity resulting from the diversity of backgrounds described above.

In summary, the significance of the demographic data is that for any individual both everyday and scientific discourse relating to acids and bases on entry to Introductory Pharmaceutical Science was shaped by a range of influences, primarily the extent of prior exposure to chemistry, language background, and by inference, differences in teaching modes. This research does not seek to explain the impact of these factors on conceptual change learning about acids and bases, but rather to present a model which is broadly applicable to a diverse population such as that encountered in the Bachelor of Pharmacy degree.

Attitudes to chemistry

The results (Table 4.3) indicated that students were generally positive about the study of chemistry, with approximately half finding it enjoyable (items 1 and 4), and more than 60% indicating interest (items 2 and 12). These findings are consistent with high student perceptions of the relevance of chemistry to the study and practice of pharmacy (at least 90%, items 6 and 10) and moderate perceptions of the overall relevance of chemistry to life (items 5 and 9). Confidence levels showed a greater spread of perceptions (items 3, 8 and 11), although these may have been influenced by the timing of the surveys (close to the students' first university examinations in the case of survey 1, and two weeks into a new semester after a long vacation for survey 2).

In terms of a sociocultural model of conceptual change based on discourse, these results suggested that students were likely to engage with the content, as it was perceived to be both interesting and relevant, however the diversity of confidence levels may have influenced the willingness of some to participate in discourse if they perceived that this might display ignorance or uncertainty.

Comparisons between the initial and final surveys are problematic, since as outlined above, the cohorts were different, and therefore no statistical analysis was undertaken. Few differences were apparent in the raw data, with perhaps a trend towards increasing confidence (items 3 and 8) and perceptions of everyday relevance (items 5 and 9), however these interpretations need to be treated with caution.

Conceptual understanding

As outlined in chapter 3, the sociocultural conceptual change model involves students discriminating between contexts, and engaging in discourse and other practices appropriate to the setting in which they are situated. Prior to commencing Introductory Pharmaceutical Science, students had little, if any, exposure to any context in which pharmacy chemistry was relevant, therefore the responses to the initial survey serve to highlight understandings which had evolved in other contexts, primarily educational. Some of these concepts were widely applicable, however others were restricted to a particular set of constraints of which students were apparently not always aware.

As previously described, both closed and open items were used to investigate conceptual understanding. With respect to the closed questions (Table 4.4), three types of probe were included: items which focussed on learned facts (items 2, 3, 4 and 7), items which probed the assumptions students had drawn from learning experiences (items 1, 5 and 6), and items which required interpretation or application (items 8, 9 and 10).

Students had few difficulties with the first cluster of items which primarily tested factual recall, and which dealt with 'universal' or non context-dependent concepts. More than 80% were comfortable with the ionic composition of both distilled water (item 7) and rainwater (item 4) while in excess of 90% recognised the fundamental definition of neutrality and the key acid-base chemical reaction (item 2).

More difficulties were experienced with the second cluster, which dealt with the concepts of acid/base strength and the significance of pKa. These concepts are highly context-dependent in that they are associated with different meanings and significance when used in pharmacy as compared to chemistry. In particular, the concepts are closely linked in pharmacy, in that pKa is a measure of strength. However in inorganic chemistry, this link is not as apparent, as the criteria for classifying acids and bases as strong or weak are different from those used in pharmacy, and pKa is rarely involved (chapter 6 includes a more extended discussion). Item 5 probed students' ability to predict the outcome of a reaction between a weak acid and a strong base, as encountered in inorganic chemistry, and approximately three-quarters of the cohort were able to make an accurate prediction. Items 1 and 6, however, revealed the limitations of many students' experience with weak acids and bases as defined in pharmacy.

Most students had only encountered acids with pKa values below 7 and bases with values above 7 in inorganic chemistry, therefore their responses related to previously experienced situations. In other words, their exposure to acids and bases in chemistry led them to expect that all acids and bases behaved in similar manner with respect to pKa, a case of confounding observation with definition. Only one-quarter had sufficient experience to answer this item correctly within the broader context, although a further quarter were unsure.

The third cluster of questions highlighted student difficulties in interpretation and application of conceptual knowledge. Items 8 and 10 extended the probing of pKa and strength, while item 9 required a calculation. All three items were presented in multiple-choice format, therefore incorrect responses did not necessarily mirror student understanding (rather they may have been simply a guess or the 'least unlikely' response), however there appeared to be some consistency between items 1 and 8 in that the distracters in 8 (C and D) which related to the pKa value of 7 were chosen by 39% of students. Item 10 was related to item 5 but was more complex, and required both integration of the concepts of strength and neutralisation, and application to a practical problem. Fewer than half of the students gave the appropriate response for each item, with item 10 producing the lowest percentage of correct choices.

As indicated previously, comparisons between the initial and final surveys were problematic, however there were indications that some students progressed in their understanding of pKa. Items 1 and 6 were answered correctly by a greater percentage of students in the final survey than in the first, which suggested a greater appreciation of the significance of pKa in the context of pharmacy.

The inclusion of open-ended items permitted a more fine-grained evaluation of conceptual understanding, and student responses revealed a number of additional dimensions (Table 4.5). Responses to three items were selected as being representative of the major aspects of interest: these items were 'List the major characteristics of acids/bases.' (Table 4.5a), 'What is meant by the pKa of an acid/base? What information does it provide about the acid/base?' (Table 4.5b), and 'What is the difference between a strong acid/base and a weak acid/base of the same concentration?' (Table 4.5c). In order to reduce the burden on individual students, each student was asked to respond about either acids or bases, not both.

A coding system was developed for the three items which identified categories of response, and these categories were further clustered as indicated in Table 4.5. In relation to the first item, characteristics of acids and bases were clustered as either structural/functional or physical/reaction. Structural/functional characteristics included the ability to donate or accept a proton (the Bronsted-Lowry definition which is currently considered the most scientifically acceptable), structural features such as functional groups which conferred acidic or basic nature, and reference to pKa as a feature of the molecule. Physical/reaction characteristics included physical properties such as taste, touch and corrosiveness, formation of H^+ or OH^- ions in water (these responses were classified as reflecting the older Arrhenius definition of acids and bases), standard inorganic chemical reactions, and reference to pH as a feature of the substance. The latter characteristics, while significant in chemistry, are largely irrelevant in pharmacy, whereas the former characteristics are more broadly applicable across contexts.

In the initial survey, physical/reaction characteristics dominated student responses, particularly physical properties and pH, although almost two-fifths also acknowledged proton donation/acceptance. This finding is consistent with prior experience of secondary school and inorganic chemistry, which focus on the behaviour of solutions of acids. In this context, 'acids' and 'bases' do possess the characteristics described by students, although many students appeared not to distinguish clearly between the acidic molecule and the solution in which it was dissolved.

By the final survey, the balance had shifted in favour of structural/functional characteristics, although many physical/reaction characteristics were retained. The major shift was the almost universal acknowledgment of acids/bases as proton donors/acceptors, however a number of new dimensions appeared in student responses, albeit with a relatively low frequency. The emphasis on inorganic reactions was reduced, however physical properties and pH were still prominent. Given the non-specific nature of the item, it is difficult to judge whether students had simply appended

additional characteristics to the concept of 'acid' and 'base', or had developed contextual discrimination.

The second open item addressed the role and significance of pKa in acid/base theory (Table 4.5b). Responses to this item were clustered as either appropriate reference/representation or error/confusion. Responses were coded as 'appropriate' if the student explained a particular concept adequately, and also if the concept was mentioned without explanation. This may have inflated the values for appropriate reference to strength and dissociation as there was no way of evaluating whether the concept was understood or not.

The initial survey revealed a moderate acknowledgement of the function of pKa as an indicator of acid/base strength and dissociation potential (29-40%), however a significant percentage of students displayed confusion in relation to these concepts (11-25%) and in the nature of pKa in general (21-24%). A small percentage of students appeared to have confused the concepts of pH and pKa (3-6%). All of these findings are consistent with the reduced emphasis on pKa in secondary school and inorganic chemistry.

In the final survey, the concept of pKa as an indicator of acid/base strength appeared to have consolidated, however little change was observed in its perceived role in dissociation. Two additional dimensions were identified, namely reference to ionisation and conjugates. As was the case for the first item, however, the development of contextual differentiation could not be inferred from the responses to this item; this required the more detailed investigation with individual students which is described in chapters 6 and 7.

The third open item specifically probed student understanding of the implications of strong and weak as descriptors of acids and bases (Table 4.5c). The majority of responses mentioned the extent of dissociation (70-73%) with a split of approximately 2:1 in favour of a dichotomy between complete and partial dissociation, in comparison to relativity in dissociation. The former is the definition encountered in high school and inorganic chemistry, thus this finding is consistent with responses described earlier in this section. Further consistency is provided through the observation that a larger proportion associated strength with pH (7-13%) than with pKa (2%).

Responses to this item in the final survey showed trends towards a reinforcement of the association between strength and dissociation (81%), and a broader conceptualisation of strength, although the dichotomous 'chemistry' definition (46%) continued to dominate the relativist 'pharmacy' definition (35%).

4.6 Discussion of results

Comparison with previous research findings

As discussed in chapter 2, previous research into conceptual understanding of acids and bases has identified a number of difficulties encountered by students. The current results displayed both similarities and differences from those findings.

The most striking similarity was the attribution of physical features such as taste, feel and corrosiveness as characteristics of acids and bases. Previous research using secondary students (Hand & Treagust 1988, 1991) identified the statement 'An acid is something which eats material away; an acid can burn you' as a common belief of year 10 (15-16 years) students in a Queensland (Australia) school, and Toplis (1998) found similar conceptions among year 8 (12-13 years) students in a school in Buckinghamshire (England). These characteristics are relevant if considering the solutions of acids and bases which are commonly encountered in secondary school experiments on inorganic chemistry. Taste and feel are used to differentiate the physical sensations associated with solutions of substances such as hydrochloric acid and sodium hydroxide, and students are frequently warned about the dangers of spilling concentrated solutions because of their corrosiveness. Since the majority of first year pharmacy students had previously experienced only secondary school chemistry, their responses were consistent with their experiences, and were appropriate in the specific context of 'chemistry'.

Also reflecting previous research was the use by students of both Bronsted-Lowry and Arrhenius definitions, either explicitly or implicitly. Cros et al (1986) studied a cohort of French first year university students using a questionnaire with open questions similar to those included in the current study, although the differences in wording (and possibly the nuances associated with use of a different language, French) must be considered in comparing results. The French study found that, in response to the task 'Write a definition of an acid/base', 52% and 47% of students used Bronsted-Lowry definitions of acids and bases respectively, which compares with the 40% frequency identified in the initial survey of the current study. Arrhenius definitions were found with frequencies of 23% and 14%, again comparable with, albeit lower than, the 28% response rate in the current study. Interestingly, the same cohort was surveyed the following year (Cros et al, 1988) as was the case with the current study, however the changes identified in the French study were less dramatic. Bronsted-Lowry definitions increased to 82% and 63% (compared to 94% and 95%), although the Arrhenius definitions were similar (5% and 25% in the French study compared to 2% and 23%).

A third similarity to previous findings was that many students displayed some confusion in relation to the meanings of strength and concentration. Although able to define strength appropriately in relation to dissociation (Table 4.5c), application of the concept to a defined task was problematic for the majority as demonstrated in the responses to item 10 of Table 4.4. This item also exploited

the distinction between the scientific and everyday usage of terms describing strength (weak, strong) and concentration (dilute, concentrated). In everyday discourse these terms are often used interchangeably: for example, a 'weak' cup of coffee is more precisely defined as dilute, but meaning is effectively communicated through the use of the term 'weak'. The most frequently chosen alternative for item 10 (B) would appear correct to students who confounded strength and concentration. Failure to distinguish strength and concentration was also reported by Botton (1995) who commented in relation to a group of year 9 students that "most linked the terms strong with concentrated (lay science) and used them synonymously" (p. 125). Further, Nakhleh et al (1996) suggested that students had difficulty explaining "the difference between a concentrated solution of a weak acid and a dilute solution of a strong acid" (p. 760).

Banerjee (1991) found that undergraduate university students apparently had difficulty comparing the pH values of an equal concentration of a weak and a strong acid. He suggested that "the students wrongly related pH directly to concentration, being unable to connect the lower H^+ ions concentration and hence higher pH in the [weak acid] solution due to lower value of [dissociation] constant" (p. 491). A similar finding was made in this study with respect to the responses to item 9 of Table 4.4, however the explanations of Banerjee and Nakhleh et al (1996, previous paragraph) were not sufficient to explain the choice of distracters A or B, both of which refer to a lower concentration of a strong acid than the correct choice, D. That the result was not an aberration was seen in the consistency of responses between the initial and final surveys, and further work is necessary to elucidate the reasons for this pattern of responses.

Despite the similarities, however, significant differences were found in the current study to previously published results based on upper secondary or tertiary student cohorts. Little evidence was found that students had difficulties with the concept of pH or regarded pH as a measure of acidity but not basicity (Ross & Munby, 1991; Garnett et al, 1995), nor that the addition of an acid to a base resulted in a physical mixture rather than a reaction (Nakhleh & Krajcik, 1993).

Conclusions and implications of conceptual understanding results

As discussed, students in the first year pharmacy cohort generally demonstrated conceptual knowledge relevant to the context in which their previous studies in chemistry had taken place, and within that relatively constrained context, a consistent conceptual profile was evident for the majority. A number of difficulties were identified in application of theoretical knowledge, which were amplified by an apparent lack of differentiation between the meaning of terms used both in the scientific and everyday milieu, such as 'weak' and 'strong'.

From the standpoint of a sociocultural approach to conceptual change and concept development, two issues were identified from the population study. Firstly, the results in this study were obtained using written rather than spoken language, together with a sign-based representational system (chemical symbols and abbreviations, equations, etc). As discussed in chapter 2, the nature of the

representational system used to probe and communicate understanding plays a significant role in shaping the outcomes of the investigation, in the sense that the communication of meaning between questioner and respondent is significantly constrained. Ambiguities not apparent to the questioner may be perceived by the respondent and may lead to differences in interpretation, particularly since the context of questions and items cannot be individually clarified. The extent to which intersubjectivity is attained cannot be easily estimated, and the omission of a response cannot validly be interpreted either as the absence of understanding or the assumption of irrelevance. Thus while the results of the cohort investigation are important in illuminating some aspects of the population characteristics, they cannot provide a full description of either the process or outcomes of conceptual change as described in chapter 3.

The second implication for the study was that minimal contextual discrimination was apparent in student understanding. Because the majority of students had effectively no exposure to alternative ways of conceptualising acids and bases, little diversity was apparent in their descriptions of the characteristics and behaviours of these substances. Their conceptions formed a generally coherent and useful model for operating within the context with which they were accustomed, which had been confirmed by experiment and experience. They were able to communicate meaning by use of written language, complemented by a scientifically accepted chemical representational system, and could be considered as valid members of a 'chemistry student community'. Consequently, they comprised an appropriate population in which to study conceptual change from a sociocultural, discourse-based perspective where both process and outcome of change are based on evidence of learning to communicate in another community.

4.7 Selection of sample

Process

As indicated earlier, a sample was selected from the population for more intensive investigation of the processes and outcomes involved in conceptual change. The process of sample selection was performed during the semester of the study, namely second semester 2001.

Small group work in Introductory Pharmaceutical Science was carried out in workshop classes of between 40 and 60 students, facilitated by two tutors. Within the overall class, students self-selected into working groups of four to six members, with whom they remained for the semester. Each small group worked around a table so that all members of the group had eye contact. Chapter 5 outlines the process of these workshops in more detail.

Using the results of the initial survey, potential participant groups were identified in the early weeks of the semester. The protocol involved inviting one small group in each of the four workshop classes to participate, and the original selection was intended to capture as much as possible of the diversity of the cohort. Members of the target groups were approached by the

researcher as a group, provided with information about the study, and invited to participate. Having indicated that if any member did not wish to participate, the group should decline the invitation, the researcher moved away from the group to allow them the opportunity to discuss the proposal, and returned only when the group indicated a decision had been reached.

Of the four initial target groups, one consisting of six female students of international origin declined the invitation upon the realisation that they would be videotaped during their classroom interactions. An alternative group was identified during the following week however it was not possible to locate a suitable group involving any international students. The alternative group agreed to participate in the study, as did the remaining three original choices. In total, three groups of 6 students and one group of 5 took part in the main study, however data from only two groups, comprising 11 students, were subsequently analysed. These groups were chosen as they represented the greatest between-group differences (Barron, 2000) in both outcomes and processes of conceptual change, and were designated as the 'transient change' (TC) group and the 'persistent change' (PC) group. All members of both groups remained in the study until its conclusion.

Comparison with population data

Although the sample was chosen for convenience, a comparison of the characteristics of the 11 students with the entire cohort was performed in order to estimate the degree to which the sample results could be extrapolated to the population.

As can be seen in Tables 4.6a and 4.6b, the sample was generally representative of the population on the parameters of gender distribution, language background and attitudes towards chemistry. The age distribution, educational experience and place of origin were less representative, but similar in trend to the population data.

4.8 Conclusion

The findings from the population study were broadly consistent with previously published results from comparable cohorts, although some distinctive features were also apparent. Common aspects included the attribution of physical characteristics and standard definitions to acids and bases, together with conceptual confusion regarding pH, strength and concentration, but little evidence of difficulties with the concept of pH itself was found. Conceptual change subsequent to the teaching semester appeared to be present, but the use of a written survey limited the extent to which changes in discursive practice could be deduced, and no comparison with previous research was possible because no studies to date had focused on the development of contextual discrimination.

The survey results provided useful input to the design of the semi-structured interviews which were held with the participants in the intensive phase of the study by highlighting those foundational beliefs and understandings about acids and bases which were prevalent among the population upon

commencement of the investigation. Comparison of population and sample data confirmed that the students chosen to participate in the intensive phase were generally representative of the cohort in terms of both demographic and attitudinal characteristics, thus permitting extrapolation of the sample findings to the population. The methodology of the intensive phase of the study is described in chapter 5, and the findings themselves in chapters 6 and 7.

CHAPTER 5 RESEARCH METHODOLOGY: CLASSROOM STUDIES AND INTERVIEWS

5.1 Introduction

This chapter outlines the methodology used in the intensive investigation of conceptual change carried out with the sample of eleven students identified and selected as outlined in chapter 4. Methods of data collection and analysis are described both for the classroom studies of the small group interactions involving these students, and for the three individual interviews carried out with each. The results of these studies are described in chapters 6 and 7, and discussed in chapter 8.

Approval for the conduct of this study was obtained from the Human Ethics Committee of the University of Sydney. All procedures were carried out in accordance with the approved protocols.

5.2 Classroom studies

Context

The cohort completing Introductory Pharmaceutical Science comprised 190 students, each of whom was allocated into one of four parallel workshop classes. Classes therefore consisted of between 40 and 60 students, and were facilitated by two tutors, one of whom was always the researcher. Classes of two-hour duration were held on a weekly basis during a thirteen-week semester, and attendance was both compulsory and monitored.

During the first workshop of the semester, students in each of the four parallel classes self-selected into groups of between four and six peers, with whom they worked for the remainder of the semester. The room arrangement allowed each group to work together around a table, with all students freely able to talk to each other and engage in eye contact. As described in chapter 4, one small group in each of the workshop classes was invited to participate in the classroom studies and interviews, and two of these groups were subsequently selected for analysis. These groups were chosen because they represented the extremes in patterns of collaboration, which has the advantage of making subtle difference more apparent (Barron, 2000).

At the beginning of each workshop session, task sheets were distributed to each student in the class (including the study participants) and any relevant instructions or advice were given by the tutor in charge. Student groups were then able to work on the tasks as they chose. All groups engaged to some extent in collaborative and individual work, although the extent varied widely between groups. Students were permitted to depart after a minimum of one hour's attendance or upon completion of the tasks, whichever occurred later. During the following week's workshop, printed guidance and/or model answers in relation to each workshop task were distributed to all students.

On three occasions, student groups were invited to submit a group answer for one of the workshop tasks in order to receive feedback from a tutor (always the researcher). This feedback was provided in written form and was returned in the following week's workshop.

Tutor facilitation occurred in two ways. Any student could request assistance from a tutor at any time, either by raising a hand or by approaching the tutor directly. Tutors indicated to students that the former method was preferred since it allowed the tutor to interact with the student's group rather than a single individual. In addition, tutors regularly circulated amongst the groups to engage students in discussion and to question them about their progress, outcomes and difficulties.

Tutors were provided with the workshop tasks and guidance in relation to their completion at least one week before each class.

Data collection

A digital video camera and two audiocassette recorders were used to capture the classroom activities of the four participant groups. The audiocassette recorders were placed at each end of the table around which the group members sat: two recorders were needed to capture as much as possible of the conversations occurring between students working in dyads and larger groupings. These recorders remained in place for the duration of the workshop, and were only moved when the cassette tape was changed. The video camera was located in such a manner as to capture facial expressions and other non-verbal forms of communication, and to assist in identification of speakers. The camera was placed on a tripod for most of each session, but was occasionally removed and carried to other positions in order to highlight specific interactions. The video camera was operated in all sessions by a research assistant who had a background in theatre and staging. The amount of usable audio captured by the microphone of the video camera was limited by the relatively high levels of background classroom noise, but was sufficient for aligning speech captured on the audiocassette recorders with the non-verbal actions of group members.

In order to accustom students to the presence of the audiocassette recorders and video camera, the four workshop sessions immediately preceding those of interest were recorded. These 'dummy' sessions were used to fine-tune the recording process, and the recordings were subsequently erased. The live workshop sessions were recorded in the final three weeks of a thirteen-week semester, and all audiocassette and video tapes were stored in a locked safe.

Students were asked to behave as they normally would during a workshop class with the following exceptions:

- students with long hair which fell forward over their faces were asked to tie their hair back during recording
- students who wore baseball-style caps were asked to remove them during recording

- students' seating positions in relation to the video camera were adjusted to provide maximum visibility, although students were permitted to choose whom they sat next to

Tutors were also asked to behave as they normally would during a workshop session.

Interviews with participants indicated that the presence of the recording equipment did not significantly affect their activities and behaviours during the live sessions (chapter 7 includes a detailed analysis).

Data analysis

Audiocassettes and videos

For each session, the audiocassettes from each recorder were separately transcribed, and subsequently integrated. Integration was carried out by aligning the two transcripts as far as possible based on common utterances, and repetitively reviewing each cassette tape in conjunction with the aligned transcript to construct a single record. Following Barron (2000), transcription of talk focused on the accuracy of what was said and the order of turns rather than on details of intonation or other details of the discourse. A turn was regarded as a segment of uninterrupted speech by a participant, and when an utterance was interrupted, the turn was regarded as complete. Comments such as "yes", "uhuh", "um" were classified as turns.

Videocassettes from the digital camera were copied onto DVDs, and viewed repetitively. The first viewing was used to construct a broad outline of the session by identifying episodes of individual work, within-group joint work between two or more students and whole-group joint work. An individual was considered to be participating in group work if there was evidence of either active or passive engagement. Active engagement involved an individual contributing to the discussion, while passive engagement was inferred when the individual was clearly paying attention to the discussion while not adding a verbal contribution to it. Where within-group joint work was identified, the identities of the participants were recorded. Subsequent viewings of the video refined these episode and engagement definitions, and were utilised to calculate the relative amounts of time spent in different activities. Viewing of the video also assisted in clarifying the identities of particular speakers where these were not clear from the audiocassette transcript, and in aligning speech with action.

Analysis of episodes

Using the transcripts of both the audiocassettes and the videos, specific episodes were selected for detailed analysis. The actions of the participants, alone and in interaction with others in the group and the facilitating tutors, were analysed through repeated reading of the transcripts and viewing of the videos. The major dimensions of the analysis included communication through language (either

with others or to self), gestures, personal and interpersonal behaviours as manifest in both verbal and non-verbal communication, use of tools other than language (for example notes, calculators, textbooks), and perceived engagement in group and individual tasks. These dimensions were interwoven in the analysis in order to explore the development of conceptual understandings of 'Acids and bases' and the mediational role of 'talking pharmacy' in the process of this development.

5.3 Interviews

Scheduling

Each participant was asked to attend an interview on three occasions. The first interview took place within the six weeks prior to commencement of the 'Acids and bases' topic in Introductory Pharmaceutical Science in order to probe prior understanding and ways of talking about acids and bases prior to exposure to the concepts in the context of pharmacy. The second interview took place within four weeks of completion of the topic, in order to evaluate any changes in conceptual understanding and ways of talking about acids and bases which occurred as a result of engaging in the learning activities associated with the topic. The final interview took place during weeks 4 to 6 of the following semester, between four and five months after completion of the topic, and following a three-month university summer vacation. This interview was used to evaluate the extent to which any changes persisted beyond the initial post-instruction period, and provided evidence of the robustness of any conceptual change observed. All participants completed all three interviews. Appendix C contains a detailed time line of the study.

Protocol

Each student was offered a number of dates and times for each interview and was able to select the preferred combination. Each interview was allocated one hour, however the majority lasted less than this time and a small number extended into a second hour.

The researcher explained to each student individually that the purpose of the interviews was to probe their general understanding of the topic, and asked each student not to make any special preparations for the interviews. In the case of the second interview, which was undertaken at times close to the final examination in the unit of study, note was taken of the students' self-reported extent of examination preparation in relation to the topic.

All interviews were conducted in the researcher's office, and were recorded on audiocassettes. All recordings were subsequently stored in a locked safe.

Each interview was semi-structured, and explored several themes. The following section outlines the content in more detail.

Interview content

Common content

All three interviews explored students' understanding of the topic of 'Acids and bases', and their ability to communicate their understanding in both verbal and representational form. The emphasis was on eliciting student explanations, in their own words, rather than simply asking questions to which yes/no answers were adequate. The aim in each case was to ascertain the boundaries of each student's individual knowledge, and therefore questioning was continued until the student was unable to answer appropriately, or until the questions were exhausted, whichever occurred earlier. The questioning approach was flexible and responsive, and additional prompting was used where it was deemed appropriate to elicit a more complete answer. A brief summary of the question types used at each interview appears below, and more details about the questions are found in Appendix D.

Paper and writing implements were available to all students, and they were encouraged to use them to supplement or constitute their answers to any question. These written responses were collected and stored in a locked safe.

First interview

The initial interview probed only the specific content in relation to acids and bases as outlined in the previous section. Analysis of the responses to this interview and the results of the population survey (chapter 4) formed the basis for a description of each student's conceptual understanding about acids and bases on entry into Introductory Pharmaceutical Science. Questions focused on elucidating students' ideas about characteristics of acids and bases, differences in meaning of the terms, differences between acids particularly in relation to strength, pH, pKa, buffers and titrations.

Second interview

The second interviews were conducted in the final week of semester, immediately prior to the examination, or within the week after the examination. Questioning about the topic content was similar to that of the first interview, but additional aspects were covered with the intention of probing any changes in understanding and/or ways of talking about acids and bases. The additional questions, which were interwoven with the questions from the first interview, included probes for changes in characterising acids, bases, pH and pKa, probes relating to the new concepts introduced during the semester, and questions designed to elicit the students' perceptions of the changes in their thinking. A further set of questions was designed to probe a number of specific aspects of each participant's personal trajectories, including details about each participant's personal situation at the end of semester in order to ascertain any significant influences on their emotional state, assessment preparation, and attitude to the assessment the topic of acids and bases. A final set of

questions was designed to illuminate each participant's perceptions of the small group processes and dynamics throughout the semester, in order to assist in the interpretation of the videotaped episodes, and to enrich the analysis through consideration of multiple viewpoints.

Third interview

The specific topic content of the third interview was closely aligned with that of the second interview, as the intent was to evaluate the extent to which conceptual understanding was maintained after a relatively long break during which little academic study was undertaken. The following additional questioning was included at the beginning of the third interview:

- How did you feel about your results from last year? What about Introductory Pharmaceutical Science? How are you finding second year so far? Why?

As in the case of the second interview, these additional questions served to illuminate a specific aspect of each participant's personal trajectory, namely perceptions and attitudes about the individual's academic performance from a temporal distance, and a general attitude towards current studies. In addition to providing some details about continuing personal trajectories, this group of questions was also designed to put the participants at ease after a prolonged absence of contact with the researcher.

To conclude the third interview and the overall research involvement, each student was also asked to comment upon the experience of participating in the study. As a follow-up to these questions, a feedback form and a stamped self-addressed envelope were provided to all students to enable them to provide anonymous written feedback. Feedback given both in person and anonymously in writing indicated that no student perceived any disadvantage or harm as a result of participation in the study.

Data analysis

Audiocassette recordings were transcribed verbatim and all written responses made by the student were annotated with the date of interview and identifying information to allow clear linking with the transcript. Transcripts were repeatedly read and analysed to elicit data relating to

- changes in ways of talking about acids and bases
- development of contextual discrimination
- confidence about conceptual understanding
- group interactional dynamics
- individual histories
- perceptions of the research process and personal outcomes

5.4 Data interpretation and presentation

Data from the classroom studies and the interviews were used to construct individual and group learning trajectories, and to propose possible explanations for the observed trajectories. These trajectories and their associated explanations are presented in detail in chapters 6 and 7, and discussed in chapter 8.

CHAPTER 6 CONCEPTUAL CHANGE OUTCOMES

6.1 Introduction

Conceptual change is considered in this chapter from two primary perspectives. The first perspective is the extent to which the participants develop in their recognition that acids and bases have different meanings in the different contexts of chemistry and pharmacy and their ability to discriminate between these contexts. This involves analysis and evaluation of the development of already familiar concepts such as the characteristics of acids and bases, and the significance of strength, pH and pKa. The second perspective is the extent to which the participants appropriate new concepts such as functional groups and their dissociation behaviour into their conceptual frameworks in ways which are characteristic of the pharmacy community. Within each perspective, key concepts will be explored by focusing on individual participant trajectories, foregrounded against the background of their membership of either the transient change or persistent change groups. Chapter 7 will foreground the processes occurring within each group against the background of the conceptual change outcomes discussed in the current chapter. Chapters 6 and 7 therefore complement each other through a focus on the personal and interpersonal planes respectively, against the background of the other.

Following an introduction which outlines the dimensions of conceptual change which are analysed for each participant, the chapter is structured into two major sections, each focusing on one of the two small groups. Within each section, after an introduction focusing on the group composition and extent of conceptual change, individual trajectories are structured as follows:

- an introductory description of the individual
- an outline of his or her conceptual framework on entry into the study*
- the investigator's evaluation of the individual's conceptual change over the period of the study, focusing on specific aspects of the topic*
- the individual's perceptions of the ways in which his or her understanding developed during the teaching semester
- the investigator's summary of each individual's development

Full descriptions are provided for 3 participants in each group. For the remaining five, asterisked aspects* can be found in Appendix F.

Supporting evidence for the summaries and interpretations presented in this chapter can be found in Appendix G, in conjunction with which this chapter should be read. References to interview transcripts are denoted in the form ^(n.xxx) where ⁿ is the number of the interview for the student (1, 2 or 3) and ^{xxx} is the turn. Some references have not been included as they were accompanied by gesture and thus do not in themselves communicate adequate meaning.

6.2 Dimensions of conceptual change

The topic of 'Acids and bases' is a complex area, and attempting to include all aspects of each participant's conceptual change is well beyond the scope of this thesis. In order to encompass the breadth of the topic, two major areas are considered. The first includes the changes observed in each participant's initial conceptual frameworks, in particular the development of contextual discrimination between chemistry and pharmacy, while the second includes the development of concepts which were introduced during the teaching semester in the context of pharmacy only. Some overlap is apparent on occasion between these two areas, and this is highlighted where appropriate.

Changes to existing understanding

Two areas were examined: the nature of acids and bases, and the relationships between strength, pH and pKa.

In chemistry, acids and bases are generally characterised by a combination of chemical and physical characteristics. The former include the ability to gain or lose a proton and to undergo particular types of reactions. The latter include specific tastes, feel and the tendency to be corrosive or cause burns when in contact with skin, and in general are properties of solutions of acids and bases. In pharmacy, acids and bases are generally not associated with these physical characteristics, but rather with the functional groups on drug molecules which gain or lose protons. The extent to which participants discriminated between chemistry and pharmacy in relation to the nature and characteristics of acids and bases was a key indicator of the development of contextual discrimination.

In order to probe changes in understanding of strength, pH and pKa, participants were asked to explain how they understood and defined pH, and to carry out some simple pH calculations in the initial interview and survey only. These activities were included not because any change was expected in these aspects during the study, but because chemistry and pharmacy conventions assign different roles and significance to pH. In chemistry, acids and bases are characteristically assigned pH values, whereas in pharmacy, pH is restricted to solutions containing acids and bases, and pKa values are considered as characteristic.

Participants were asked to articulate their understanding of strength in all three interviews, because strength is one of the major differences between chemistry and pharmacy. Chemistry conventions state that strong acids and bases dissociate completely in solution, whereas weak acids and bases dissociate only partially. In pharmacy, no acids or bases meet the criterion of complete dissociation, and strength is determined by the relative magnitude of pKa. Strong acids and weak bases are characterised by pKa values of less than 7, whereas weak acids and strong bases possess

pKa values of greater than 7. Appropriation and retention of this concept was a key indicator of significant conceptual change.

Concepts new to pharmacy

Again, two major areas of new understanding were explored.

Firstly, in both interviews 2 and 3, participants were shown a series of chemical structures which had been encountered during the teaching semester, and were asked to identify the functional groups which were acidic and basic. On this basis of this they were then asked to classify each molecule as an acid, a base or neither. The same set of structures was used with all students and in both sets of interviews, however not all students received all of the structures on every occasion. The structures and their relevant features are found in Appendix E, and are summarised in Table 6.1.

Drug	Classification
codeine	base, contains amine
lignocaine	base, contains amine plus amide
amoxycillin	neither because has both acidic and basic functional groups, contains carboxylic acid, phenol, amine and amides
cephradine	neither because has both acidic and basic functional groups, contains carboxylic acid, amine and amides
ticarcillin	acid, contains carboxylic acids and amides
diazepam	neither because has no carboxylic acid, phenol or aliphatic amine groups, contains amide and double-bonded nitrogen
ibuprofen	acid, contains carboxylic acid
phenacetin	neither because has no carboxylic acid, phenol or aliphatic amine groups, contains amide

Table 6.1: Drug molecules analysed by participants in interviews 2 and 3

Secondly, participants were asked to draw acid dissociation equilibria for at least one of the drug molecules, one of which was always amoxycillin as this was the most complex molecule in the list. A particular method of drawing the equilibria for acids and bases in pharmacy had been emphasised, using the K_a (acid dissociation constant) for both acids and bases, and avoiding the K_b (base dissociation constant) for bases. The primary difference between the equilibria in chemistry and pharmacy was the requirement to keep the acidic form of the drug on the left hand side of the equilibrium expression on all occasions in pharmacy.

6.3 The transient change group (TC)

Group composition

This group consisted of five students, two male and three female, all aged between seventeen and nineteen years of age, and all in their first year of University, although Larry had taken a 'gap' year

between finishing school and commencing university. All students were thus enrolled in first year Chemistry for Pharmacy in addition to Introductory Pharmaceutical Science (IPS). Four of the students were native English speakers and spoke only English at home, while the fifth (Geoffrey) was a native Cantonese speaker.

The group had largely formed before the start of the semester because all five members were friends from two adjacent residential colleges of the University. The males were members of a mixed-gender college, while the females were members of a female-only college, however the two colleges shared both academic and social activities. Thus the five students knew each other well, despite having met only that year when they commenced university. In fact, they indicated to the researcher very early in the semester that they had carefully manipulated their second semester timetables so as to be able to share all of their classes, and, where given a choice, to work as a group (this was communicated in a non-recorded conversation although Janine later contradicted this assertion). Their social interactions tended to revolve around college functions, however two members of the group (Larry and Emma) were, at the time of the study, 'going out' with each other. It was not clear how long this latter arrangement had been in place as it was only mentioned by Emma in her second interview.

During the early weeks of the semester, Emma was diagnosed with glandular fever, which she continued to suffer throughout the period of the study. The extent of her incapacity was such that she was unable to attend university for a significant portion of the semester, and spent long periods at her parents' home in Wollongong (approximately 90 minutes' drive south of the University). Her friends, primarily the other members of the group described here, provided her with lecture and other materials which she attempted to study by herself. On occasions, particularly after Emma had returned to living on-campus, some of the other members of the group appeared, at least from Emma's perspective, to be unaware of the effect that her illness was having on her – particularly the effect on her sleeping patterns – and to be somewhat grudging in sharing their notes: *'it was hard, because if I missed one lecture, especially Calculus, I mean I missed a lot of Calculus coz that was on in the morning, and I just couldn't get up. It got to the point where I just couldn't get out of bed. Um and I think that the others, like Larry and Janine and Geoffrey got very resentful of the fact that they had to get up in the morning, and they had to go to class, and I just sort of didn't. Um, so they, I did have trouble getting notes from them sometimes, and ah, Larry especially didn't, I think, believe that it was a big thing, yeah, he didn't understand why I kept sleeping all the time.'*

(Emma 2.14-2.20). Emma was not present at either of the two workshop sessions during which her group was videotaped, although she was sufficiently recovered so as to be able to attend the final workshop of the semester. For reasons which are outlined in chapter 7, this workshop was not videotaped.

All students performed above the cohort average in the IPS examination, with Janine achieving High Distinction, Geoffrey Distinction, and the remaining three achieving Credit grades.

Extent and nature of conceptual change – summary

Group members' dialogue in interviews held immediately after completion of the topic of 'Acids and bases' provided evidence of short-term learning in that contextual discrimination was generally apparent in relation to those aspects which were common to chemistry and pharmacy, and participants displayed familiarity with the new concepts which were restricted to pharmacy. However it was also clear that several members of this group had adopted strategies targeted towards optimising examination performance in preference to conceptual understanding. Dialogue from interviews held at the conclusion of the study indicated that much of this short-term learning was no longer apparent. In particular, when pharmacy and chemistry concepts were in direct competition, the chemistry concepts tended to dominate, and in some cases the pharmacy concepts were no longer articulated at all. In general, the concepts which were unique to pharmacy were retained more effectively, however prior chemistry foundations also appeared to confound conceptual development relating to these ideas which were new. As a consequence, this group was designated as the Transient Change (TC) group.

Janine

Janine was a particularly high achieving student, having scored the maximum possible tertiary entrance rank in the final secondary school examinations the previous year. She held the highest of the University's entrance scholarships, and had achieved very high marks in all of her first semester subjects. She spent a great deal of time in private study, and by her own admission perhaps worked a little too hard^(2.156-2.158). She was very confident in her own abilities, and tended to be single-minded about achieving to her potential wherever possible. She was academically competitive, disliked being outperformed, and tended to minimise articulations which suggested that she did not fully comprehend the material or how to solve a problem. Janine finished the degree with First Class Honours and the University Medal, the highest award available.

Initial conceptual framework

At the time of commencing the study, Janine demonstrated a very thorough and confident understanding of the properties associated with acids and bases as she had learned them at secondary school, and could explain them in both verbal and written form. She volunteered all three definitions for acids and bases (Arrhenius, Bronsted-Lowry and Lewis) and was aware of the historical development of the ideas^(1.8-1.22). She was also able to recall accurately and with little difficulty the physical characteristics of taste and feel which were characteristic of acids and bases as encountered in secondary school chemistry, and corrosiveness was also strongly associated with both acids and bases^(1.26-1.30).

Janine identified pH as a defining characteristic of both acids and bases ^(1.89-1.91), and associated low pH with more extreme conditions ^(1.102-1.103), and with corrosiveness and toxicity ^(1.103). She clearly articulated the definition of pH and her definition was concise and accurate ^(1.89-1.91).

While tending to conflate somewhat the concepts of strength and concentration ^(1.61, 1.145), Janine demonstrated an appreciation of the difference between them ^(1.73-1.75), although she admitted that it was something she needed to remember rather than something which she understood more fundamentally: *'Um, strong versus weak is different to dilute versus concentrated, I have to remember that all the time'* ^(1.73-1.75). Janine defined strength accurately according to the conventions she had learned at school and which had been reinforced at university in relation to inorganic chemistry ^(1.77-1.79).

Janine's trajectory

Changes to existing understanding

Interview 2

Immediately after her examination in IPS, Janine very clearly demonstrated that she remembered a great deal of the material studied during the semester. She restricted her definition of acid and base to that of proton donor, which had been emphasised in pharmacy ^(2.366-2.368), without mention of the other definitions. She knew that there were differences between acids and bases in chemistry and pharmacy, and was able to recite the list of characteristics associated with the latter almost verbatim from the lecture notes ^(2.376-2.380). However her skill in recitation suggested that she perceived these characteristics as a list to be learned, rather than as a conceptual description of the notion of 'acid'. She also struggled to articulate clearly how these characteristics differed from chemistry ^(2.382), suggesting that she had learned the concepts for the purpose of the examination rather than attempting to work out how the new material related to her existing understanding. She saw pharmacy as a more restrictive domain, with *'narrower definitions'* ^(2.390) and concepts, which appeared more *'set in stone'* ^(2.384). In contrast, chemistry was seen as broader and less strict in its definitions, in that terminology could be used more loosely ^(2.382-2.384).

Janine was also able to recall accurately a great deal of the material she had studied in relation to strength and pKa. Her articulation of the difference between the definitions of strong in chemistry and pharmacy was confident, concise and accurate ^(3.398-3.400), although she was a little more hesitant in relation to weak acids in that she was able to articulate a correct response, but required some thought and paused slightly before completing her answer ^(2.402-2.404). The discrepancy in confidence between her descriptions of strong and weak acids was consistent with her strategic and logical approach to learning for examinations in that she was aware that she could deduce the relevant information for weak acids provided she knew sufficient about strong acids. The relationships were apparently not seen as part of an integrated whole, but as a logical sequence of remembered facts.

Janine's rationale for emphasising the differences between chemistry appeared to be pragmatic, in that it was important in her academic study of two separate subjects: *'I see them as separate because I think if you started seeing them as, like I'm sure it's all together and it's all one, but you've got to keep your concepts different for the different subjects straight yeah, otherwise you'll get confused'* (2.396). She recognised that the material was all interrelated, but chose not to focus on the interrelationship, which was consistent with her general (and successful) approach of maximising examination performance.

Interview 3

Five months later, Janine continued to define an acid as a proton donor (3.80), however, little progression was evident, since she did not advance in either her second or third interview to the more conceptually developed notion that an acid is a compound which contains acidic functional groups. The characteristics which she associated with acids in pharmacy continued to be those which she had learned for her examination, although she was only able to remember half and required a longer period to recall them (3.85-3.90). She remembered more about bases, perhaps because she had more time to organise her thoughts as the question about bases was asked second (3.100-3.108). Her accurate but incomplete recall suggested that Janine continued to rely on her memory of relatively unconnected facts, rather than a more holistic concept of an acid or a base, which was problematic when she was asked to recall material she had not used for an extended period of time. She was considerably more hesitant and less confident in her answers than at the second interview when her memory was fresh: this hesitancy was characterised by frequent pauses and filler phrases such as *'yeah, I just, (pause) no, I don't, yeah, I don't think, I'm kind, kinda'* (3.92).

Janine did remember that there was a difference between acids and acidic solutions (3.96-3.98), which indicated understanding of a fundamental conceptual difference between chemistry and pharmacy, but she appeared to be thinking in terms of *'which is right and which is wrong'* (3.92), rather than specific ideas which were differentially relevant in the two different domains. She expressed strong opinions about knowledge and truth in science, which she saw in terms of black and white (3.66), and she retained a belief in the chemistry approach as the one which represented the truth: *'I remember like, when we were doing it we were saying OK, what's right in chemistry isn't necessarily right in pharmacy. But it's still, I think it's more like bending the rules. Like, the chemical rules were really the right ones like you know, if something was an acid or a base in chemistry, it was really an acid or a base whereas in pharmacy we, broadened our definitions a little bit, because that's the way we wanted to use them but it's not necessarily the absolute truth'* (3.70-3.76).

Janine continued to relate strength of acids and bases to pKas but was considerably less confident in articulating her ideas, and required prompting to stimulate her thinking (3.112-3.116). She struggled with assigning pKas to weak acids and bases, and appeared only to remember the association through her memory of phenols (3.118-3.136). She did however clearly make the distinction between chemistry and pharmacy conventions relating to strength: strong acids in chemistry were defined as

those which dissociated completely in solution ^(3.140-3.142), whereas in pharmacy '*hardly any of the drugs completely dissociate*' ^(3.144) and the degree of dissociation determined the relative strength of acids and bases ^(3.148-4.152).

In summary, it appeared by the third interview that Janine was no longer attempting to keep her chemistry and pharmacy ideas separate, and the pharmacy usages were perceived as a form of corruption of the truths of chemistry. Her academic purposes no longer required this discrimination, since she had successfully completed both chemistry and pharmacy subjects in first year, and chemistry was not taught in second year.

Janine did not at any stage spontaneously associate acids and bases in pharmacy with ideas of molecular structure and functional groups. She learned lists of characteristics of acids and bases in both chemistry and pharmacy, and recalled these lists when asked to respond either verbally or in writing, and her ability to recall items on the lists was dependent on how recently she had studied them. She maintained a deep-seated belief in the rightness of the chemistry meanings, and although she was able to describe aspects of contextual discrimination between chemistry and pharmacy, she did not appear to have developed any conviction about its necessity. She had learned new information, but this information had not been incorporated into her existing conceptual understanding, which remained firmly grounded in the domain of secondary school chemistry. Little fundamental conceptual change was evident in Janine's understanding of the nature of acids and bases.

Janine did demonstrate conceptual development in her ideas about strength, and was able to discriminate between the domains of chemistry and pharmacy in relation to this idea. However, she still appeared to rely heavily on memory and logic to augment her conceptual understanding, an approach which suited her as a logical and organised thinker. She appropriated a series of facts about strength and pKa, rather than a coherent conceptual framework, and, as with her understanding of the nature of acids and bases, although to a lesser extent, Janine preferred the conventions of chemistry as her fundamental standard and regarded the pharmacy notions as additional information.

Concepts new to pharmacy

Interview 2

At the end of the teaching semester, Janine was confident and clear in identifying almost all of the relevant functional groups on all eight molecular structures (Table 6.1), and accurately classified all drugs on the basis of these groups. She gave appropriate explanations of the process by which she identified the potentially problematic phenol and aliphatic amine groups ^(2.440, 2.418-2.420), and correctly identified groups which might have been mistaken for aliphatic amines, particularly amides ^(2.428, 2.476). On only two occasions did she seem doubtful. Firstly, she could not explain the

rationale for classifying drugs such as amoxicillin as neither acid nor base ^(2.450-2.452), indicating that she did not recall hearing it in lectures, and secondly she struggled to distinguish between amines and quaternary ammonium salts ^(2.546-2.550), although the latter was not a critical issue.

Since she was demonstrating excellent familiarity with pharmacy material, Janine was only asked to attempt the more complicated of the dissociation equilibria tasks. She immediately and accurately allocated the three pKa values to each functional group on amoxicillin, and proceeded to draw the equilibria with confidence and ease. Having been asked to voice her thought processes as she carried out the task, it was evident that Janine was using appropriate reasoning ^(2.566-2.594). Further, she was able to use the relationship between pH and pKa to predict the form of the molecule and the state of ionisation which predominated at different pH values ^(2.598-2.604).

Interview 3

Janine was again able to identify the relevant functional groups and classify familiar drug molecules accurately, although she was a little more hesitant than in the previous interview. Significantly, she indicated that she had memorised the drug structures that she had encountered during the previous semester, and was actually identifying them largely from memory ^(3.157-3.164). However, when presented later in the interview with three structures which she had previously not seen, Janine was able to identify and classify two new molecules easily, thus suggesting that she had not needed to memorise the complete molecules. She was momentarily wrong in her identification of the third, ephedrine, but immediately corrected herself on prompting ^(3.341-3.342).

Janine was asked to draw the dissociation equilibria for both ibuprofen ^(3.236-3.252) and amoxicillin ^(3.256-3.280), and was as confident about the task as she had been during the second interview. She completed the ibuprofen equilibrium accurately, but the diagram she drew to accompany her comments about amoxicillin was inaccurate in that she forgot to include all relevant functional groups in the structure at each step, therefore each structure was only drawn as a fragment of the whole. This omission was important because it is fundamental to the ability to identify the state of ionisation of the molecule at different pH values. Indeed, Janine was initially incorrect in suggesting that amoxicillin was completely unionised at pH values below 0.4 ^(3.282-3.284), and this is likely to have resulted from her poor diagrammatic representation of the dissociation equilibria. Although she subsequently recognised and corrected her error, and identified correctly that amoxicillin was ionised at all pH values ^(3.284), there was a clear decline in her responses in comparison to those of her second interview.

She was also less confident about the means by which the secondary amine group on ephedrine became ionised and needed considerable assistance which she had rarely needed in the second interview. The interchange that ensued ^(3.350-3.357) suggested that she was confident with familiar examples, whereas when the form changed only slightly, her lack of familiarity resulted in error as her memory could not provide the correct response.

In summary, Janine learned to identify functional groups and use that identification to classify molecules appropriately as acid, base or neither, and this learning persisted until the end of the study. In both interviews, she appeared to rely significantly on her memory of the actual structures when presented with familiar drugs, but she was also able to use her knowledge of functional groups to identify unseen structures. She was able to draw up dissociation equilibria, but the accuracy of this skill declined significantly by the final interview, and her diagram in the third interview was fragmented. The latter observation exemplifies Janine's conceptual understanding, which comprised a series of loosely connected facts, rules and lists rather than a more coherent and integrated whole.

Janine's perception of the change in her understanding

Janine's primary perception was that pharmacy and chemistry were essentially distinct contexts, and she had little difficulty in compartmentalising her understanding into separate domains. The notion that chemistry and pharmacy used the same terms with different meanings was not an issue for her, as she saw them as different applications^(2.360), and did not find them confusing because she was not attempting to learn the two simultaneously^(2.348). She believed that her understanding had therefore expanded rather than changed or deepened during the semester, and she did not perceive any changes to her chemistry understanding as a result of studying pharmacy: *'you go into different fields, and if I went back to do chemistry now on acids and bases, I don't think it would be like a better understanding, it's just different applications'*^(2.360). Although this comment might be interpreted to mean that Janine had developed significant contextual discrimination, this was countered by her perception that the pharmacy material was regarded as additional to her underlying knowledge: *'And on top of that then you look at stuff like effect of solubility, and um, (pause) yeah you just, you do other stuff that you haven't done before'*^(2.356). Further, Janine's comments suggested that her previous knowledge still dominated her thinking, and that the new material relating to pharmacy was less well developed. For example, she commented that the examples of acids and bases she had encountered in pharmacy were ones that *'you wouldn't classify as acids and bases in chemistry'*^(2.352-2.354), suggesting that she was not convinced of the legitimacy of the new material. This observation is consistent with the suggestion described previously that Janine's discrimination between domains was primarily a pragmatic strategy to avoid confusion between the two academic subjects in first year, and also with her third interview comments as described above about the absolute truth of chemistry^(3.76).

In summary, Janine appeared to have learned the new material in such a way as to maximise her examination performance, suggesting a strategic approach which resulted in promoting reproduction rather than conceptual change. This interpretation was reinforced by her responses in the third interview, where she appeared to retain a fundamentally chemistry approach when there was no longer any conflict between the two domains in terms of examinations.

Summary of Janine's conceptual development

It is clear that Janine did learn a considerable amount about acids and bases during the study, and she believed that the most important aspects were those which supported applications in pharmacy (2.784-2.788). However it was apparent particularly at the time of the final interview that a number of her fundamental ideas had not developed, and that she retained a trust in the chemistry definitions, to which she had added skills in pharmacy problem-solving – identifying functional groups, classifying molecules, and solving partition problems. She retained a pragmatic approach, in that she would do what was necessary in pharmacy contexts, and was indeed highly competent in them, but she did not see the pharmacy concepts as true or trustworthy in comparison to what she knew from chemistry. Her learning could not be regarded as encompassing significant conceptual change, since she retained chemistry notions of the nature of acids and bases, and regarded anything which contradicted them as fraudulent and suspect. Five months after completion of IPS, she had largely discarded the differences she had learned in order to perform well in her examination. She was comfortable in accepting new material which did not conflict with her prior knowledge, but this was best considered as a form of accumulation rather than change. The latter learning was considerably more persistent, but this persistence could reasonably be attributed in large part to Janine's excellent memory and her reliance on it.

Geoffrey

Geoffrey had performed very well in the Higher School Certificate, and at university set high standards for his performance. He aimed for High Distinctions in both Calculus and IPS (3.10-3.24), since these were his preferred subjects as they were less descriptive and more numerical (3.60-3.62), however he only obtained a Distinction in IPS which nonetheless placed him in the top 15% of the cohort. He was a diligent student, and recognised that hard work was necessary for success, although he did not perceive the need to work as consistently as Janine. Geoffrey finished the degree with the second highest grade of Honours.

Geoffrey's perception of the change in his understanding²

Geoffrey believed that his understanding had changed during the semester, but the evidence suggested that the primary outcome was the learning of new material rather than conceptual change. Although he described his understanding as having '*broadened*' (2.446) and '*changed*' (2.448), he struggled to articulate specific areas which exemplified this assertion, and concluded that '*I've just added on top of what I already know*' (2.450). The discussion of Geoffrey's understanding of acids and bases at the end of the teaching semester tends to corroborate Geoffrey's self-assessment: he could answer questions which directed him to specific concepts, but he did not demonstrate a holistic appreciation of the topic across the two domains of chemistry and pharmacy and did not look for connections between the two. This impression was confirmed by the third interview in

² Geoffrey's trajectory is described in Appendix F.

which Geoffrey appeared to have discarded almost all of the new material where it contradicted his prior understanding.

Summary of Geoffrey's conceptual development

During his second interview, Geoffrey demonstrated the ability to complete tasks and activities related to the pharmacy domain, and could on prompting differentiate to some extent between chemistry and pharmacy, but his conceptual understanding appeared to be highly compartmentalised. He appeared to rely on recognition of patterns and familiar problems, although he suggested that he did not learn by rote (which appeared to be substantiated by the responses in both his second and third interviews). Most significantly, he demonstrated a limited metacognitive awareness, which reinforced his knowledge compartmentalisation. He 'knew' the material and could use concepts appropriately in relation to specific problems, but in most cases could not articulate why he believed something to be true without significant prompting.

Geoffrey's motivations appeared to be primarily pragmatic although not solely for the purpose of performing well in examinations, since he was interested in the application of what he was learning (2.1213-2.1230). Rather his pragmatism took the form of the simplification of complexity, by reducing the possibilities to the most current idea, or by taking the most practical approach to problem solution.

By the time of the third interview, Geoffrey exhibited an essentially complete reversion to the chemistry concepts where they differed from the corresponding concepts in pharmacy, suggesting that his responses in the second interview were not a result of productive transformative internalisation. Rather he had memorised new definitions which he knew were expected of him in IPS, and was able to articulate them when asked, but only for a short period of time. After a longer period, he was not able to remember the new definitions, and appeared unaware that he had ever known them. Further, when he did retain a little of the new material, it frequently resulted in confusion as he could not connect it with his prior chemistry understanding. As a consequence, even some of his previously well understood concepts were confounded by a vague memory of pharmacy alternatives. Geoffrey had also learned to apply procedures to specific problems, and when he could recognise the problem he was able to tackle it with some confidence. Particularly where the task involved new material which had little, if any, link with his chemistry conceptual understanding, he was generally able to solve problems, despite being a little out of practice at the time of the third interview (3.800-3.802). His learning could therefore be primarily characterised as exhibiting little fundamental conceptual change, but rather an addition of new ideas which did not conflict with his prior knowledge. He himself acknowledged the latter: '*I haven't unlearned things I've just added on top of what I already know*' (2.450).

Larry

Larry was a reasonably high achieving student who was returning to study having taken a year off after finishing secondary school in Melbourne. He found this return difficult, particularly in first semester, and had not re-established effective study patterns. *'Last semester I'd just forgotten how to study so much, I had no idea...Coz I couldn't remember what I did in high school to remember things, I really couldn't...I just couldn't remember how to study, what to do, when exams came around, I just panicked'* ^(2.324-2.328). He set high standards for himself, was academically very competitive, and enjoyed being asked for assistance since it provided him with opportunities to demonstrate his mastery of the material. Larry was *'very, very, disappointed, extremely disappointed...bitterly disappointed'* ^(3.4-3.6, 3.20) with the low Credit grade he achieved in IPS, and the poor mark he received for chemistry, because he *'put the same amount of effort into IPS and chemistry, coz I knew they were the most important, probably equally weighted, but I put so much effort'* ^(3.16-3.18). Larry appeared to have overestimated his level of understanding, as he in fact achieved the lowest examination score of his group. He did, however ultimately graduate from the degree with First Class Honours.

Initial conceptual framework

At the beginning of the study Larry demonstrated a fairly limited and fragmentary understanding of the nature of acids and bases, and although he was generally able to state the elementary ideas, he was uncertain and hesitant. His first comment about acids was that *'they're acidic'* ^(1.2), spoken in a flippant tone, however he did proceed to identify acids as proton donors ^(1.4) and bases as proton acceptors ^(1.8). His lack of certainty was apparent in the manner in which he qualified his responses: *'I'm fairly sure they do, anyway...I actually don't remember but anyway'* ^(1.6-1.10). Larry only specified a pH for bases ^(1.10), although he indicated that he was familiar with pH as a descriptor of both acids and bases ^(1.14-1.16). Larry did not volunteer a name for his definition of acids and bases.

Significant probing was necessary to elicit Larry's understanding of the physical characteristics of acids and bases. Initially he appeared unaware of the meaning of 'physical' characteristics and incorrectly assumed that chemical reactions were included ^(1.31-1.38). Even when prompted with examples such as taste and touch, he continued to struggle. Eventually, he was able to recognise the corrosiveness of both acids and bases ^(1.42-1.44), but he appeared unable to articulate his concept of the taste of an acid, merely describing it as *'acidic'* ^(1.46). Vinegar and lemon juice were correctly classified as acids, but he described their taste as *'bitter'* ^(1.48) instead of the chemistry convention of sour.

Larry identified the purpose of pH as *'measuring whether it's an acid or base'* ^(1.90), and was able with only slight difficulty to remember the appropriate equation relating pH to hydrogen ion concentration ^(1.92) and to use it in a simple calculation ^(1.106). Although initially suggesting that *'the larger the pH, the more acidic it is'* ^(1.88), he later corrected himself to identify low pH as highly

acidic ^(1.96). He also found it relatively straightforward to calculate using pOH and hydroxide ion concentration, indicating that he was familiar with the relationship linking hydrogen and hydroxide concentrations ^(1.126). Somewhat surprisingly he did not appear to link his mathematical understanding with a more descriptive one, and was uncertain about the presence of hydroxide ions in solutions of low pH ^(1.116-1.118). Subsequently he indicated that hydrogen ions would be present in solutions of high pH, but was unwilling to make an attempt to use the mathematics ^(1.127-1.128).

Larry associated strong acids in chemistry with high concentrations of hydrogen ions in solution ^(1.138), suggesting that he did not clearly distinguish between strength and concentration. Support for conflation of these concepts came in his explanation of how acids differed from each other, which he based on the magnitude of the pH ^(1.82) rather than extent of dissociation ^(1.88). Conflation of the concepts was perhaps understandable in the light of his weak background, since in many cases a strong acid would produce a lower pH than a weaker one. However without an understanding of the mechanism of complete and incomplete dissociation, his understanding of this concept could more appropriately be described as naïve rather than scientific.

Larry explained strength differently in his survey response, suggesting that '*a strong base goes fully to completion in a reaction. A weak base does not*'. This statement indicates a rudimentary understanding of the concept, but one which was limited by his failure to specify the dissociation reaction. However the fact that Larry provided slightly different definitions in his interview and survey was consistent with his lack of familiarity and confidence with the material, which meant that on any one occasion he was only able to recall isolated fragments rather than an integrated explanation.

In summary, at the time of commencing the topic of 'Acids and bases' in pharmacy, Larry's understanding of the chemistry meanings of these terms was incomplete, unconnected and uncertain, and in all aspects of the interview he displayed similar levels of doubt. This observation was somewhat surprising, since he had studied acids and bases in chemistry in the previous semester; however a likely explanation lay in his different secondary school circumstances. Larry had studied a different chemistry curriculum (at secondary school in Melbourne rather than Sydney), and he had covered particular topics in different depth. In particular he commented that he had struggled with acids and bases in first semester chemistry ^(1.448). He had also delayed commencing university by a year, which meant that his memory of the topic was not as fresh as the other students in his group. However he had received assistance from the tutor at his college in first semester ^(1.448), and felt that he had understood the material adequately at the time. Nevertheless, his preference for studying by attempting large number of examples and completing past papers ^(1.408, 1.416, 1.430) appeared to have constrained the way he conceptualised acids and bases, resulting in the fragmentary understanding which he displayed at the beginning of the study.

Further insight into the fragmentation of his conceptual understanding came from a comment about the importance of definitions to his learning ^(1.402-1.406). For Larry, this topic was significant only

insofar as he needed to know it to perform well in examinations, and prior experience had demonstrated that understanding definitions was unnecessary. He was clearly successful in his examination performance since he had achieved a sufficiently high ranking to allow him to enter pharmacy. Larry had adopted a range of strategies for examination preparation, of which disregarding definitions was only one (further evidence is presented in later sections) and this strategic approach had brought him success in the past. Unfortunately, however, his strategies had left him with a limited conceptual foundation for learning about acids and bases in pharmacy.

Larry's trajectory

Changes to existing understanding

Interview 2

On the day following his examination, Larry's articulation of his understanding had become a little more confident, but it still tended to be fragmentary and unconnected. He struggled to recall whether acids donated or accepted protons ^(2.224), although he eventually concluded that they did, apparently by linking to the idea of acid dissociation ^(2.226). Although he was able to reason his answers, the lack of precision of his responses suggested that he had maintained the disregard of definitions exhibited in his first interview.

Larry did recognise that strength in pharmacy was determined by the value of the pK_a ^(2.186), and was able to describe the relevant pharmacy conventions for both acids and bases ^(2.189-2.198). He was also able, albeit after discussion with the interviewer, to articulate the different definitions of strength in chemistry and pharmacy ^(2.229-2.246). In both of these exchanges, Larry provided appropriate answers, which appeared to suggest that he had learned the concepts effectively, however, he freely admitted that this ability was a consequence of memorisation of the relationships ^(2.197-2.202).

In general, Larry continued to adopt the strategy of memorising difficult concepts, and was quite successful using this strategy as a method of preparing for examinations. He indicated that he was selective about what he chose to memorise, citing a table which had been given in the lecture notes as an example which provided maximum benefit for effort ^(2.280-2.296). To accompany his dialogue Larry drew his memorised table (Figure 6.1), which very closely matched the layout of the table presented in lectures. He was clearly proud of his ability to memorise as a critical strategy for studying, and did not regard it as in any way detrimental to his learning.

$pH > pK_a$	$pH < pK_a$
ionised	unioned
unioned	ionised.

Figure 6.1: Larry's representation of the table

Given the sparse nature of Larry's conceptual understanding of acids and bases in both chemistry and pharmacy contexts, he did not exhibit great confusion between the two domains ^(2.174-2.176). However he highlighted the differential concept of strength as of some concern, both for himself and for Lucy: *'that's what Lucy was identifying as the problem, because, in chemistry carboxylic acids are weak acids and in pharmacy they're a strong acid. And she was chucking a narky fit about the fact that "why is this so"? ... "Why, why can't we just do it the chemistry way? Why does it have to be all so confusing?"* ^(2.256-2.258, 2.170). Although he claimed that the dilemma was resolved by group discussion: *'it took us a fair bit of throwing it around the table before we actually got it through our heads that there was, what the differences were, why they were such, and so you could do the problem...I think we got it though our heads in the end'* ^(2.152-2.162), his final response to Lucy was *'I don't think I could explain it, I just said "that's just the way it is. Just accept it."* ^(2.258). From his responses outlined above, it appears that Larry followed his own advice.

Towards the end of the interview and with significant prompting ^(2.597), Larry recalled that acids were liable to cause burns ^(2.608), and suggested that this characteristic was limited to chemistry ^(2.609-2.610). However he did not associate the notion of ionisation states at specific pH values with his concept of acids and bases, demonstrating no recognition of the connection even when the interviewer explained in a significant amount of detail ^(2.553-2.558), and he continued to miss this connection during his third interview. He recalled that this explanation had been given to him in the second interview ^(3.272), but his memory of the explanation did not include the notion of acids being unionised at particular pH values.

Larry's failure to make this connection illustrates much of his approach to this topic. It was clear that he was able to select pH values at which acids and bases were unionised (see later section) because he had memorised the table relating pH, pKa and ionisation. However, he had not connected the table, which for him was a problem-solving tool, with its conceptual foundation that acids existed as the unionised form at pH values below their pKa. The dislocation of concept from tool was observed in almost every aspect of the topic, and was a significant source of his difficulties, since it left him unable to approach unfamiliar situations or problems.

By the end of the teaching semester, therefore, Larry appeared to have learned how to express his ideas a little more precisely, and to have learned additional pieces of information, but not to have undergone any significant conceptual development in his thinking about acids and bases. His

conceptual framework remained fragmented, and when confronted by difficulties in understanding, he handled them by accepting external authority without attempting to work through to a satisfactory explanation. Contextual discrimination was apparent, but it was largely memorised rather than incorporated into his conceptual framework. To some extent he mirrored Janine's belief that chemistry was correct and pharmacy incorrect, in that he suggested that carboxylic acids were actually weak ^(2.599-2.602), however he did not express this opinion as forcefully as Janine.

Interview 3

Five months later, Larry remained able to explain the salient features of acids and bases, but continued to express his ideas in an uncertain and hesitant manner ^(3.148-3.154). Larry's expression was very similar to his responses in the second interview, however he appeared to have made some progress, in that he was able to reason out his answers more quickly than previously. Two aspects stand out from Larry's first turn in this exchange. Firstly he appeared not to own the definition of acid, describing it as '*your definition*', thus suggesting that definitions were still not of great significance to him. Secondly, he referred to the definition as something in the past – '*it used to be*' – which suggests two potential interpretations. Either Larry regarded the whole topic as one which had been completed and was no longer relevant to his current study, or he may have continued to regard the chemistry conventions as true but apparently superseded by the less satisfactory pharmacy approach. It is difficult to judge if either (or neither) of these interpretations is valid.

Larry strongly associated the concept of pH with acids ^(3.159-3.164), and in relation to this characteristic did not appear to distinguish between chemistry and pharmacy. His responses suggested that he had reverted to his chemistry understanding, and the distinction that he had made at the time of his second interview between acids and acidic solutions was no longer evident. When specifically asked '*is there a difference between an acid and an acidic drug in your mind?*' ^(3.165), he appeared to understand that a difference existed in relation to strength, but was unable to articulate a clear explanation ^(3.166-3.168). The imprecision of his language suggested that he had not appropriated the ideas which he expressed at his second interview, but reinforced the interpretation that he had memorised them for the purpose of the examination. Larry appeared to have forgotten the use of pKa as an indicator and descriptor of strength, and was forced to resort to very imprecise terminology such as '*not as acidic*' in an attempt to express his ideas.

The physical characteristics of acids and bases were not covered in any depth as Larry did not volunteer any information of this type in response to probing. In his two previous interviews, Larry did not at any stage spontaneously connect acids and bases with their physical characteristics, therefore it was not followed up when Larry again failed to make an unprompted connection in the final interview.

Larry demonstrated significant difficulties in identifying and describing the strength of acids and bases, and the learning that he had exhibited at his second interview had not persisted to the end of

the study. He was quite confused about the implications for strength of the extent of dissociation, although he did appear to have some understanding of the concept which he struggled to articulate. For example, he identified that pharmacy acids contained '*weaker acidic groups, like the um, (pause), forgotten its name, car, carboxylic acid is it?*'^(3.170), and that '*most acidic drugs don't dissociate completely*'^(3.172), but could not explain (or did not make the connection) how incomplete dissociation related to strength in pharmacy. He no longer mentioned pKa as a measure of strength, and appeared to have forgotten the dilemmas expressed in the second interview about acids which were classified as weak in chemistry but strong in pharmacy. He struggled even to maintain a dialogue about strength, suggesting that his understanding consisted of a set of fragmentary ideas, some of which had names associated with them, but few of which were associated with coherent meaning.

Strength and extent of dissociation were identified as different between chemistry and pharmacy, but Larry's answers strongly indicated a confusion of ideas from different aspects of the topic^(3.175-3.182). He correctly identified the chemistry convention for strong acids, but for pharmacy, he conflated dissociation in water with the effect of pH on solubility. For the former, the pharmacy convention is that no acidic or basic drug, not even one which is classified as strong, dissociates completely in water, however if the pH is manipulated to certain values and held constant, then effectively 100 percent ionisation can be achieved. These concepts are peripherally related but not interchangeable, and Larry's inappropriate association of ideas was consistent with the lack of structure to his understanding. The '*weird prac*' was revealed as a workshop in which a graph of solubility as a function of pH was constructed: Larry was recalling aspects of the graph from memory without understanding what it signified^(3.186-3.196).

In summary, Larry retained a fragmented and tenuous understanding of acids and bases in both chemistry and pharmacy, although he tended to favour his chemistry concepts. A certain amount of short term learning was apparent in his second interview, however he lacked a coherent conceptual framework, and was forced to rely on memorisation of rules and patterns rather than on eliciting underlying meanings and relationships. As a consequence, his concept articulation was imprecise and long-winded as he struggled to find the words to express his ideas, and his ability to engage in meaningful dialogue about acids and bases was transient. He relied on his memory, which was sufficient in the short term, but since he had not appropriated the underlying relationships, his articulation of the pharmacy conventions did not persist. By the time of the final interview, most of them were forgotten, and there was little evidence of significant progression in understanding from his chemistry foundations, which were in themselves still shaky. In many respects, persistent conceptual change was almost impossible, since Larry lacked a framework which **could** undergo change.

Larry was clearly much happier with equations than with definitions, and he was hampered by both an approach to learning and strategies which had served him well in secondary school, but which

were no longer successful at university in helping him achieve his goals of high examination performance.

Concepts new to pharmacy

Interview 2

Larry approached this task as a challenge or test, and began speaking rapidly as he identified functional groups. He was confident and accurate in his analysis of codeine, lignocaine, amoxicillin, ticarcillin, diazepam and ibuprofen, and correctly classified each of the molecules as acid, base or neither. His reasoning was sound, as he was able to explain exactly what he was looking for in order to identify each relevant functional group, carboxylic acids^(2.362), phenols^(2.356-2.358), amines^(2.342), and amides^(2.362). The latter were distinguished on the basis of hybridisation, with sp^3 hybridisation correctly inferred '*if it's got four bonds to it*'^(2.342). Only once was he slightly uncertain about the overall classification of a molecule, when he momentarily considered that amoxicillin, with one basic and two acidic groups, might have been acidic. However, again relying on memorisation, he was able to correct himself^(2.382-2.390). In this exchange Larry referred to a discussion from lectures in which the logic of classification was discussed, using a sequence of four steps and an explanation of the reasoning. Although he was able to use the logic he had learned to solve the problem at hand, Larry had memorised the rules without appreciation of the rationale behind them. Further, he admitted that '*I know all of these structures basically off by heart now*'^(2.412), thus making it easier for him to carry out the task in the interview.

Larry was asked to carry out the dissociation equilibrium task for both ibuprofen and amoxicillin, and was able to complete both successfully without apparent difficulty. He used the pharmacy conventions with respect to arrows and placement of the pK_a above the arrow^(2.440), but appeared to rely on his memory of the pH/pK_a relationship table (see previous section) to explain that ibuprofen would be ionised at pH values greater than its pK_a ^(2.446). At this point therefore, he appeared not to have made the connection between his table and drawing the dissociation equilibrium; one of the reasons for drawing the equilibrium was to create a visual representation of the tabulated data so that it was not necessary to remember the table. Again, Larry appeared to favour memorisation of rules over understanding the underlying concepts.

However, when asked to indicate the structure of amoxicillin which predominated at pH 5, he chose to use the visual representation to select the appropriate structure^(2.570-2.576). It is not obvious why Larry elected to use different strategies to solve such closely related problems, although the explanation may lie in his stated preference for the use of specific rules in particular situations. If he did not actually recognise that the two problems were closely related, it is possible that he perceived a need for separate strategies. In a single-step dissociation, he may have decided that the table was easy to recall and apply, whereas for a multi-step problem he may have learned the visual

strategy. That he appeared to lack the insight to recognise the similarity between the problems is consistent with his general approach to the topic.

Interview 3

Five months later, Larry demonstrated significant error in assigning acidic or basic nature to two groups which he had correctly classified during the second interview. Firstly, he correctly identified the phenol group ^(3.214), but declared that the presence of the OH group made the molecule basic ^(3.214-3.216), strongly suggesting conflation of the concept of OH (hydroxyl) group with OH⁻ (hydroxide) ion, presumably because of their similar chemical representations ^(3.256). Whilst this confusion was understandable, the potential for confusion had been repeatedly emphasised during the teaching of acids and bases, and no other student exhibited this error in interview.

Secondly, Larry struggled with some aspects of amine groups. He could identify them ^(3.218), and was quite adept at distinguishing them from amides, although he did not identify either by name, consistent with his stated disregard of definitions. Initially he thought that identification related to stereochemistry ^(3.222) but subsequently decided that he needed to look at the atoms bonded to the carbons next to the nitrogen atom in order to decide if it was an amine or amide ^(3.242). His terminology was imprecise and idiosyncratic ^(3.228, 3.236, 3.248), and hybridisation was not mentioned.

However, despite his ability to identify the correct molecular patterns, Larry described amines as acidic ^(3.248-3.253). No reason was apparent for the source of this error, and no subsequent probing was carried out.

Carboxylic acids continued to be easily identified and classified by Larry, and once his difficulties with amines and phenols had been resolved by discussion, he was able to identify further examples correctly.

In relation to amoxicillin, Larry recalled the exchange from the second interview in which the interviewer explained why it was classified as neither acidic nor basic ^(3.272), but could not recall the details accurately. His response was a confused and generally inappropriate reference to pH, pKa and ionisation ^(3.272-3.274), suggesting that he may have grasped the concept at some level, but with incomplete recall.

Larry was again asked to draw the dissociation equilibria for ibuprofen and amoxicillin, and completed these tasks with no assistance and with little difficulty ^(3.291-3.298, 3.330-3.348). The diagrams were drawn in accordance with the conventions of pharmacy as covered during the previous semester, and Larry was able to identify the structure which predominated at different pH values. However, unlike the previous occasion when he utilised the visual representation, in the final interview he used an idiosyncratic reasoning process for the dissociation of amoxicillin, based on

the table he had memorised for the examination. Larry's initial strategy was to write out the table, which he was able to reproduce as easily as he had in the second interview^(3.330-3.332), and he agreed with the interviewer that he had '*really drilled that in*'^(Interviewer 3.331). With the table available to him, Larry wrote out the equilibria illustrated in Figure 6.2. As a first step, he drew the arrows and put the pKa values underneath them, then identified the ionisation states of one functional group at a time – first the carboxylic acid, then the amine, and finally the phenol. The last step involved drawing the links between the groups^(3.344-3.349).

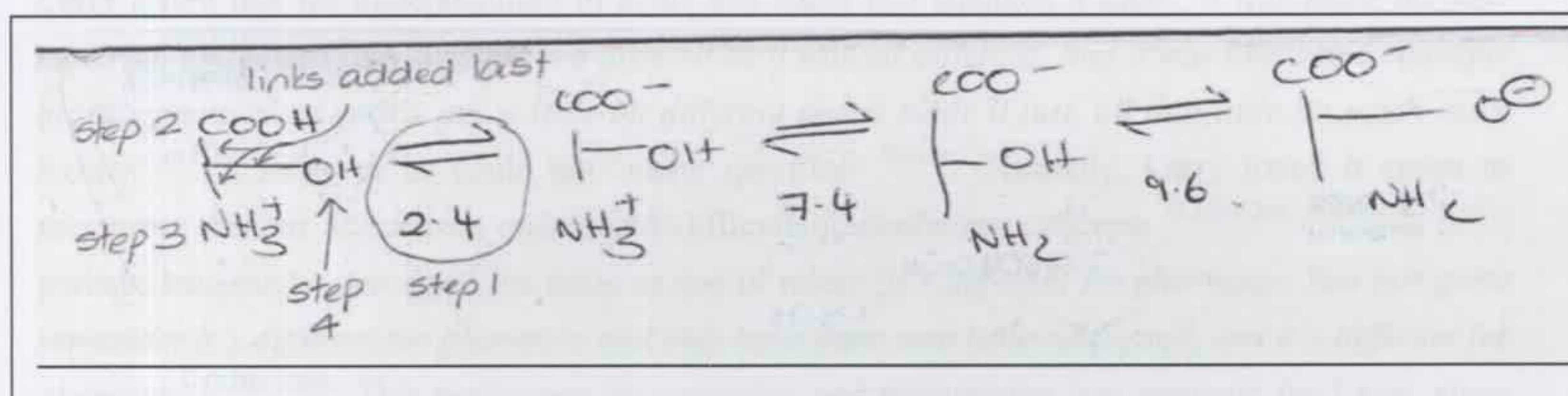


Figure 6.2: Larry's approach to multiple dissociation (with annotation)

Whilst this strategy was effective, it strongly supported the interpretation that Larry had forgotten the purpose behind drawing the visual representation. The concept underlying the visual representation was that molecules such as amoxicillin dissociated through loss of protons starting with the lowest pKa, and that the whole molecule needed to be considered at each step of the dissociation. Larry was on the right track with his approach but he should not have needed the pKa values themselves in order to draw the structures at each step. A coherent understanding would have allowed him to recognise that the molecule lost the proton firstly from the carboxylic acid group, then from the amine group and lastly from the phenol group, rather than needing to consider the state of ionisation of each group at four different pH values. Larry's approach was fragmented into a 'join-up-the dots' technique, rather than a holistic appreciation of the totality of the molecule.

That Larry now used his table to solve both simple and complex dissociation problems may suggest that he no longer perceived differences between the two types of problems, but it is more likely that he had misconstrued the purpose of drawing the visual representations. Had he been able to understand the principles behind drawing the equilibria and using this diagrammatic representation to summarise and represent conceptual understanding, the need to remember the tabulated information would have been obviated. However, as in the previous interview, he preferred to rely solely on his memory in order to carry out what he perceived as a 'task'.

In summary, Larry relied significantly on memory for identification and classification of acidic and basic groups and molecules, although some exchanges indicated that he understood the principles. However by the end of the study the rules and patterns he had memorised for the examination had not persisted, and he made fundamental errors in assigning acidic and basic nature to the groups which he had no previous difficulty identifying. He fared better with remembering the table

relating pH, pKa and state of ionisation, which he indicated was '*the most important thing*'^(3.332) he had learned, and which persisted almost unchanged, but his use of it had altered over the five-month break. Although Larry had learned a number of significant facts, his conceptual framework continued to be fragmented, and showed little evidence of significant change.

Larry's perception of the change in his understanding

Larry stated that his understanding of acids and bases had changed a little: '*it was more the new material, and it was like, twisting it a little bit so it was all different. And it was like, same concepts but it's just twisted so it's just a little bit different and it made it just, all that little bit much more harder*'^(2.156), however he could not '*name specifics*'^(2.210). Generally, Larry found it easier to memorise than to attempt to understand difficult or confusing concepts^(2.200-2.204, 2.286-2.288, 2.320), perhaps because he perceived the issue as one of rules: '*it's different for pharmacy. You just gotta remember it's different for pharmacy and they have their own little rules, and, and it's different for chemistry*'^(2.206-2.208). This preference for codifying and memorising was strategic for Larry, since his background from secondary school was weak, however it clearly hampered his longer term learning, because the rules were not based on strong foundations and were occasionally in conflict with what he believed from chemistry. Larry had perhaps internalised the rules, but they did not form part of a coherent conceptual framework for understanding acids and bases. As a result, his application of the rules was dependent on his memory, and limited to the context in which he had learned them.

Summary of Larry's conceptual development

At the beginning of the study, Larry's conceptual understanding of acids and bases in chemistry was fragmentary and appeared to consist of a series of relatively unconnected ideas. He appeared not to find this problematic, since he had in the past been able to perform successfully in chemistry examinations by knowing equations rather than definitions, and by being able to select correct equations for particular problems because of repeated practice of similar questions from past papers^(1.402-1.418). In IPS, this approach proved less successful because of the emphasis on definitions and concepts, and probably contributed to Larry's failure to live up to his own expectations of performance in the final examination.

By the time of the second interview Larry had learned a number of rules which were intended to assist his performance in the examination. In most cases he had successfully learned the rules, but had not focused on understanding the underlying rationale and his knowledge was therefore very superficial. He appeared to be comfortable with this strategy, and saw it as his most effective approach. It was clearly consistent with his aims in learning, and his perceptions of the significance of what he had learned during the semester: '*It was all important for the exams, put it that way*'^(2.714). Larry did concede that pharmacists needed to be able to apply reasoning in order to solve problems: '*you would probably have to know why that would happen and how to solve it*'^(2.722), but

he did not seem to connect the need for problem solving with what he was learning in IPS about acids and bases. For Larry, it was a matter of jumping through the hoops and trying to achieve the highest score.

Corroboration of this perception is found in his final interview where it appeared that he perceived chemistry to be correct and pharmacy incorrect: *'like you came in and said that there, in Pharmacy we study acids and bases this way. And in Chemistry you've learnt that this is what acids and bases do. You're type of like "I'm in IPS now, I'll learn it your way just for the fact that you're setting the exam"'* (3.104). This statement strongly supported the contention that Larry was primarily focused on performance rather than learning.

At the end of the teaching semester, evidence of some conceptual change and contextual discrimination was apparent but Larry appeared to have appropriated few of the concepts underlying the nature and applications of acids and bases in pharmacy. He remained uncomfortable with definitions and meanings, and exhibited a strong preference for solving problems which required highly specialised cognitive tools – the use of equations or the application of rules or patterns which he had memorised. Because these patterns and rules had been memorised primarily for the purposes of examinations, and he tended to rely on recognition of particular types of examination questions to trigger the appropriate tool use, he was frequently unable to recall them accurately, and required correction by the interviewer in order to channel his thinking into familiar paths. Once he was 'channelled', he was generally able to follow his rules appropriately, and could solve some types of problems with relative ease. However, he was not challenged with unfamiliar problems, and it is unclear whether his specially tailored rules would have continued to suffice.

By the end of the study, however, it had become apparent that much of the ostensible conceptual change was short-term and transient, since Larry's learning had been essentially used as a strategy for examination performance. Most of the change had disappeared, and he had reverted in many cases to pre-pharmacy conventions, although his memory could be refreshed in some cases through prompting. Fragments of novel conceptual understanding were evident, but these usually related to ideas which were new to pharmacy and thus did not require Larry to discriminate between the two different domains. Further, Larry's language had significantly reverted to pre-pharmacy (and in some cases naïve) conventions, suggesting that he had not effectively appropriated the discourse of pharmacy to any great extent.

Despite his strong examination focus, Larry appeared unaware that his learning and studying strategies had been less successful than in the past, and that his high performance expectations were unrealistic. His rather fragmented and shaky foundation of acids and bases from chemistry may have contributed to this outcome, but it was also clear that Larry had not developed or progressed significantly in his approaches to learning, nor did he appear to appreciate the need to connect the solution of problems with their meaning and practical relevance. The topic of acids and bases was something to be learned for exams and then not used again, except perhaps for future exams.

Lucy

Lucy was not amongst the highest performers on entry into the degree, but had achieved an entrance rank close to the lowest that would allow her to study pharmacy. Her entry rank was still very high in the overall scheme of tertiary entrance, however, and indicated a strong performance in the final secondary school examinations. Her family background included pharmacists, and non-recorded casual conversations suggested that her choice of pharmacy was strongly influenced by her parents. She did not appear to be as competitive about performance as most of the rest of her group, and seemed happy simply to achieve passing grades. As a consequence, she was pleasantly surprised at her Credit grade for IPS: *'I was very happy with them, yeah. Yeah, yeah. It was good, like I didn't get anything that was out of this world or anything but I was, like for me I thought that was really good'* ^(3.2-3.4).

Initial conceptual framework

At the commencement of the topic, Lucy demonstrated an understanding of acids and bases which was quite limited, but she was confident about the concepts with which she was familiar, the exchange of protons and pH. She immediately and accurately identified acids as proton donors ^(1.6) and bases as proton acceptors ^(1.8), but did not use the name of this definition and did not offer any alternatives. She could not spontaneously name any other characteristics, physical or chemical, of acids, although on prompting she admitted that she had heard of litmus paper but was unsure of its behaviour ^(1.18). She was able to recall that bases were slippery ^(1.22), because she associated the idea with household detergents ^(1.26-1.32). She also volunteered the idea that some acids caused burns ^(1.46) but she did not appear to regard this as a general characteristic.

Lucy was able to state precisely and concisely the equation relating pH and hydrogen ion concentration ^(1.70), but was less certain of the purpose of pH, suggesting that it was used *'to measure the concentration, I think it is, of an acid or base'* ^(1.72-1.74). This purpose is relevant since in chemistry the concentration and pH of solutions of strong acids and bases are numerically related, but Lucy seemed less aware of the conceptual nature of pH as a guide to the acidity or basicity of the solution. She was confident in associating pH values with strong acids, strong bases, and neutral solutions ^(1.80-1.82), but did not mention weak acids or bases. Lucy easily calculated the concentration of hydrogen ions in a solution of pH 1 ^(1.88), but was very unsure about the concentration of hydroxide ions at that pH: *'pH 1, there could be, I'm not sure. (pause) No, there coz. Oh no, I don't know'* ^(1.116). In contrast, she was unable to carry out the simple pH calculations in her survey.

Lucy appeared to conflate the concepts of strength and concentration in that she related the extent of dissociation to concentration rather than strength ^(1.54). That her concept of strength was essentially tied to concentration was substantiated by two further incidents. Firstly, she clearly identified low pH and high concentration with strong acids ^(1.80). Whilst these two conditions are

usually coincident in that low pH values are most easily achieved by the use of strong acids, pH is essentially a measure of concentration rather than strength. Secondly strong acids were perceived as always dangerous^(1.46). A more discriminating concept of corrosiveness would have allowed her to recognise that strong acids were only corrosive in high concentrations, and that low concentrations of even the '*really strong*' acids were quite safe in contact with skin. Further, although vinegar contains a low concentration of acetic acid, high concentrations of even weak acids such as acetic acid are in fact also potentially corrosive.

Lucy's survey response provided greater insight into her understanding of strength as she indicated that a strong acid had greater ionisation or dissociation than a weak one. However the survey question specifically asked '*What is the difference between a strong acid and a weak acid of the same concentration?*' which may have masked her lack of discrimination between concentration and strength by removing concentration as a confounder. Lucy did not at any stage in either the interview or survey offer the definition of a strong acid as one which dissociated completely in solution.

In summary, Lucy demonstrated a restricted conceptual framework for the nature of acids and bases, and was uncertain about many aspects, particularly strength for which the concept was confused with concentration. She displayed a fundamentally numerical appreciation of pH, with the equation foremost in her understanding, although she was not always able to use it effectively. She was able to describe the meaning of pH in words but appeared to regard the verbal description as secondary.

Lucy's trajectory

Changes to existing understanding

Interview 2

On completion of the teaching semester, Lucy continued to define an acid as a proton donor^(2.146) and a base as proton acceptor^(2.164). Somewhat surprisingly she indicated a slightly broader conception of chemistry acids than she had outlined in the first interview^(2.148-1.152). She continued to associate few other characteristics or properties with either acid or base and needed prompting to mention them, although strong acids and bases were acknowledged as dangerous when the specific question was asked^(2.437-2.442). In relation to pharmacy, she admitted that formation of salts^(2.153-2.156) and ionisation behaviour^(2.159-2.160) were not integral to her understanding of pharmacy acids, although she was aware of them.

Lucy was aware that additional differences existed between acids and bases in chemistry and pharmacy, but she struggled to articulate them clearly. She identified the fundamental difference as one of application^(2.434), suggesting that she had at some level grasped the significance of context in

determining meaning, but she did not expand on the ways that acids and bases were perceived or used differently in these two contexts.

More specific differences were generally restricted to issues surrounding the strength of acids and bases^(2.108), which she tended to see as a source of confusion^(2.98), and her strategy for dealing with this confusion was simply to memorise the rules^(2.12, 2.112). She appeared not to have considered whether pharmacy acids and bases were dangerous in the way that she regarded chemistry acids and bases, but on prompting suggested that because pharmacy acids were weak from a chemistry perspective, they probably were not dangerous unless *'you take them the wrong way or if you take too much of them or whatever then they can probably be harmful'*^(2.438).

While she was aware that the concepts were different, Lucy continued to display very little comprehension of the meaning of strength either in chemistry or pharmacy, and she had still not linked the notion of dissociation with strength^(2.130). Instead, she found it easier to remember rules and names rather than the fundamental rationale^(2.116-2.132). The interviewer spent some time in explaining the rationale^(2.133-2.141), but it seemed not to trigger any significant response or recognition on Lucy's part and the explanation did not appear to interest her greatly. In addition, she conflated pH and pKa^(3.356), and while appearing to accept the interviewer's response *'Not necessarily'*^(2.357), Lucy did not seem concerned that her ideas had been refuted, and did not seek further clarification from the interviewer.

Lucy's attitude to the differentiation of meaning between chemistry and pharmacy was conveyed more definitely by Larry, who, as already outlined, described her reaction as one of frustration (page 115).

Eventually, after several attempts at probing and prompting, the interviewer elicited the values of pKa as a method of distinguishing between strong and weak acids in pharmacy^(2.342, 2.348-2.350). It was clear however that she recalled these relationships only in the context of identifying functional groups (on amoxicillin), rather than as a constitutive aspect of her concept of strength. The explanation given by the interviewer of the link between strength and pKa, based on the meaning of the equation for acid dissociation equilibrium constant K_a ^(2.351-2.367), appeared to be unfamiliar to Lucy, despite the fact that she could write out the equation itself, and she was not particularly enthusiastic or interested. As with other members of her group, her understanding was somewhat fragmented and firmly situated in specific problem-solving contexts, particularly those which were perceived as likely to appear in the examination.

Thus by the end of the semester, Lucy had become aware that differences existed between chemistry and pharmacy in the meaning and use of acids and bases, and in their strength, and she had learned that some things which applied in chemistry did not apply in pharmacy and vice versa. However, she struggled to explain why the differences were important, and appeared to have

grasped the 'new' material she had learned about acids and bases in pharmacy in a superficial and fragile manner.

Interview 3

Five months later, Lucy continued to retain the concept of an acid as a proton donor^(3.104) and base as a proton acceptor^(3.120) in essentially the same form as she had learned from chemistry. She still did not spontaneously associate any other characteristics, physical or chemical, with either acids or bases, but when prompted, stated that '*acids are smaller pHs and bases are higher pHs*'^(3.124), suggesting a reversion to pre-pharmacy understanding.

She indicated that she understood that differences existed between chemistry and pharmacy in the meaning and function of acids and bases, but struggled to frame her understanding in words. She suggested that the acids used in the two domains were actually distinct from each other^(3.114) but did not offer any specific examples. She identified strength as a discriminator, but could not explain cogently why strength was perceived differently in chemistry and pharmacy^(3.142-3.144). Similarly, she appeared to recognise that there was something different about the essential nature of acids and acidic drugs in the two domains, but her articulation was imprecise and inconsistent with the conventions of either^(3.148-3.150). These latter concepts were interesting in that they were expressed only by Lucy, and appeared to result from a blending of ideas and imagination. The concept of an acid (chemistry) as a liquid clearly stemmed from the experience in chemistry with **solutions** of acids such as hydrochloric and nitric, which always appeared as clear liquids, however the notion that an acidic drug was '*made from an acid*' was idiosyncratic, and nothing to this effect had been discussed. It is likely that Lucy created this explanation as an attempt to put into words a concept which she had not fully worked out in her own mind, but the explanation was not followed up so this cannot be confirmed. Lucy's reversion to associating pH values with acids and bases (described above) was probably closely related to her description of an acid as liquid '*sitting in a jar*'.

Somewhat surprisingly, Lucy's concept of strength appeared to have undergone some development between the second and third interviews, in that she was able to state confidently that '*a strong acid is something that dissociates more easily than a weak one*'^(3.128), a concept which is relevant both in chemistry and pharmacy but which she had not articulated at either of her previous interviews. It is possible that the explanation which had been given by the interviewer in the second interview may have helped Lucy to understand the concept, but other explanations are possible and a causal relationship cannot be established. This progression in understanding was limited, however, and Lucy remained confused about how the extent of dissociation related to bases as well as to acids^(3.129-3.134). Further, she struggled to express the meaning of pKa^(3.162), and its application^(3.168-3.170), and agreed with the interviewer's evaluation that '*So pKa has something to do with strength but you would need to re-memorise which one went with which*'^(3.171).

In relation to her memory of these concepts, Lucy commented '*That's terrible it's only been, it hasn't been very long*'^(3.168), suggesting that she was aware that she had forgotten much of what she had studied in the previous semester, and was surprised at how quickly this had occurred. This metacognitive awareness provided an interesting contrast to other aspects of the topic, where she appeared oblivious to the fact that she had reverted to earlier knowledge.

Further evidence in support of Lucy's difficulties with pKa was provided when she attempted to associate specific functional groups on amoxicillin with appropriate pKa values. Although she was easily able to identify carboxylic acid as having a low (2.4) pKa, Lucy erroneously assigned 7.4 to the phenol group rather than to the amine, suggesting that she no longer associated weak acids with high pKa values. Although this was a common error among participants in the study, Lucy admitted that her assignment of the pKa values was by guesswork rather than understanding^(3.369-3.370). Other students (in the PC group) used a clear, though incorrect, rationale when making the same error.

In summary, Lucy demonstrated little evidence of persistent conceptual change throughout the study with her initial narrow framework remaining largely unchanged apart from a small number of minor points. In some cases she appeared to have mixed concepts together to form something idiosyncratic which fitted into neither domain. Her descriptive language remained at a generally naïve level, and the apparent lack of development of her externalisations suggested that transformative internalisation of the language patterns of pharmacy had occurred to a limited extent only. Similarly she appeared to begin the semester with an underdeveloped concept of acid and base strength, and appeared to retain only rudimentary fragments of the overall concept by the end of the study. Some evidence of progression in understanding was apparent, but the extent was minimal and did not extend to the application of the concepts to problem-solving beyond the examination period. Material which was not consistent with her understanding from chemistry was often memorised without comprehension, and was used in examinations by means of pattern recognition. Little, if any, conceptual change was apparent in these aspects of acids and bases at any stage during the study.

Concepts new to pharmacy

Interview 2

At the end of the teaching semester, Lucy found identification of most groups on the molecules to be relatively easy and straightforward. She was particularly familiar with carboxylic acid and phenol groups^(2.284), and was confident in distinguishing between OH groups which were phenols and those which were not^(2.200, 2.212-2.214). She knew that in order to be an amine, a nitrogen needed to be attached to carbons which were sp³ hybridised, and was aware of the features which characterised an sp³ carbon^(2.193-2.196). She was aware that amides involved a double-bonded oxygen, and could identify relevant functional groups when the molecular structure was drawn in a

clear and unambiguous fashion^(2.222), however she struggled when the formula was written in a particular linear manner^(2.225-2.236). Although not a focus of the current investigation it was clear that the manner of representing chemical structures was significant in affecting Lucy's identification of functional groups.

Lucy correctly classified carboxylic acids and phenols as acidic^(2.212-2.218), and located amines accurately in the molecules and identified them as basic, although she did not use the term amine itself^(2.190, 2.206-2.208, 2.220). She recognised that the presence of both acidic and basic groups in the same molecule rendered it '*both or neither or something I think*'^(2.258), but was uncertain of the reason for that classification, and seemed not to recognise the interviewer's explanation^(2.483). With a modicum of assistance she was ultimately able to assign the correct classification to all of the molecules which were presented to her.

Lucy was asked to draw the dissociation of both ibuprofen and amoxicillin and was able to carry out these tasks quickly and essentially correctly, using appropriate pharmacy conventions^(2.300-2.303, 2.380-2.389). She associated the pKa values with the pertinent functional groups, but admitted that these particular molecules were very familiar and that her ease in carrying out the task was '*coz I've done it so many times*'^(2.340). Her single error in drawing the dissociation equilibria was to omit the positive charge on the nitrogen on the second structure of amoxicillin. However she struggled to explain the purpose for drawing the equilibria in this way, suggesting that '*it just shows which, which, which form of it's going to be at different pKas*'^(2.390). Whilst this was similar to the reason for drawing the equilibria that had been discussed during the semester³, subsequent dialogue with the interviewer suggested that she had not appropriated this concept in a way which enhanced her understanding, and that she retained a fundamental confusion between pKa and pH^(2.391-2.398).

As had Larry, Lucy memorised the table relating pH, pKa and ionisation for acids and bases^(2.308-2.312), and used it in solving problems. This was not surprising since Larry and Lucy had studied together to a greater extent than any other members of the group^(2.8), and had developed joint strategies. Even more so than Larry, however, Lucy appeared to perceive pH and pKa primarily as algebraic variables, and important only insofar as they related to the equations she had learned. She did not recognise that her use of pKa^(2.391-2.398) was inappropriate until it was specifically pointed out to her, and she was only able to correct herself through use of her memorised table. The meanings of pKa and pH did not appear to figure in her use of them.

Having drawn the equilibria appropriately, Lucy nevertheless preferred to use the table in order to work out which form of the molecule would be present at pH 5, although she struggled. She eventually selected the correct structure but indicated that it was something of a guess^(2.404-2.418), and her rationale for selection was incorrect^(2.418). Unlike Larry, who was able to use the visual representation⁴, Lucy attempted to identify the ionisation state of each group independently, and

³ The appropriate expression required pH to be substituted for pKa.

⁴ In the second interview only. By the third interview he was using the approach demonstrated by Lucy here.

then to find a structure which matched the correct mix. She appeared to be successful with the carboxylic acid and phenol groups, but it is not clear how she perceived the amine group as she did not mention it. It is likely that the error she made in omitting a positive charge on the second structure resulted in confusion about the ionisation state of this group. The interviewer explained the alternative approach using the visual representation as it had been outlined during the semester, and Lucy appeared to grasp the concept as it was outlined^(2.419-2.424). The ease with which Lucy appeared to understand the alternative approach is interesting since she did not indicate any recognition of this approach from her learning, yet her study partner Larry had used it in his corresponding interview. It may be that, in contrast to Larry, Lucy did identify the single and multi-step dissociations as similar problems and preferred to adopt a single strategy for both. Unfortunately for Lucy, her strategy was the less effective and more potentially confusing alternative.

As she was attempting to solve this problem, Lucy appeared to lose sight of the goal of the reasoning processes as she was employing them, and needed to ask for the question to be repeated^(2.412), suggesting that she had not connected her knowledge, in particular the tabulated relationships, with strategies for solving particular problems. In this she differed from Larry, who had memorised the table as a specific problem-solving strategy, and who was more effective at identifying differential strategies to use in a particular situation⁵. Lucy appeared to be quite dependent on Larry's assistance, and it is likely that she simply copied his techniques and strategies without really understanding their purposes. Consequently, she was less confident in applying the strategies and tended to become confused or forget what she needed to do^(2.428-2.430). In the context of solving a problem relating to the table or relationships, she appeared to have learned the details in the table but not the associated meaning, and was confused when the problem was more than a simple one step equilibrium.

Furthermore, despite her almost accurate drawing of the dissociation equilibria, Lucy suggested that at pH values below all three pK_as amoxicillin would be unionised^(2.463-2.470), and the interviewer needed to prompt her to look at the diagram in order to identify her error^(2.471). At this point, Lucy appeared to remember that amoxicillin was always ionised in solution^(2.474-2.476), suggesting that she had memorised the fact, rather than recognising it from the diagram.

Interview 3

Five months later, Lucy remained able to identify most of the relevant functional groups, but was considerably less confident than she had been at the end of the previous semester. Carboxylic acid groups were again the easiest to locate and she found all of these groups with no difficulty and complete accuracy. Phenols caused slightly more confusion than previously in that she was confident in identifying the phenol on amoxicillin^(3.238-3.240) but was uncertain about the OH group on codeine^(3.194-196). Her final decision to classify it as a non-phenol was correct, but her lack of

⁵ This was less apparent in the final interview.

confidence contrasted significantly with her response in the second interview. She continued to recognise that phenols were acidic.

Lucy was generally able to identify amines, but was unsure of the criteria which were used to make the identification, and used reverse logic to distinguish them from amides ^(3.186) rather than articulating the specific amine characteristics which she had previously been able to describe. It was certainly important that she be able to distinguish between these groups, but her response suggested that she had conceptually divided all nitrogens into only two classifications, rather than recognising a larger number of possibilities. This inference was supported by her hesitation in relation to diazepam, which had a nitrogen double-bonded to a carbon, which was outside her two definitions ^(3.280-3.296). Although she claimed that the carbon atom in question did not have a double bond, she did not appear to recognise the carbon-nitrogen double bond because her expectations were based on finding carbon-oxygen double bonds. Once the double bond was identified, Lucy erroneously classified it as an amide⁶, and required correction by the interviewer, however it was not clear whether she understood the distinction. Lucy had already stated a preference for learning names rather than concepts, and it is possible that she used the same strategy to categorise nitrogens. Adoption of this idiosyncratic dichotomous classification system thus resulted in confusion for Lucy when she was confronted by groups which did not fall within her system.

Consistent with her experience in the second interview, Lucy continued to struggle with the different ways of writing amide groups. Significantly, however, she now failed to recognise the representation which she had found straightforward on the previous occasion, and she required a long explanation before becoming able to rectify her error ^(3.202-3.235). Once alerted to her difficulties, however, she was able to recognise all versions of the amide grouping in subsequent molecules.

Lucy recognised that the presence of both acidic and basic functional groups in amoxicillin resulted in something unusual, but her explanation remained confused ^(3.257-3.260) and she did not specify that it was neither acidic nor basic. In this exchange, Lucy did not actually answer the question posed, but introduced descriptions relating to the state of ionisation, thus suggesting that she had confounded the latter concept (which did depend on the pH) with the nature of the molecule (which did not). Her generally imprecise language in relation to classification of functional groups and molecules was consistent with her ways of describing many other aspects of acids and bases.

As was the case in her second interview, Lucy was again asked to draw the dissociation equilibria for ibuprofen and amoxicillin. Ibuprofen did not appear to cause any difficulties ^(3.312-3.316), however she was unable to use the diagram or the pKa value to identify the state of ionisation at a specific pH ^(3.321-3.328). Earlier in the interview, Lucy had indicated that she could not remember the relationship between pH and pKa, and did not mention the table which she had memorised for the

⁶ This is not apparent from the quoted dialogue but was clear from the context of the discussion.

examination. This exchange supports the view that Lucy no longer recalled the table as a tool for solving this type of problem.

As she had done at the end of the previous semester, the interviewer again explained the rationale and relationship to Lucy, however in contrast to the previous occasion, Lucy did not appear to pick up on the explanation and use it to solve the problem at hand ^(3.329-3.346). The key difference appeared to be her failure in the third interview to recall the ways that pH and pKa related to each other. During the second interview, when the table of relationships was part of her conceptual understanding, she appeared to be able to grasp an alternative visual explanation when the table did not provide the correct response. When she no longer thought of the table as a problem-solving tool, she was unable to recognise the visual alternative as a viable approach, since the fundamental principles had not been appropriated.

When attempting to draw the dissociation equilibria for amoxicillin, Lucy used a much abbreviated diagrammatic representation lacking most of the required features which she had previously included. Instead of drawing the molecule as a coherent whole, she drew each step simply as the dissociation of a single group. Further, she drew the amine group reaction as an association, or addition of a proton, rather than a dissociation, and required significant probing to recognise and correct the error ^(3.389-3.404). Further she admitted that she was '*going a wild stab in the dark for that one. I can't remember that one*' ^(3.386).

In summary, Lucy developed the ability to identify acidic and basic functional groups, and much of this new conceptual framework persisted until the end of the study. However, she was not able at any point to explain why the presence of both acidic and basic functional groups on a molecule rendered the molecule neither acidic nor basic, and her language in the final interview was generally less precise and more hesitant than in the second interview.

In relation to dissociation phenomena, Lucy appeared to have learned only fragments of the new material. Under some circumstances, she was able to use some of these fragments in appropriate ways, however she appeared not to have appropriated the underlying principles. Instead she preferred to rely on memorisation and pattern recognition in order to select appropriate tools for solving particular problems, but was less successful in memorising than others in her group, notably Larry. She appeared to be attempting to imitate Larry's approaches to the material and the examinations rather than developing her own, but since she did not necessarily share Larry's strategic approach, she may have appropriated, to some extent, the form but not the underlying strategy. As a result, her problem-solving was limited by her incomplete understanding of the use of the tools she chose, and the dislocation of form from strategy resulted in at best only short term conceptual change which was no longer apparent at the end of the study.

Lucy's perception of the change in her understanding

Lucy believed that her understanding had not changed a great deal apart from the addition of new material: *'it didn't change that much. Like I, yeah, like I, yeah I did learn new things and it's still, like it's still the same stuff, had to do all the other things in chemistry. But yeah, it's these things added on now'* ^(2.144). Although she did not respond directly to a question about whether anything in pharmacy was contradictory to chemistry, she recognised that some aspects were common to both ^(2.100) while others differed ^(2.144). She identified strength as an area which was different and therefore confusing between the two domains ^(2.108), but believed that she had resolved the issue to her satisfaction before the exams ^(2.100). Despite this statement, however, it was clear that her confidence was primarily based on learning the differences rather than understanding them, since she admitted that *'I just went "OK I'm just going to learn this for the exam". Um, I didn't, yeah I don't really know lots about the differences'* ^(2.112).

In summary, Lucy appeared to have learned by adding to her prior knowledge of chemistry those aspects of pharmacy which she believed would be useful for the exam. She did not appear to value either chemistry or pharmacy more highly than the other, but found the chemistry more familiar because it was more deeply rooted. Although she claimed to have understood the ways in which chemistry and pharmacy differed, she demonstrated little evidence of fundamental conceptual change, or even an appreciation of the reasons for regarding concepts differently in the two domains. In keeping with her apparent lack of engagement with the domain of chemistry in general, she appeared satisfied with the strategies she adopted for the achievement of her study goals. The topic itself did not engage her and had little personal significance.

Summary of Lucy's conceptual development

On commencement of the study, Lucy demonstrated some understanding of most aspects of the topic of acids and bases from a chemistry perspective, but her knowledge was rudimentary and she tended to talk in non-scientific language more representative of naïve conceptual understanding ^(1.162, 1.164, 1.258). She appeared to favour concepts based on equations, and to be best able to recall the mathematical or symbolic rather than descriptive definitions.

It is likely that Lucy's superficial understanding of the topic was closely related to her beliefs about, and attitude to it. In her first interview she indicated that the difficulty of the material meant that she would remember it effectively only if she continued to study it ^(1.300-1.302), suggesting that the topic was not one which interested or engaged her to any significant extent. Her responses in the second and third interviews strongly supported her contention in this respect. Coupled with her comment that she really did not enjoy the topic ^(1.302), it is clear that Lucy saw little personal relevance to the study of acids and bases, and regarded it primarily as part of *'chemistry, um school, um studying'* ^(1.2-1.4).

By the end of the teaching semester, Lucy had added to her knowledge of acids and bases by learning, primarily through memorisation, new material which related to pharmacy. She was aware that her new learning was sometimes similar to and sometimes different from what she knew in chemistry, but she was uncertain of the details and struggled to articulate her thinking. In many cases she needed prompting to direct her thinking, both for definitions and problem-solving, which suggested that the new material was largely disconnected and fragmented, and that she had learned the form but not the meaning. She was highly dependent both on personal memorisation and the assistance of her peers, primarily Larry, but her memorisation was less effective than Larry's.

Lucy was less concerned with detail than the others in her group, thus the strategies which the others employed more effectively did not produce the same outcomes for Lucy. All members of the group indicated that much of their learning had been directed at the examination, but unlike Lucy, the others were better able to articulate their strategies and the rationale for adopting them. Lucy appeared generally less reflective and less metacognitively aware, and more dependent on external assistance, all of which constrained the depth of her learning and extent of conceptual change.

Lucy's learning behaviours and the outcomes she demonstrated were consistent with her generally relaxed attitude to study, and her relative indifference to the material itself, which, like the chemistry she had previously learned, lacked personal relevance and importance. She could not name anything particularly important about what she had learned during the semester^(2.568).

Little evidence for conceptual change was evident in Lucy's interviews, and most of what was apparent in the second interview did not persist to the end of the study. Development of contextual discrimination was minor and transient. During the second interview she was able to articulate some of her learning, but she struggled to connect ideas together and use what she had learned to solve problems of any complexity. By the final interview, she was able to express only limited fragments, suggesting that appropriation of the concepts had been incomplete and largely ineffective. Her language use was imprecise and reflective of naïve, rather than scientific, conceptual understanding, and she was unable to solve even those problems which had been within her capacity at the second interview. Lucy's opportunities for conceptual change may have been constrained by her reliance on external assistance, which meant that she often adopted approaches which were not well suited to her learning styles, and her general lack of motivation to succeed academically coupled with a low level of interest in the chemistry of drugs.

Emma

Emma classified herself as someone who aimed for high marks – not the highest possible but certainly in the top 25%^(2.102) – but because of her illness during the semester, she understood that she would need to settle for less on this occasion^(2.96). Nonetheless she commented that she would not be happy with minimum passes, even under the difficult circumstances she had experienced during the semester: *'no I'm not going to be happy with it. I won't be happy with it, I. But I should*

be happy with it' ^(2.94), because she normally set higher standards for her own performance. At high school she had aimed to be the top student ^(2.76-2.78), but she recognised that at university she would be competing with an academically stronger group of peers ^(2.76-2.78). High standards were clearly important to Emma and she was prepared to work competitively towards achieving her goals.

Emma found IPS difficult to study without attending the lectures and workshops: '*IPS is very difficult to learn by yourself, in bits*' ^(2.26-2.28), unlike subjects such as Biology, which '*was fine, because I think you can do a lot of Bio by yourself, I mean you can read the textbook. And I missed a lot of lectures, but you can read it and you can learn it and if you've got the will, you can do it.*' ^(2.22-2.24). She identified her main difficulty with IPS as an inadequate understanding of the conceptual basis for the problems that were set: '*when you did those things in class, um, I'd be sitting there going "OK, we'll wait until it comes out", because you know, I'd missed all the theory*' ^(2.20). By the end of the semester, she described herself as '*floundering*' in IPS ^(2.22).

*Emma's perception of the change in her understanding*⁷

Initially Emma suggested that her understanding had not changed during the teaching semester ^(2.308), but subsequently identified '*well, maybe classification of acids and bases, obviously, because it's different*' ^(2.310-2.312) as an area of change, in that pharmacy used pKa as a classification tool ^(2.367-2.368). However, as outlined above, she was able to recognise where chemistry and pharmacy overlapped, and was able to use what she had learned in chemistry as the basis for understanding the relationship between pH, pKa and ionisation state ^(2.312-2.326). It is not clear whether Emma saw this as a broadening of her understanding, or as additional knowledge, or simply as the same understanding applied in a new situation, and the topic was not followed up.

Summary of Emma's conceptual development

At the beginning of the study, Emma demonstrated a general understanding of most of the relevant concepts underlying acids and bases, but in a superficial manner. She appeared to be more confident using qualitative and descriptive terminology rather than equations, and was not always able to solve numerical problems despite knowing the equations. She was frequently happier to write her ideas down on paper than to articulate them verbally, and her written responses tended to be more complete and precise.

At the end of the semester Emma's frustration at her circumstances was apparent – she wanted to understand but was constrained by the impact of her illness. She was aware that she had not learned the fundamentals of the topic ^(2.923-2.928) and understood that her preferred learning method of 'cramming' was successful only if built on a strong foundation of understanding the basics. As a result, she found IPS to be more difficult than chemistry where she was much more confident about the fundamentals. Despite her limited study time, she did not demonstrate the same intensity of

⁷ Emma's trajectory is described in Appendix F.

exam focus as did Larry. She did rely on her good memory, since she claimed that she did not forget anything ^(2.880-2.896).

Emma herself admitted that her lecture notes were fragmented ^(2.138), particularly in relation to the latter parts of the subject, because she was reliant on other students' notes. As a result, she relied heavily on the course reader (the orange book) ^(2.150), and when she had trouble with the orange book, she struggled ^(2.138-2.144). She was unable to use the group study technique because she felt overwhelmed by what she did not know ^(2.150). For some small sections she was able to gain assistance from others ^(2.152-2.154) but for the rest of the content she was reliant on devising her own approaches, which were sometimes idiosyncratic and unreliable. Interestingly she did seem to realise the benefits of discussing the material with others ^(2.150), but chose to use this strategy only sparingly ^(2.154) because she felt so far behind the others ^(2.150) and because Janine was only willing to give limited assistance ^(2.192-2.194). Her major use of discussion with other students appeared to be when she sought reassurance from Geoffrey about her likelihood of passing ^(2.210-2.216).

Her self-reported ability to compartmentalise her knowledge ^(2.298, 2.414) was both an affordance and constraint to her learning. On the one hand it allowed her to separate conflicting concepts (such as what constituted strong and weak in the two domains) and simply learn what was relevant in each, so that she could complete her examination papers with minimal confusion. On the other hand however, because the knowledge was strictly separated, she was often unable to make linkages between isolated fragments of information and as a consequence was frequently uncertain of the underlying conceptual framework and unable to explain what she "just knew" and why she knew it. When combined with the often idiosyncratic rules she had devised, this fragmentation of understanding sometimes led to confusion which Emma was unable to resolve. On balance, in the circumstances in which she found herself, Emma's approaches were strategically appropriate, and her pragmatic approach did allow her to achieve her stated aims of passing all her units despite her illness, but her learning and conceptual change was less than it could have been.

Sometimes, however, she demonstrated significant insight, and an ability to link concepts from chemistry and pharmacy. In general this appeared to occur when she had a solid grounding in the chemistry, and the pharmacy was sufficiently similar that she could make the connections unassisted. Where Emma struggled was when the concepts were all new and she had little in the way of reference points in chemistry, or the reference points from chemistry provided conflicting concepts. In the absence of dialogue to provide a framework, she sometimes could not identify the important aspects, and so chose ones which did not provide her with the tools she needed to solve all of the problems. Had she had time, it is possible that she would have been able to work through these new concepts and the apparent conflicts, however this hypothesis was impossible to evaluate.

At the end of the study, Emma's conceptual understanding had not changed significantly, and she freely admitted that *'I had a whole lot of, probably still do have a whole lot of mismatched theories that I concocted myself'* ^(3.86), an admission consistent with her responses in both her second and

third interviews. She appeared not to have benefited from the explanations provided in the second interview, although some development in thinking may have been detectable. These outcomes are unsurprising, since although Emma appeared to find the explanations plausible, she did not have the opportunity to use the explanations in any meaningful context (eg discussion with others or solving subsequent problems). As a consequence these patterns were not appropriated, thus limiting the possibilities for persistent conceptual change. Emma managed to complete the exam by memorising rules rather than understanding the fundamentals, but by the third interview she was largely unable to recall the rules, most of which were counter to her own intuition. As a result she had reverted to her own approach to reasoning about the concepts. In a number of cases, her reasoning was insufficient to allow her to solve the problems and she was generally unaware that previous conversations had been directed at modifying her understanding. The exception to this general observation was her recall of a significant error made in the second interview, but even in this case, Emma remembered making the error rather than the underlying reason why her answers were incorrect.

6.4 The persistent change group (PC)

Group composition

This group consisted of six female students, all aged between seventeen and nineteen years of age, and all but Denise in their first year of University. Denise had transferred into pharmacy after one year in another degree program which had not included chemistry, and all students were thus enrolled in first year Chemistry for Pharmacy in addition to IPS. Two of the students were native English speakers, while three were native Cantonese speakers and one a native Vietnamese speaker. All spoke a language other than English at home, however all were very highly fluent in written and spoken English.

The group consisted of a nucleus of two school friends, Veronica and Kellie, and four acquaintances who were known from first semester. Jasmine did not know any of the others well from first semester, but she was perceived by others as very friendly: '*she's very well known and popular coz she says 'hi' to everyone*' (Isabelle 2.150). Four of them shared a timetable and did other classes with each other – Jasmine, Veronica, Kellie and Isabelle (Jasmine 1.132). Denise was involved socially with Jasmine, Veronica and Kellie (Jasmine 1.158). Only Alicia was not closely involved with the others outside class but she had been specifically invited to join the group at the beginning of the first workshop (Veronica 2.78-2.80).

This group therefore differed from the TC in that they interacted less with each other outside class, although they were all on good terms with each other, and in general described themselves as friends or friendly with each other.

As a group, their final examination performance was an average of 11 marks lower than the TC, with Denise achieving a Distinction, Jasmine and Kellie achieving Credits and the other students achieving Pass grades.

Before exploring each individual's learning, it is worth pointing out that every member of this group made an identical error in their third interview when assigning pKas to the functional groups of amoxicillin in preparation for drawing the dissociation equilibria. Each suggested that the pKa of the phenol was lower than the pKa of the amine group, reasoning that bases should have pKa values higher than acids. Possible origins of this error are discussed later in the chapter.

Veronica

Veronica entered pharmacy with an entrance score towards the lower end of the cohort, although still high in comparison to all HSC candidates. She described herself as a '*pretty slow*'^(2.360) student, and as someone who '*needed it pounded into my head, a lot of times*'^(2.358). She found the workshop activities '*really taxing on the brain*'^(2.164), although '*they were all helpful*'^(2.152).

Veronica was satisfied with moderate results at university. She indicated that she was happy with the credit and pass grades she obtained in First Year, and that perhaps she had not studied as diligently as she might: '*well if I had studied more, I would've, you know, done well... I didn't put in much effort, but I'm happy that I passed*'^(3.6-3.12). Her extracurricular interests had distracted her from study at the end of the teaching semester, since she was '*on the committee for the Buddhist Society, yeah. And it's been more fun to think about them than like work*'^(2.12-2.16), and she believed that this involvement was detrimental to her study^(2.17-2.20).

Veronica attended her second interview immediately after her final workshop in 'Acids and bases' and had therefore not studied the material in any depth. Her responses in this interview are therefore taken to represent the learning she had achieved simply through participation in classes and general revision during the semester rather than the level reached through studying the material in preparation for an examination. Interestingly, however she commented to her group during the workshop that '*this is my level. I can't know any more than I can now*'^(PC 3.736).

Initial conceptual framework

In her first interview Veronica identified primarily physical characteristics of both acids and bases, and focused on strength as a means of distinguishing different behaviours. Acids were '*sour*'^(1.2), '*a liquid that's acidic*'^(1.4), '*corrosive*'^(1.12) and able to react with metals to produce gases^(1.16-1.18), whereas bases were '*powdery*'^(1.24), '*corrosive*'^(1.46) and able to neutralise acids^(1.26). All acids and bases were perceived to have these characteristics, but strength determined the extent, in that strong acids and bases were '*more corrosive*'^(1.54) and '*more reactive*'^(1.56). pH was considered to be a property of both acids and bases, with strong acids (low) and strong bases (high) possessing

extremes of pH, and weak acids and weak bases possessing higher and lower pH values respectively than their strong counterpart^(1.34-1.50).

Veronica was initially confused about the definition of pH, stating that '*I think it's how readily a, a substance like loses its H, um, hydrogen*'^(1.148), suggesting some conflation between pH and strength, and substantial prompting was necessary before she eventually agreed that pH was a measure of hydrogen ion concentration^(1.159-1.171). Once prompted, she was able to explain the mathematical relationships accurately^(1.172-1.180). She did not perceive pH as relating to the concentration of hydroxide ions, citing pOH as the relevant parameter in this case^(1.181-1.186). She was unable to solve simple pH calculations in her survey, however her understanding of pH appeared sufficient as a foundation for future learning.

Veronica did not initially comment about proton donation and acceptance as characteristics of acids and bases, but she subsequently identified the tendency to lose protons as indicative of the strength of acids^(1.152-1.154). She was more vague about bases, and did not specifically indicate that bases accepted protons, although the notion of proton acceptance was evidently part of her conceptual framework^(1.150).

Veronica differentiated between strong and weak acids and bases when writing out their reactions. She used different types of arrows to indicate reactions which proceeded to completion, and those which reached equilibrium through partial dissociation. Interestingly Veronica appeared not to distinguish strong and weak acids on the basis of the chemistry convention of full or partial dissociation. She tended to use the terms '*strong*' and '*weaker*' rather than '*strong*' and '*weak*', which suggests that her conceptual framework contained some ambiguity in relation to strength. The notion of a '*strong acid*', which suggests an absolute, included the notion of relative dissociation, and was contrasted with the relative term '*weaker*'.

Veronica's trajectory

Changes to existing understanding

Interview 2

At the end of the teaching semester, Veronica demonstrated contextual discrimination in perceiving acids and bases differently in chemistry and pharmacy. She did not expound specifically on this difference, but described acids and bases in pharmacy as characterised by the presence of specific functional groups, which did not feature in her perceptions of acids and bases in chemistry^(2.295-2.304). Her description suggests that Veronica had developed a significantly different understanding of the nature of acids and bases which was grounded in the distinction between drugs and non-drugs^(2.268). Subsequent discussion, both in her second and third interviews, reinforced this inference. The primary distinction between the two contexts appeared to be that the concepts of

dissociation and proton donation were closely linked to pharmacy, whereas previous concepts such as pH were seen as relating to chemistry^(2.305-2.316; 2.363-374). Further, she regarded corrosiveness as characteristic of acids and bases only in chemistry^(2.711-2.716).

Strength of acids was also perceived differently in chemistry and pharmacy, in two ways. Firstly, as described above, she did not initially distinguish between relative and absolute dissociation of acids, however by the time of the second interview her externalisations suggested that she had internalised the explanation of the differences^(2.274-2.282). Secondly, pKa was regarded as more significant in pharmacy than in chemistry with strength now linked to pKa, where '*pKa is the acid dissociation constant so it's how easily it, it dissociates to form ah, ions*'^(2.580), and pKa, rather than pKb, seen as characteristic of bases as well as acids^(2.336-2.344).

Veronica was confident about the relationship between pKa and strength for acids^(2.582-2.586), but she was not specifically asked about the relationship between pKa and the strength of bases. She did, however, indicate that she struggled with the concept of an acid having a pKa greater than 7, primarily because '*I associate, well pHs larger than 7 as being basic*'^(2.594), and that the link between pH and pKa was still present in her thinking. Although she had learned to distinguish somewhat between them during the semester, she believed that '*if I didn't study or anything, I'd still think of it like that yeah, because it's like back to before, back to what I knew before*'^(2.604-2.608). Evidence from her third interview suggested, however, that this belief was not justified.

Veronica summarised her thinking towards the end of the interview in holistic terms^(2.696-2.708), thus providing evidence of the development of both pharmacy conventions and contextual discrimination in relation to the nature and strength of acids and bases in chemistry and pharmacy.

Interview 3

Five months later, Veronica indicated that low pH^(3.192), the presence of acidic functional groups^(3.194) and proton donation^(3.200) figured in her concept of 'acid', and high pH^(3.206) and the ability to accept protons^(3.204) were perceived as characteristics of bases. However she also indicated a clear contextual discrimination in relation to these ideas, and to the meanings of 'acid' and 'base' in chemistry and pharmacy in general^(3.222-2.230, 2.235-2.238). Veronica's externalisations demonstrated both chemistry and pharmacy conventions in these latter exchanges, supporting the inference that she had effectively appropriated not only the new concepts but also the contextual differences such that they persisted beyond the teaching period.

Veronica continued to distinguish between acids and acidic drugs, and used very similar terminology to that of her second interview^(3.290-3.294, cf 2.704-2.706). She was not able to pinpoint any particular incident or point in time where this distinction became apparent^(3.297-3.298) but its persistence to the end of the study period suggested it was strongly appropriated into her conceptual framework.

In addition to recognising that some acids were categorised differentially as strong and weak in chemistry and pharmacy, Veronica retained the conventions of strength in pharmacy terms, and was also able to explain the concept of pKa and how it related to strength^(3.242-3.266). She did remain somewhat confused about the similarity of the numerical scales for both pH and pKa. She suggested that she had '*incorporated*'^(3.250) both concepts into her framework for understanding the topic although she admitted that '*I don't know how well*'^(3.250). However, since she still defined strong and weak acids on the basis of pKa values, it is reasonable to suggest that she had appropriated the concept effectively, and that the expectation expressed in her second interview that her thinking would revert to '*what I knew before*'^(2.608) had not been realised.

She was a little uncertain about how chemistry and pharmacy differed in relation to the extent of dissociation of strong and weak acids, and needed to be reminded that chemistry focused on complete and partial dissociation^(3.271-3.288). Thus this aspect of the difference appears not to have been effectively appropriated, however since the forgotten notion related to chemistry rather than pharmacy, it may have been discarded as having no future relevance.

In summary, Veronica demonstrated significant conceptual development and discrimination over the teaching semester which persisted to the end of the study. She recognised both similarities and differences between acids and bases in the contexts of chemistry and pharmacy, and discriminated between them on the most critical issues. Her externalisations indicated that she had appropriated pharmacy conventions effectively into her conceptual framework and that she was confident in their use. She was a little less able to articulate contextual discrimination between chemistry and pharmacy at the end of the study, but the persistence of the pharmacy conventions suggested that fundamental conceptual change had occurred.

Concepts new to pharmacy

Interview 2

At the end of the teaching semester, Veronica was confident and accurate in identifying the majority of relevant functional groups on codeine, lignocaine, amoxicillin, ticarcillin, diazepam and ticarcillin, and correctly classified all molecules as acidic, basic or neither according to the functional groups contained in them^(2.491-2.552, 2.563-2.572). She identified phenols according to their proximity to a benzene ring^(2.502), and amines by reference to sp³ hybridised carbons^(2.492-2.498). She was a little confused about the amine in amoxicillin, because she was not certain what other atoms, apart from sp³ hybridised carbons, could be attached to the nitrogen in an amine group^(2.520-2.526). She was generally accurate in identifying amide groups, but misclassified one as an amine because of the manner in which the structure was drawn^(2.528). Once she had drawn out the structure in full, she was able to explain why it was an amide rather than amine^(2.538-2.550). Her explanation of the rationale for classifying a molecule containing both acidic and basic groups as neither acidic nor basic was expressed in quantitative terms^(2.553-2.554), suggesting she had not effectively appropriated

the pharmacy convention. The interviewer engaged in an extended discussion of the rationale^(2.561, 2.677-2.687), but there was no opportunity for Veronica to indicate how well she had understood the concepts in the same interview. Her responses in the third interview suggested that she was better able to articulate her ideas and that her thinking had developed somewhat, but they did not correspond to any significant degree with the interviewer's explanations. Veronica experienced no difficulties in recognising that neither of the nitrogens in diazepam was basic.

Veronica was only asked to draw out the dissociation equilibria for amoxicillin, and she completed the task confidently and efficiently. She correctly allocated the pKas to the appropriate functional groups and added the proton to the relevant nitrogen without prompting^(2.626-2.628). She did not articulate her thoughts as she wrote the equilibria on paper, but she carried out the process without error and without any hesitation. She wrote the pKa values above the equilibrium arrows and immediately identified the relevant structure at a specific pH from her diagram^(2.653-2.656). With prompting, she recognised that amoxicillin was ionised at all pH values^(2.659-2.676), but she was not particularly confident. She was, however, confident about pH values where acids were completely ionised or unionised^(2.725-2.738).

Interview 3

Five months later, Veronica remained confident and accurate in identifying the majority of relevant functional groups on codeine, lignocaine, amoxicillin, ticarcillin, diazepam and ticarcillin, and retained her ability to classify all molecules as acidic, basic or neither according to the functional groups contained in them^(3.312-3.438).

She was initially confused by the representation of the structure of codeine^(3.302-3.310), but once the ring structure was explained she readily identified the amine functional group^(3.312) and explained the ways she distinguished amines from amides^(3.322-3.326).

Veronica continued to describe molecules with both acidic and basic functional groups as neither acidic nor basic^(3.378-3.384). As suggested above, this expression represented increased clarity of expression and some development in understanding from her previous explanation^(2.554), however there is little in her later explanation that suggests she had appropriated any of the interviewer's stated concepts as the basis for the classification of these molecules. Instead, she appeared to have integrated the presence of zwitterions into her rationale, since the zwitterion contains both positive and negative charges which do not cancel each other out. Veronica had been reminded of the notion of zwitterions immediately following the interviewer's explanation in the second interview^(2.683-2.687). It is therefore possible that the idea of the zwitterion, rather than the remainder of the explanation, became linked with the concept that molecules with both acidic and basic functional groups were neither acidic nor basic.

With only minimal prompting, Veronica reasoned that diazepam had no basic functional groups. The amide was clear to her, and the other nitrogen was classified as not an amine on the basis of sp hybridisation ^(3.412-3.416).

In the third interview Veronica was asked to draw the dissociation equilibrium for ibuprofen, a task which she completed confidently and accurately, and she continued to write the pKa above the equilibrium arrows. She was able to explain the reason for the latter ^(3.458-3.462); although a little confused in terminology, Veronica was clearly able to use the written expression of equilibrium to solve a relevant problem. She was also able to explain, albeit somewhat tentatively, the pharmacy convention relating to effectively complete ionisation ^(3.467-3.476).

Veronica was also very confident in writing the equilibria for amoxicillin ^(3.518-3.528), and remembered without prompting that she needed to add a proton to the amine group before removing any of the other protons ^(3.514-3.517). As was the case with the other students, Veronica interchanged the pKa values for the amine and phenol groups ^(3.534-3.538), however, apart from this common error, her equilibria were clearly drawn and representative of pharmacy conventions. With prompting, she recognised that amoxicillin was never unionised in aqueous solution ^(3.557-3.563).

In summary, Veronica demonstrated that she had appropriated the new concepts relating to functional group chemistry and dissociation equilibria, and had retained most of what she had learned until the end of the study. Although some loss of precision was apparent, she articulated her understanding and reasoning in similar terms to those of her second interview. In addition, her ability to solve problems using the new concepts persisted with only minor decline, thus strongly suggesting that her learning was effective.

Veronica's perception of the change in her understanding

Veronica agreed that her understanding of acids and bases had changed during the teaching semester ^(2.271-2.272), and suggested a number of ways in which this was the case. Primarily, her concepts of 'acid' and 'base' had changed to include drug molecules, specifically drug molecules containing particular functional groups ^(2.260-2.264). Her understanding of strength, and the role of pKa had also changed, and she was conscious of the differences in meaning between the two contexts of chemistry and pharmacy. She described this change '*an expansion, it's not a change*' ^(2.290), which is in accord with the development of contextual discrimination. She suggested that her expanded understanding was a consequence of '*constant usage*' ^(2.348) of the concepts '*in lectures and in workshops when we had to use the equations and I got used to it*' ^(2.348-2.350), and she was helped by '*a lot of repetition*' ^(2.356). Interestingly this comment was made during an interview immediately after Veronica's final workshop for the semester, when she would not have had a great deal of time for reflection or studying for her examination, and supports the role of the workshops in shaping Veronica's changed understanding.

Veronica indicated in her second interview that she still found chemistry challenging ^(2.24) because 'there's a lot to remember' ^(2.30), but she felt more comfortable with IPS because 'I think there's less to remember but I think if you just get the concept then you can work things out' ^(2.36). This comment suggested that Veronica perceived chemistry as more a series of facts to learn and remember, but IPS, which 'concentrated on like the pharmacy side of things' ^(2.34) appeared to be seen as more conceptually coherent and practically oriented.

Veronica did not experience a great deal of confusion in the use of similar terms with different meanings in chemistry and pharmacy although she admitted that 'I was a bit confused at the beginning' ^(2.252). However, the provision of a summary sheet resolved her confusion, and 'after reading that, then it was clear' ^(2.258). In particular, the emphasis on functional groups in pharmacy assisted her to understand the different usage of the terms ^(2.254-2.256).

Summary of Veronica's conceptual development

Veronica began the study with a solid conceptual framework of acids and bases from chemistry, although some aspects were a little confused or vague. During the semester she developed significant contextual discrimination in relation to characteristics which were pertinent to both contexts, and in general this discrimination persisted to the end of the study. Further, she appeared to appropriate the pharmacy conventions well, and was able to articulate clearly the new aspects she had learned, as well as use them in solving relevant problems, both at the end of the teaching period and after a long hiatus. Veronica's externalisations thus provided strong evidence of transformative internalisation and persistent conceptual change.

In her final interview, Veronica indicated that she could see the connection between what she had learned in IPS and what she was now learning: 'actually I can see it fitting in with like the second year things. Yeah, and I say, "Oh yeah, remember that in Erica's lectures"' ^(3.88-90). This comment provides support for the contention that Veronica's learning in IPS could be legitimately classified as conceptual change.

Veronica attributed her learning and its persistence primarily to repeated opportunities to use the concepts both in lectures and in workshops. The latter were particularly significant since they provided occasions for transformative internalisation of the concepts as articulated by peers and tutors, as well as a safe environment for externalising her transformed understanding.

Denise

Denise was the only member of the group who had studied previously at university, and her performance in her single prior year was above average. However she had not studied chemistry in this year, and perceived herself as 'not that good at chemistry' ^(2.20), and 'really rusty on it' ^(1.300) because 'it's been two years since high school' ^(1.302).

Denise did not aim for particularly high levels of academic performance, and admitted in her third interview that, even though she had not taken the full first year load, '*I don't think I put in a lot of work last year, and I did a lot of last minute cramming*'^(3.6). As a result she was happy just to have passed all of her subjects^(3.8). Denise invariably left her workshops earlier than the others in order to catch transport to her place of work, and as a consequence, was the least able to benefit from discussion during the workshops. She indicated that she enjoyed IPS more than her other subjects^(3.16).

*Denise's perception of the change in her understanding*⁸

Denise indicated that her understanding had expanded during the teaching semester, and that '*from my knowledge before I started doing this. Yeah, I think I know a bit more*'^(2.360-2.364). She identified three areas where her understanding had grown:

- definitions of acids and bases^(2.366-2.368)
- strength of acids and bases^(2.370)
- the significance of pKa

Denise indicated that had not experienced any great confusion in using the same terms but with different meanings in chemistry and pharmacy. After some initial difficulties^(2.340), the emphasis provided in classes helped her to develop contextual discrimination^(2.340-2.348). She admitted she was a little uneasy at first about the idea of these words having different meanings, but that '*I just take what you tell me, kind of thing. I just take your word for it. I didn't really delve into it any more, like I didn't go and find out why they're different or anything*'^(2.350-2.356). Her pragmatic and somewhat detached approach suggested that the concept was not one which troubled her greatly.

When asked specifically, Denise mentioned only a few differences between acids and bases in chemistry and pharmacy. She considered that there were different aspects although the definition was essentially the same: '*It has different ideas but it still kind of has that one definition which is like proton donor*'^(2.994-2.996), but strength and corrosiveness distinguished acids in the two contexts. In relation to strength she did not expand on her notion of difference^(2.1000-2.1006), however she had previously indicated that the difference related to the extent of dissociation^(2.370-2.392). She continued to associate the potential for burning with acids in chemistry but not with pharmacy^(2.1022-2.1026): '*chemistry...yeah I do*'^(2.1008-2.1010), and attributed this to the fact that '*we're doing more pracs in chemistry and they always warn us that these acids are really strong so they, they can burn*'^(2.1014-2.1018).

Summary of Denise's conceptual development

Denise commenced the study articulating the standard Bronsted-Lowry framework, although with only the most important elements, and an acknowledgement that it was '*rusty*'^(1.300). By the end of

⁸ Denise's trajectory is described in Appendix F.

the teaching semester, she had developed considerably in her conceptual understanding, and appeared able to discriminate between the chemistry and pharmacy contexts. However, she was not challenged to demonstrate the basis of this discrimination, and the small amount of recorded discourse suggested that she was content to accept external authority as sufficient reason for keeping the notions separate^(2.340-2.356). She identified the major characteristics of acids and bases according to pharmacy conventions, and demonstrated important conceptual development in relation to the significance of pH in pharmacy which persisted to the end of the study. Also persistent were pharmacy conventions in relation to functional groups and pKa, which suggested that these critical concepts had been appropriated effectively. Denise continued to associate acids and bases with specific pH values, however it was not clear if she retained this concept in relation to both chemistry and pharmacy as the distinction was not pursued.

Denise's self-reported reliance on external authority is supported by her acknowledgement in the second interview that she was someone who '*just remember[s] the rules*'^(2.1232), which she believed she understood and would be able to remember^(2.1237-2.1238). In contrast, '*when you ask me practical questions...I don't know how to answer that*'^(2.1234-2.1236). This self-evaluation was consistent with her performance in the second interview where she struggled on a number of occasions with problems she was asked to solve, however it was less appropriate by the time of her third interview when she appeared to be more comfortable with solving problems, and had forgotten some of her rules. Denise's evolving understanding of the role of pH illustrates the changing significance of rules and applications in her conceptual development. Denise described pH in her second interview as an influence on acidic and basic drugs rather than as their property^(2.450-2.460) and this exchange highlights a major development in Denise's conceptual understanding, because of the manner in which she linked a number of concepts together – the pH affecting the state of ionisation and the state of ionisation affecting the solubility⁹. Nevertheless the relationships she explained at this point in the interview corresponded to her perception of 'rules', which she struggled to apply later in the same interview when drawing multiple dissociation equilibria^(2.776-2.830). Denise's problem-solving in relation to these multiple equilibria appeared to have developed significantly by the time of her third interview, when her new understanding continued to be manifest as the basis for solving problems, but she struggled to explain her rules in response to explicit questions.

Further, at the time of the third interview she was less forthcoming than in her second interview with the rationale for her identification of functional groups, particularly amines, where she did not refer to hybridisation at any stage. It is likely that the concept of hybridisation as a means of distinguishing amines was one of the 'rules' that she had forgotten by her third interview.

Her conceptual development in relation to molecules with multiple functional groups is interesting, since she received direct modeling of the concepts from the interviewer about two aspects during the second interview, and it appeared that she appropriated the ideas differentially. From the second

⁹ This is a critical change as the nature and significance of pH has been observed to be one of the more confusing aspects of the differences between chemistry and pharmacy, and the chemistry framework has appeared resistant to transformation.

to the third interview she did not change her explanation of the effect of multiple groups on the nature (acidic/basic/neither) of the molecule, but she did develop significantly in her concept of the relationship between dissociation, pH, pKa and form of the molecule. By the third interview she was able, without prompting, to articulate the multi-form conceptual framework which was explained to her in the second interview, rather than the dualism which she had previously described. This differential conceptual development may be related to the novelty and intuitiveness of the material – in the former case, Denise may have felt that it was intuitive that the relationship was semi-quantitative, whereas in the latter case her preconceptions may not have been as strongly held and the new concept was not contrary to anything intuitive.

Isabelle

Isabelle was one of the lowest performing students based on her entry score into pharmacy, although her overall rank was still high in relation to the whole secondary school cohort. She did not articulate high goals for her academic performance, but indicated that she was happy to '*aim for a pass*'^(2.16). She had struggled significantly to adjust to university study, and described her preparation for first semester exams as a time where she '*was crying and all, like I had strange moods and stuff*'^(2.8), however by the end of second semester she knew what to expect and was '*much more relaxed*'^(2.10). She felt that her second semester results were a reasonable reflection of the amount of work she had put in for the examinations^(3.27-3.28), and that although '*I wanted to do better, I had to put more effort in and I didn't*'^(3.30).

Isabelle was the most self-deprecating of the group and appeared to have the lowest self-esteem, describing herself as '*a bit stupid*'^(2.118), '*less intelligent*'^(2.140) and '*not up to scratch*'^(2.154), in contrast to the other members of the group who she perceived '*were all really smart*'^(2.128). However, evidence from her interviews suggested that her self-evaluation was not entirely justified. Her preferred types of workshop problem were those which were set out in a systematic manner with all of the intermediate steps made explicit^(2.212-2.214) because '*I work really slowly through calculations so I don't make an error even though I often do. But I like to work through it really slowly, yeah and write down everything. So I liked that*'^(2.224-2.230), suggesting that she preferred to adopt a methodical and logical approach to problem solving.

Isabelle's home situation provided a number of distractions to her study^(2.104), and she indicated that her father's sporadic employment and her grandmother's Alzheimer's disease created significant tensions. Isabelle also felt pressured by her mother to work around the house when she preferred to study^(2.84-2.98). Despite the distractions, Isabelle indicated that she did not study other than at home: '*I hate studying anywhere else, I love being at home and in my room, and yeah. I have all my books next to me and everything in front of me*'^(2.106-2.112).

*Isabelle's perception of the change in her understanding*¹⁰

Isabelle was eloquent and expansive in describing the change in her understanding of acids and bases as a result of her participation in IPS. Overall, she described her experience as '*I had to change a lot of my thinking*'^(2.298); she perceived not only that '*I learnt new things but I changed my learning*'^(2.304), and that pharmacy was '*more specific*'^(2.300, 2.324) and '*more drug oriented*'^(2.302). The major differences were in relation to definitions: '*I think the definitions you had um we had to change our thinking about it*'^(2.314-2.316), and the change from inorganic to organic chemistry^(2.308-2.312). The new material and her changed thinking was not a source of confusion^(2.297-2.298), but Isabelle was able to differentiate clearly between the two contexts of chemistry and pharmacy^(2.319-2.322).

Isabelle indicated on a number of occasions that what she had learned in pharmacy had been enlightening with regard to chemistry. Key issues for which this was true were the significance of pKa^(2.402-2.406) and hybridisation^(2.572-2.584).

Summary of Isabelle's conceptual development

Isabelle began the study with a precisely articulated conceptual framework which conformed closely to the conventions of chemistry. During the study, she appropriated pharmacy conventions, both with respect to the characteristics of acids and bases, and the new material which was unique to pharmacy. She was able to externalise her thinking clearly and concisely, providing evidence of the existence of transformative internalisation of the concepts which she had encountered, and the persistence of a changed conceptual framework. Her language strongly suggested a robust recognition of the contextual dependence of meaning and understanding, and she applied appropriate problem-solving approaches in each context. She displayed metacognitive awareness of her learning, and particularly emphasised 'change' as a feature of her learning experience. Her use of the past tense in relation to chemistry^(eg 2.406-2.422) suggested that she did not necessarily see it as relevant any longer.

Isabelle appeared to benefit greatly from participation in the small group. Although she was not the most prolific in terms of utterances, it was clear that the externalisations of others in the group, together with the tutors, provided sufficient input for transformative internalisation which resulted in her constructing a conceptual framework consistent with pharmacy conventions. Isabelle appeared to be an example of the type of student who required less externalisation for learning, but benefited from listening to others as she constructed her own learning. She was also observed to talk to herself on the videotape, therefore it might be concluded that her externalisations were more private than public, but nevertheless effective for Isabelle.

¹⁰ Isabelle's trajectory is described in Appendix F.

Jasmine

Jasmine was above average in academic performance, but was quite modest about her abilities and goals. She described herself as '*honestly I think I'm one of the, not as bright students from my table*'^(2.122), and was comfortable in verbalising her difficulties in understanding without being worried about the potential reactions from her fellow group members. She did not articulate her academic goals during any of her interviews, however she was the most academically well-performed of her group throughout the degree where she averaged high Credit grades. In common with Larry, she completed the degree with the second highest class of Honours, the only one of her group to achieve Honours. Also like Larry, Jasmine had completed her secondary schooling in Melbourne.

Jasmine was widely perceived as a friendly person, who interacted well with other students. Isabelle described her as '*very well known and popular coz she says 'hi' to everyone*'^(Isabelle 2.150).

Initial conceptual framework

Jasmine initially demonstrated a fairly narrow view of acids and bases, and identified them primarily by their pH^(1.8, 1.28). Secondary characteristics included their reactions with water^(1.10, 1.30-1.32), which suggested an understanding based on the Arrhenius rather than Bronsted-Lowry definition. Jasmine associated corrosiveness with both acids and bases but only if they were '*really really strong*'^(1.4-1.14, 1.34), where strength was identified as high molarity^(1.16-1.20).

Jasmine introduced the topic of pH during a discussion of weak acids and bases^(1.92), and was able to define pH with some confidence^(1.98-1.108). She was aware that the concentration of both hydrogen and hydroxide ions could be described by pH, and was able to write the equation linking pH to hydrogen ion concentration. She could calculate these concentrations for a solution of a given pH^(1.138-1.158), but not consistently^(survey).

Jasmine introduced the concept of strength without any prompting by the interviewer when discussing the characteristics of acids and bases^(1.40). Her definition of strength was idiosyncratic in that it was not defined in terms of the extent of proton donation or dissociation, but rather in terms of a concept which she described as conversion^(1.40). Jasmine struggled to explain what she understood by conversion^(1.53-1.58), however she was able to use this concept to differentiate between strong and weak acids^(1.48-1.50), and in drawing acid dissociation equations, it became clear that she was using the term conversion in a way that was similar to the concept of dissociation^(1.67-1.70). Jasmine also included bases in her concept of conversion/dissociation^(1.250), and her survey responses provided corroboration as she identified a strong base as one which dissociated nearly completely in water and a weak base as one which only partially dissociated in water. Further, in drawing reactions involving acids and bases, she clearly distinguished between reactions which went to completion, and those which reached equilibrium, through the use of different types of

arrows. Jasmine appeared to conflate the concepts of strength and concentration to some extent^(1.60-1.62)

In summary, at the time of commencing the topic of 'Acids and Bases' in pharmacy, Jasmine displayed only a rudimentary and fragmentary conceptual framework which appeared to be dominated by Arrhenius concepts. Although she was aware of proton donation and acceptance, her understanding appeared to be based primarily on the physical characteristics of pH and corrosiveness. She appeared to have some understanding of dissociation but struggled to articulate it clearly.

Like Larry, Jasmine had completed her secondary schooling in Melbourne, and some similarities were apparent between them. Both exhibited limited conceptual backgrounds in the topic, and did not appear to associate characteristics such as taste and feel which were commonly mentioned by students schooled in NSW. Both tended to conflate strength and concentration, and both used terms other than 'dissociation' to describe what happened to acids and bases in water. Unlike Larry, Jasmine did not indicate that she struggled with the topic, however it was clear from her initial interview and survey that she did not have as strong a foundation in chemistry conventions as other participants in the study.

Jasmine's trajectory

Changes to existing understanding

Interview 2

By the end of the teaching semester, Jasmine clearly demonstrated an awareness of contextual discrimination, as when she was asked to describe how she would classify acids, her initial response was to ask '*in terms of pharmacy or chemistry?*'^(2.456). Her comments and written expressions suggested that she perceived acids and bases in terms of the generic molecular structures which had been commonly used during the teaching semester in pharmacy – HA and B^(2.470, 2.518) – rather than their pH values, as had previously been the case. In conjunction with this approach, she identified acids as proton donors^(2.532), and bases as proton acceptors^(2.534-2.536). She associated pKa with both acids and bases, and identified pKa as a measure of strength^(2.480). Importantly, she recognised that the protonated form of both acids and bases lost its proton in the dissociation reaction^(2.522-2.524).

Jasmine indicated that she still associated pH with acids and bases^(2.538-2.540), however the nature of this association had changed from the first interview, as she now combined the concepts of strength, dissociation and pH. When discussing the dissociation of acids, she drew a representation of the dissociation:



and discussed it as follows:

Jasmine: So if you have a lot of H plus here on this side then that H will be a large number and so the pH will be a large number

Interviewer: Negative log¹¹

Jasmine: Negative log, make it small, small number^(2.552-2.560)

Although not explicitly stated, Jasmine displayed a line of reasoning that suggested she perceived the relationships as:

- strong acids dissociated more completely to produce high concentrations of H⁺ ions on the right hand side of the equation
- high concentrations of H⁺ ions created a low pH
- therefore strong acids were associated with low pH

Thus her understanding appeared to have developed in that **all** acids now were not necessarily associated with a pH below 7, but that the dissolution of strong acids in water did produce low pH solutions. When combined with her explanations of acid strength, it appeared that her understanding of these concepts had moved beyond that which she had expressed in her original interview.

Strength was also identified with pKa in that a low pKa was described as a characteristic of strong acids^(2.480). She further associated pKa with extent of dissociation and ionisation^(2.490-2.492, 2.502). Jasmine was able to classify carboxylic acid groups as strongly acidic and phenols as weakly acidic^(2.806-2.810) and associated each of these with specific pKa ranges^(2.812-2.816). She had no difficulty with acids having pKa values above 7, having rationalised it in terms of *'I always like think of 7 as a neutral number and just go from there. If something is above that then it is less acidic'*^(2.818-2.822). Although not necessarily the accepted approach to the concept, this version appeared to suit Jasmine and did not appear to result in difficulties in understanding or application. It was certainly consistent with the reasoning she displayed in relation to strength as discussed earlier. However it appeared that this conceptualisation hindered Jasmine's longer-term ability to assign pKa values to functional groups (see below). Jasmine was not asked about the pKa values associated with strong and weak bases in her second interview.

Jasmine's conceptual understanding clearly developed during the teaching period, and some evidence of appropriation of pharmacy conventions was apparent. However she also articulated a number of idiosyncratic concepts which blended aspects from chemistry and pharmacy, and which

¹¹ Jasmine had correctly stated the pH relationship immediately before this exchange: *'well p is negative log...for the pH, so negative log to the concentration of H plus'*^(2.544-2.550), therefore her error in this exchange was considered to be a momentary lapse rather than evidence of a fundamental misunderstanding.

appeared to suit her immediate needs. Some contextual discrimination was apparent, although Jasmine was not asked to specify examples of different meanings.

Interview 3

Five months later, Jasmine immediately volunteered the definition that acids were proton donors (3.227), and that they dissociated in solution to produce hydrogen ions (3.233). When asked about bases, she indicated that they were the opposite of acids (3.247), including the fact that they were proton acceptors (3.255). It is interesting that Jasmine articulated these concepts immediately, since in her previous two interviews, the proton-donation aspect of acids and bases had been subsidiary to other notions. Further, she continued to recognise that both acids and bases were defined by pKa values, and that pKa was a measure of strength (3.416-3.437).

She still articulated aspects of her pre-instruction conceptual understanding for acids and bases, however, suggesting that the Arrhenius definitions still constituted part of her conceptual framework, and were held in parallel with the Bronsted-Lowry. She continued to associate pH with both acids and bases, whereby a pH of below 7 was associated with acids (3.243) and a pH of between 8 and 14 was associated with bases (3.253), and bases dissociated to form hydroxide ions in solution (3.249). She appeared to distinguish somewhat between acids and acidic drugs, but the nature of this distinction was not clear: although she described them as '*different ends of the scale*' (3.265), she could not explain what she meant by this statement.

Jasmine's ideas about strength also appeared to be an amalgam of chemistry and pharmacy conventions. Her discussion about pKa and acid strength suggested that she had understood the pharmacy approach to this aspect of strength, in that low pKa was associated with strong acids and higher pKa with weak acids (3.416-3.423, 3.552-3.553). Further she was able to identify the archetypal exemplars of strong and weak acids which had been introduced in IPS, namely carboxylic acid and phenol. However she appeared to have developed an idiosyncratic version of the relationship between strength and dissociation. While confirming that strength was a determinant of the extent of dissociation (3.290-3.295), Jasmine differentiated between what she defined as strong acids and stronger acids (3.296-3.299). Strong acids were those which dissociated completely, while stronger acids dissociated more than weaker ones. The former concept involves thinking in absolute terms, while the latter involves the notion of relative strength. The former also relates clearly to chemistry conventions, and was previously articulated by Jasmine in her initial interview. The latter is the pharmacy convention, and was articulated in her second interview. Thus by the time of her final interview, Jasmine had intertwined these two concepts in an individualistic and apparently undifferentiated way that allowed her to retain elements of both sets of conventions.

This idiosyncratic conceptual framework appeared to satisfy Jasmine with respect to acids, however it did not assist her with the strength of bases. As discussed above, her description of the dissociation of bases involved the chemistry convention of generation of hydroxide ions (3.300-3.311).

Further discussion revealed that she also favoured the use of pK_b rather than pK_a, and that while she remembered that bases were associated with pK_a, she could not remember the specific relationships ^(3.426-3.437).

In summary, Jasmine began with an Arrhenius framework, whereby acids and bases were characterised by the formation of hydrogen/hydroxide ions and specific values of pH. By the end of the teaching semester she had appropriated the Bronsted-Lowry approach, where proton donation and acceptance were of primary significance, and she continued to articulate this approach in the final interview, although her responses at this time suggested that both frameworks were still relevant to her, with primacy accorded to Bronsted-Lowry. She used pharmacy conventions for the representation of acids and bases, and associated both with pK_a values. Jasmine demonstrated contextual discrimination in her second interview, together with conceptual development with regard to the significance of pH as a characteristic of acids, however their persistence was not explored in the final interview.

Jasmine began the study with idiosyncratic explanations for strength, and although she developed in her understanding during the semester, her new conceptual frameworks were also idiosyncratic and not clearly aligned with pharmacy conventions. She appeared to experience difficulties in articulating her ideas, and her externalisations may have hampered her learning, as the transformations which occurred when she spoke may have led her in unproductive directions.

Concepts new to Pharmacy

Interview 2

At the end of the teaching semester, Jasmine was able to identify all carboxylic acid, phenol and amine groups on codeine, lignocaine, amoxicillin, ticarcillin, diazepam and ibuprofen accurately, and correctly classified the drug molecules as acidic, basic or neither on the basis of the functional groups contained in them ^(2.578-2.664, 2.692-2.704, 2.756-2.764, 2.798-2.804). Phenols were easily identified ^(2.640-2.644) and contrasted with alcohols ^(2.580-2.584). Initially Jasmine found the amine in codeine difficult to locate, but reasoned its presence and identity without assistance or prompting ^(2.590-2.604) and she experienced no further difficulties with the identification of amine groups.

She was confident in identifying amide groups and classifying them as not basic ^(2.612), and was also able to locate amides in amoxicillin, where the structure was not immediately obvious ^(2.656-2.662), however she demonstrated confusion when confronted with a nitrogen which was neither an amine nor an amide, in diazepam. She was aware that the nitrogen was not basic, but struggled to fit it into her classification system. She tentatively suggested an explanation based on lone pairs ^(2.710), and significant explanation by the interviewer was needed before she could recall the significance of sp³ and sp² hybridisation ^(2.717-2.737). The remainder of the interview did not permit analysis of the extent to which Jasmine appropriated this explanation. However evidence from her third interview

strongly suggested that she did not incorporate the proffered explanation into her conceptual framework.

Jasmine recognised that the presence of acidic groups rendered the molecule acidic, and the presence of basic groups rendered the molecule basic, and was also able to explain that the presence of both groups on the same molecule resulted in a structure which was neither acidic nor basic, however she was not entirely clear why this was the case. She admitted that her answer was a guess^(2.666, 2.670) and the interviewer needed to explain the rationale on the basis of differential pH-dependent ionisation.

Jasmine was only asked to draw the dissociation equilibria for amoxicillin, and she was able to complete the task with little assistance from the interviewer. She correctly allocated the three pKas to the appropriate functional groups, and added the necessary protons^(2.842-2.844). She was aware that the task involved elaborating what happened to the molecule as pKa increased, although she was somewhat disconcerted by realising that the acidic pKa for the phenol was higher than the basic pKa for the amine until reassured that this was normal^(2.866-2.872). She remembered to write the pKa values above the equilibrium arrows at each step, and she was able to articulate the rationale for carrying out the activity, and the information thus provided^(2.900-2.908).

Jasmine appeared therefore to have understood that this representation of the multiple equilibria was of assistance in relating structure to pH and pKa, and she showed no evidence of having memorised tools such as tables. Her ability to solve problems by returning to principles, rather than relying on her memory of solving the same example on previous occasions, suggested that she had appropriated the concepts to a useful extent.

Interview 3

Jasmine retained her abilities in identification of functional groups until the third interview, including those where she was correct and those where she experienced difficulty. She identified all carboxylic acid, phenol and amine groups on codeine, lignocaine, amoxicillin, ticarcillin, diazepam and ibuprofen accurately, and correctly classified the drug molecules as acidic, basic or neither on the basis of the functional groups contained in them^(3.332-3.371, 3.390-3.413, 3.458-3.485, 3.518-3.521). She was able to recognise phenol groups by their proximity to a benzene ring^(3.349-3.351), and to recognise amide groups in lignocaine, amoxicillin and ticarcillin, although she did not immediately recall the name of the group^(3.361). However, the confusion she displayed in the second interview about the nitrogens in diazepam, and the rationale for recognising non-basic nitrogens in terms of lone pairs instead of carbon hybridisation remained unresolved. It is likely that the single explanation given by the interviewer in the second interview was insufficient to promote transformative internalisation, and Jasmine had little if any subsequent opportunity to externalise her thinking in relation to this explanation in discourse with others.

Jasmine remained confident and accurate in her classification of molecules as acidic, basic or neither according to the presence of particular functional groups in their structures. She was however still uncertain of the rationale for classifying molecules with both acidic and basic functional groups as neither acidic nor basic^(3.411). Again, the single explanation provided to her in the second interview appeared to be an insufficient resource for effective transformative internalisation.

In this interview, Jasmine was asked to draw the dissociation equilibria for both ibuprofen and amoxicillin. She had no difficulty in accurately representing the dissociation of the former, and was concise and confident about why she wrote the pKa above the equilibrium arrows^(3.531-3.533). With respect to the assignment of pKas to the three functional groups in amoxicillin, Jasmine made the same error as the others in her group, highlighting the common perception that bases had the highest pKa irrespective of the presence of weak acids. Jasmine articulated this concept most clearly^(3.542-3.559).

In Jasmine's case, the common error appeared to be reinforced by her particular method of relating pKa and strength as articulated in her second interview: '*I always like think of 7 as a neutral number and just go from there. If something is above that then it is less acidic*'^(2.818-2.822). Since, to Jasmine, bases were less acidic even than weak acids, she reasoned that they must have the highest pKa values.

Jasmine remembered that she needed to start the dissociation process with protons attached^(3.595-3.599), and to remove them one at a time in accordance with increasing pKa^(3.601-3.607), but was momentarily confused when this resulted in an unfamiliar structure^(3.609). Only minimal prompting was necessary before Jasmine recalled that she had forgotten to add the proton to the amine group at the beginning, and her series of equilibria were able to be corrected easily^(3.610-3.613).

In summary, Jasmine appeared to appropriate most of the pharmacy conventions relating to the new material she had learned, and these conventions generally persisted to the end of the study. She struggled to recall the significance of hybridisation in both interviews, and the notion that acids could have higher pKa values than bases was problematic, however her externalisations identifying functional groups, classifying them as acidic and basic, and depicting single and multiple dissociation equilibria provided strong evidence of appropriation of the concepts into a conventional conceptual framework.

Jasmine's perception of the change in her understanding

Jasmine described the change in her understanding over the semester as an expansion^(2.454), but also indicated that her interest in, and perceived relevance of the topic had increased significantly as a result of studying acids and bases in pharmacy^(2.446-2.452). She believed that her understanding of pharmacy concepts^(2.440) was built on the foundations of chemistry^(2.434-2.436), but that there was a

difference between the two domains^(2.416-2.426). On specific questioning, Jasmine suggested that this may have had the potential to cause confusion^(2.398-2.400), but indicated that the potential confusion caused by this difference in ‘template’ and the cross-disciplinary teaching was not generally realised^(2.406-2.410). The potential confusion was also possibly eased by the compartmentalisation of conceptual understanding for the purposes of examinations, exemplified by the comment that ‘we’ve had chemistry’s exam now, when we study everything’s OK, we just clear our minds’^(2.400-2.402), suggesting at least a partial role for pragmatism, combined with the increased perceived relevance of the topics in pharmacy, in her approach.

Jasmine indicated twice in her interview that her definitions of acids and bases had changed^(2.414, 2.944) however her explanation of the change was somewhat unclear. She described two major areas of change, namely corrosiveness and strength, which were interrelated in her explanation. The notion that drugs, which are administered into the body, could be described as acids and bases, and the recognition that body fluids such as blood could be described as having a basic pH, appeared to have modified Jasmine’s previous beliefs about the dangers posed by acids in particular, however she retained contextual discrimination in that chemistry ‘acids’ could still be considered as corrosive^(2.944-2.968). This distinction between chemistry and pharmacy in relation to corrosiveness appeared closely linked with the notion that pharmacy acids were less extreme in strength, although it was not clear if Jasmine used the term ‘strong’ in accord with her definition of strong acids as ones with low pKa values.

Surprisingly, Jasmine did not perceive much difference between chemistry and pharmacy in relation to the concept of strength^(2.979-2.988). pKa had not figured in her description of strength in the first interview, and evidence presented earlier in this chapter has revealed that change had occurred since that time, but Jasmine appeared unable to distinguish between the two contexts.

Interestingly, in interview 3, Jasmine commented: ‘as you learn from like Year Twelve, Year Eleven, until now, so far everything is, well it’s the same thing, but they’ve just gone into more depth’^(3.131), suggesting that she did not really perceive fundamental changes in her understanding, but rather a deeper appreciation of the concepts and content.

Summary of Jasmine’s conceptual development

Jasmine began with a relatively sparse conceptual framework for acids and bases, possibly derived from a weaker grounding in the fundamentals, although she did not express any perceived disadvantage. She showed evidence of appropriation of pharmacy conventions in relation to the fundamentals and the new material, but also demonstrated a tendency towards idiosyncrasy rather than contextual discrimination. Principally in relation to the characteristics and strength of acids and bases, her conceptual framework appeared to be a blend of chemistry and pharmacy conventions, which served Jasmine’s short-term purposes, but constrained the effectiveness of conceptual change. She was more successful with new material, particularly the identification of

functional groups and their dissociation equilibria, but even in this area, her atypical concept of strength hindered her ability to assign pKa values accurately.

The tendency towards idiosyncrasy may have had its roots in her weak background in that she was attempting to learn aspects of both chemistry and pharmacy concepts simultaneously, resulting in a *mélange* rather than two distinct frameworks. For example, when considering the strength of acids and bases, Jasmine appeared to hold a concept which confused the notions of absolute and relative, neither of which had figured prominently in her original understanding. However Jasmine also displayed some conversational habits which may also have contributed to her difficulties. She was a 'chatty' individual who clearly found it easy to engage in conversation, however in her interviews she often did not answer questions directly. She displayed a strong tendency to discuss the first thing that came into her mind in relation to the topic underlying the question, and needed to be brought back on track after a diversion into areas of her own interest. This may have portrayed her as lacking understanding of the concepts, but it may have been simply the way she responded to questions of any sort. As a consequence her internalisations were potentially transformed in more idiosyncratic ways, which may have led to the formation of mixed conceptual frameworks which then became apparent as she externalised her ideas.

Nevertheless, Jasmine's conceptual understanding developed significantly during the study, and most of the pharmacy conventions of the new material were clearly appropriated. Importantly, these conventions persisted to a significant extent, suggesting that the processes in which she had participated were effective in strengthening the frameworks which she developed, both conventional and idiosyncratic.

Kellie

Kellie entered the degree with a ranking that placed her in the middle of the cohort, and she continued to perform at an equivalent rank throughout the degree. She failed one subject in third year, but managed to finish the degree in the minimum four years.

Kellie was quite self-deprecating in relation to the extent of her recall in the topic of acids and bases, and appeared to be self-conscious during her interviews. She commented in her first interview that *'it just feels like I should know this stuff, but I don't...Because it's like, been taught to me so many times. And like, it just seems like really important. Yeah, it's a big part of chemistry or something, so I should know it, but I don't remember everything'* ^(1.327-1.329). She continued to emphasise her poor memory throughout the interview process in that

- she described many of the concepts as *'really vague to me as well. I know it, I know I've learnt it, but then, yeah, I can't recall exactly what it is'* ^(1.337)
- she indicated at her final interview that she would be reluctant to participate in a similar study in the future because *'coz I feel like I should know this stuff and then I don't. (laughs)...It does help like, when you go over these things again, it helps you*

learn...I feel like I should know the stuff and I know I'll just forget all the things again'
(3.612-3.622)

Kellie's perception of the change in her understanding¹²

Kellie indicated that her understanding of acids and bases had both expanded and deepened during the semester, with more emphasis on the expansion ^(2.339-2.342). She indicated that before IPS she experienced difficulties in both understanding and recalling the concepts of acids and bases, and that as a consequence, she did not enjoy studying the material ^(2.334-2.336). At the end of the teaching semester, however, she indicated that she had understood, and enjoyed the material more ^(2.334-2.338).

Kellie indicated that she had not experienced any confusion between chemistry and pharmacy, and she used the example of strength to explain her reasoning ^(2.292-2.304). She discriminated between the two contexts on the basis that '*Pharmacy is more like the reality of it*' ^(2.308), in contrast to chemistry which was perceived as more theoretical ^(2.313-2.314). Kellie explained that she believed that '*it doesn't really dissociate, nothing really dissociates completely*' ^(2.310), therefore it appeared that she found the pharmacy convention more satisfactory.

Further, she perceived the pharmacy context as more useful and relevant ^(2.344-2.346), while chemistry was perceived as less relevant and less straightforward ^(2.348). Kellie indicated that drawing the molecular structures was of assistance in visualising the significance of drugs as acids and bases, but that it was the writing of dissociation equilibria that was the most helpful ^(2.350-2.352).

Summary of Kellie's conceptual development

Kellie began the study with a fragmented and incomplete conceptual framework for acids and bases, and also a relatively weak background in the structures of organic molecules. She was not particularly confident about much of her knowledge, and relied heavily on her memory to support those aspects she had understood ^(2.898-2.900). She did appropriate most of the pharmacy conventions discussed during the teaching period, and these conventions persisted to a large extent throughout the study. However her chemistry background constrained the development of a coherent pharmacy framework, and particularly in the second interview Kellie tended to recall isolated aspects or groups of facts. She appeared to understand the fundamentals, as evidenced by their persistence, but struggled to apply them in solving specific problems. Interestingly, by the time of the final interview, a more coherent framework was apparent, and Kellie appeared more aware of links between notions which she had previously not recognised.

Kellie's chemistry background also appeared to hinder the development of contextual discrimination, however by the end of the study she did not appear to recall much of the chemistry framework and thus displayed little if any confusion between the two contexts. Thus her difficulties

¹² Kellie's trajectory is described in Appendix F.

with chemistry appeared to act as both affordances and constraints to conceptual change. Where pharmacy conventions differed from those of chemistry, she was able to appropriate the pharmacy concepts without conflict, but where the pharmacy notions required a basis in chemistry, particularly structural organic chemistry, she struggled to build an appropriate framework without some of the foundations.

Alicia

Alicia was a very quiet student, and tended to remain on the fringe of the group. She was specifically invited by the other members to join their group at the start of the semester so she had not seen herself as part of this particular group initially. She entered pharmacy with an entrance score which put her in the lower half of the cohort but closer to the middle than the bottom. Alicia passed all of her first year subjects at the first attempt, but subsequently failed second and third year subjects which resulted in her candidature lasting six years instead of the standard four.

Initial conceptual framework

Alicia demonstrated a very rudimentary conceptual framework for acids and bases in her initial interview and her answers were generally brief and tentative. She indicated that she associated acids with '*hydrogen ions floating around in solution*'^(1.4), low pH^(1.10), a distinctive smell^(1.16) and corrosiveness^(1.14). Bases were characterised by the presence of the '*OH group*'^(1.26) and high pH^(1.36). Alicia did not perceive bases to be corrosive in the same way as acids^(1.33-1.34), nor did she mention proton donation or acceptance as characteristics of acids and bases. She did however indicate in her survey responses that a base '*accepts protons in aqueous solutions*'.

Alicia associated strength of acids with pH^(1.110), and was aware that pH was based on the concentration of hydrogen ions^(1.106-1.108), but was unable to provide the mathematical relationship. She indicated that her concept of pH changed at pH 7, which she described as '*neutral*'^(1.136) and where '*the um, concentration of OH and Hs are equal*'^(1.134). Above this pH, Alicia indicated that '*I think of OH concentration. It would be more, coz they're bases*'^(1.128), however she indicated that there would be hydrogen ions present even at very high pHs, up to 14^(1.131-1.132).

Alicia discriminated between acids in her first interview on the basis of strength, which for her was indicated by pH and the extent to which it was corrosive. Strong acids were characterised by low pH and higher corrosiveness^(1.58-1.64). Only in her survey did Alicia relate strength to extent of dissociation of acids or bases, where she indicated that '*a strong base would more readily accept protons in solution, nearly all*' whereas '*a weak base would not accept all of the protons in solution*'. Although this definition is closer to the chemistry convention than to pharmacy, it is interesting that she did not define dissociation in the traditional manner of complete and partial.

Alicia's trajectory

Changes to existing understanding

Interview 2

By the end of the teaching semester, Alicia demonstrated some conceptual development about the characteristics of acids and bases, although she was by no means as clear about pharmacy conventions as the others in her group, and she continued to provide relatively brief responses to questions. Her immediate responses were couched in terms of proton donation and acceptance^(2.270-2.272, 2.276), and she associated pKa with the strength of pharmacy acids and bases^(2.302-2.306). However she continued to associate pH with both acids and bases^(2.294, 2.298), suggesting that, although her understanding had developed to some extent, she did not discriminate fully between chemistry and pharmacy. She qualified this association somewhat in suggesting that *'a weak acid (pause) its pH would be (pause) higher, so, not as low in solution. Mm, it can be. (laughs) Um, above seven?'*^(2.308-2.312), and although the latter utterance was made tentatively, it nevertheless represented an important development in contextual understanding. It was clear however that Alicia's conceptual framework was an amalgam of chemistry and pharmacy concepts.

Alicia could articulate clearly the pharmacy conventions regarding strength and pKa^(2.302-2.306) and recognised the significance of pKa^(2.316), however she struggled with the concept that pKa alone was not a characteristic which would allow classification of a drug as acid or base^(2.319-2.334). Her explanation suggested that Alicia had not sufficiently internalised the concepts in a manner that allowed her easily to articulate her understanding. She may have understood at some level, but not to the point of being able to express her ideas in a logical or explanatory way. She did not mention the extent of dissociation in connection with either pKa or strength until prompted to consider the issue by the interviewer^(2.529-2.534).

The interviewer suggested a range of possibilities in which Alicia's understanding might have differed between chemistry and pharmacy, namely strength of acids, relative danger of acids, indicators and buffers. Alicia indicated that she could see some differences, but she struggled to articulate them clearly. She appeared to have appropriated the importance of pKa in the context of pharmacy, which she contrasted with her initial understanding of chemistry where pH was the more relevant parameter. However she was unable to express the difference explicitly^(2.615-2.628), and her externalisations suggested that her transformative internalisation of the concepts from pharmacy had resulted in an anomalous rather than conventional framework. In chemistry, strong acids were generally defined as those which dissociated completely in solution, whereas Alicia's concept lacked this absolute aspect. When the distinction between chemistry and pharmacy was highlighted in class, the aspect which was emphasised was that virtually no acids in pharmacy met this absolute dissociation criterion. Alicia appeared to have appropriated only part of this concept, that 'no acids in pharmacy would be classified as strong acids', rather than the conventional notion that 'no acids

in pharmacy would be classified as strong acids in **chemistry**'. Thus the lack of a strong foundation in one context hindered the development of contextual discrimination because the contrasts were unable to be perceived.

Interview 3

Five months later, Alicia continued to describe acids and bases as proton donors and acceptors^(3.106-3.108, 3.136-3.138). Further she continued to associate both pH and pKa with acids and bases, but her descriptions still indicated conceptual confusion. She retained the concept that pH was not a definitive indicator of acidic and basic nature, which suggested that she had developed conceptually in this regard from her pre-study notions. However she remained confused about the role of pKa, and struggled to distinguish between pH and pKa as indicators of strength, suggesting that all acids had low pKas and all bases had high pKas^(3.112-3.118, 3.140-3.142) while indicating that pH could be high or low depending on the strength of the acid or base. Subsequently however, she suggested that low pKa values were associated with strong acids, and that weaker acids had higher pKa values^(3.275-3.278); similarly strong bases were associated with high pKas and weak bases with low pKas^(3.452-3.456). She did not at any stage indicate actual ranges, nor did she refer to values relative to 7. When allocating the pKas to the functional groups in amoxicillin, Alicia indicated that the phenol would have the lowest pKa because it was a stronger acid than carboxylic acid^(3.275-3.282). Whilst this assignment was incorrect, it demonstrated that she retained some association between low pKa and strong acid, but it was nevertheless apparent that significant confusion remained in Alicia's conceptual framework.

Alicia did not volunteer any additional characteristics of acids or bases, nor did she distinguish between the meanings of the terms acid and acidic drug^(3.167-3.168). She struggled to articulate her understanding of the differences between acids and bases in chemistry and pharmacy, however the notion that pKa applied only to pharmacy had persisted^(3.158-3.164).

Perhaps surprisingly given her inherent confusion, Alicia was actually able to express the relationship between strength and dissociation for both acids and bases with more clarity and confidence than she had in her second interview^(3.124-3.148).

In summary, Alicia displayed the weakest conceptual understanding at the beginning of all of the participants in the study, and her conceptual development during the teaching semester was also the slightest, with her responses to questions in the second interview suggesting considerable conceptual confusion. Conceptual change and development in relation to characteristics of acids and bases was hindered by a foundation in chemistry that was weak and fragmented, however, the areas in which she did develop tended to persist until the end of the study, suggesting that she had appropriated the ideas rather than simply memorising them for the examination.

Alicia demonstrated that she had appropriated the fundamental pharmacy conventions relating to strength, dissociation and pKa, but the persistence of these notions was not uniform. She retained the more descriptive aspects relating to dissociation well, and indeed was able to articulate them more effectively at the end of the study than at the time of her examination. On the other hand, the more numerical aspects appeared to be less persistent, although they were occasionally apparent in her final interview.

Concepts new to pharmacy

Interview 2

Alicia was able to identify accurately and confidently all of the relevant functional groups on codeine, lignocaine, amoxicillin, ticarcillin, diazepam and ibuprofen. She indicated that she found both carboxylic acids and phenols easy to identify^(2.480-2.482), however she was able to explain the basis for her recognition of phenols^(2.424-2.426, 2.350), amines^(2.356, 2.396, 2.401-2.402) and amides without hesitation. She was confident in differentiating amines from amides^(2.428-2.432), and was also able to recognise that the second nitrogen in diazepam was neither amine nor amide because of the double bond on the nitrogen^(2.455-2.460).

Alicia was confident in stating that molecules with only acidic groups were acids^(2.452, 2.474), and that molecules with only basic groups were bases^(2.410, 2.422). Further she recognised that molecules such as diazepam, which contained neither type of group were neither acidic nor basic^(2.468). Amoxicillin, containing both types of group, was also identified as neither acidic nor basic, but with a different explanation which was consistent with the pharmacy conventions of possessing properties of both acids and bases^(2.490-2.502).

Alicia was asked to draw the dissociation equilibria for amoxicillin and ibuprofen, in that order. She tended not to articulate her thinking to any great extent while drawing, but remembered without assistance to add the additional proton to the amine group, remove the protons in increasing order and write the pKa values above the equilibrium arrows^(2.506-2.514). However, she erroneously allocated the acidic pKa values, assigning the lower value to the phenol and the higher to the carboxylic acid. It became clear that she had learned this material wrongly, in that she believed that phenols were stronger acids than carboxylic acids^(2.515-2.526)¹³, and this error needed to be corrected specifically by the interviewer. She subsequently drew the dissociation of ibuprofen accurately. It would have been illuminating to have observed her allocation of pKa values in amoxicillin had she been asked to carry out these equilibria in the reverse order.

Alicia was able to indicate that the significance of writing the pKa values above the equilibrium arrows was to facilitate identification of the relevant form at particular pH values^(2.537-2.540), and was able to apply this conceptual understanding given specific pH values, both for amoxicillin^(2.538-2.561)

¹³ In other words, this was not an error of recall but of learning, ie erroneous appropriation.

and ibuprofen^(2.573-2.574). She recognised without prompting that amoxicillin is 'ionised, (long pause) it's always ionised, because there's always a charge on one of its'^(2.562-2.564). She was also able to indicate pH values where ibuprofen was completely unionised and completely ionised^(2.675-2.684).

Interview 3

Five months later, Alicia continued to be confident and accurate in her identification of functional groups on the same set of molecules as she had evaluated during the second interview. She had no difficulty in distinguishing between phenols and non-phenolic OH groups^(3.213-3.214), nor did she attempt to label as phenols any OH groups which were separated from the benzene ring by one carbon. She continued to recognise amines^(3.184-3.186, 3.228) and to contrast them with non-basic nitrogens which were 'attached to a C which has a double bond'^(3.194). Alicia was not specifically asked to name the amide group, but she did not identify any amide group as basic; further she correctly indicated that the non-amine non-amide group on diazepam was not basic because of the presence of the double bond on the nitrogen.

Alicia continued to be confident about the classification of molecules containing acidic and basic functional groups: molecules containing only acidic groups were acids^(3.224, 3.236), molecules containing only basic groups were bases^(3.208, 3.212), and molecules containing both types of group were neither acid nor base^(3.196). She was not specifically asked to expand on the latter but offered the explanation that 'it's something else, because they have um, both acids and bases...So should I just write 'neither'?'^(3.196-3.200).

With respect to the dissociation equilibria, Alicia displayed very similar conceptual understanding in her third interview to that expressed in her second interview, and carried out the dissociation task in an almost identical manner. On this occasion she was asked about ibuprofen first, and she experienced no problems in drawing up the equilibrium and explaining the utility of this activity, indicating that placing the pKa on top of the arrow allowed her to identify the form of ibuprofen which would be found at specific pH values^(3.239-3.256).

However she again mis-assigned the pKa values for amoxicillin, suggesting that the pKa of 2.4 belonged to the phenol group, 7.4 belonged to the carboxylic acid and 9.6 belonged to the amine^(3.260-3.274)¹⁴. She made this allocation because she continued to believe that phenols were stronger acids than carboxylic acids^(3.276-3.282), a concept which she had articulated in the second interview, and again needed to be told specifically by the interviewer that this was not the case.

This exchange highlights the persistence of inappropriate concepts through conceptual change learning as a result of transformative internalisation. It is likely that Alicia's confused conceptual

¹⁴ It is important to note that in the second interview the pKas were labelled as acidic and basic whereas in the third interview the pKas were given without this identification.

framework regarding pH, pKa and strength contributed to a distortion of the process of appropriation by transformative internalisation of the relative strength of the two functional groups, and that this persisted because the learning had been 'effective'.

Alicia's representation of the dissociation equilibria was consistent with her assignment of the pKa values, and she remembered to add the proton at the start of the process to the amine group. She was not asked about the state of ionisation of amoxicillin at different pH values.

In summary, Alicia developed a conceptual framework with respect to functional groups which was almost completely consistent with pharmacy conventions, and she was able to apply this framework to the solution of relevant problems involving both familiar and unfamiliar structures. Her major difficulty appeared to be a distorted appropriation of the relative strength of carboxylic acid and phenol groups, which resulted in inappropriate assignment of pKa values. The majority of her conceptual understanding persisted to the end of the study, including both those aspects which she had learned in accord with conventions and those which were anomalous.

Alicia's perception of the change in her understanding

When asked specifically Alicia indicated that she did not believe that her understanding of acids and bases had changed during the semester^(2.263-2.268), however it was clear from the comparison of answers from her first and second interviews that she held a significantly different conceptual framework at the end of the semester. It was possible that her acknowledged difficulties with the chemistry concepts of acids and bases hindered her from exercising the metacognitive processes necessary for her to recognise a difference in her understanding.

Alicia indicated that she perceived that there was potential for confusion between the two contexts of chemistry and pharmacy^(2.259-2.260), but that she was not actually confused^(2.248-2.258). She indicated that '*for like what I need to know for pharmacy, I think I get it, understand it better*'^(2.590), however she continued to struggle somewhat with chemistry concepts^(2.590). She was often uncertain, suggesting that the concepts were not clear^(2.595-2.596), and indicating her belief that in chemistry '*I think this is what it's about*'^(2.252), whereas in pharmacy she was more certain: '*this is what it is*'^(2.254)¹⁵. Alicia identified as the critical issue that her high school study had not prepared her adequately for university chemistry^(2.600-2.608) and this self-evaluation was consistent with her responses in her first interview, where it was apparent that she had a rudimentary and fragmented conceptual understanding of the chemistry conventions of acids and bases.

Summary of Alicia's conceptual development

Alicia began the study with the weakest conceptual understanding about acids and bases of all the participants, and finished with a confused and distorted conceptual framework relating to those

¹⁵ Emphasis added.

aspects which featured in both pharmacy and chemistry, namely the characteristics and strength of acids and bases. She developed contextual discrimination to some extent, but her difficulties with chemistry limited the degree to which she could recognise differences. However, she was able to appropriate effectively those novel aspects of the topic which did not rely on a strong foundation from chemistry, and with the exception of an erroneous understanding of the strength of carboxylic acids and phenols, displayed a conceptual understanding of these aspects which was consistent with pharmacy conventions. Significant persistence of her developed understanding was apparent, including both aspects which were consistent and those which were inconsistent with conventions.

Alicia's interchanging of the strength of carboxylic acids and phenols was intriguing, because she was unique in making this error. It is impossible to be certain of the basis of the error, but it could be speculated that her poor background may have contributed to some extent. If she associated OH groups with hydroxide ions (strong base) and carboxylic acids with weak chemistry acids, she may have attributed higher strength to molecules containing OH than to those containing carboxylic acids.

6.5 Assessment outcomes

This study has used interview responses to evaluate the extent of learning, and particularly the long-term learning, of each participant, since this is consistent with the general discourse model. Other methods of assessment of learning are routinely used in educational settings however, most commonly student performance in unseen written examinations. It is worth noting that students in the TC group actually outperformed those in the PC group by approximately eleven percentage points in the end-of-semester examination in IPS, probably because the former were more focused on examination performance and used strategies which had been effective in past examinations. While not a major aspect of the research study, the discrepancies between examination performance and the long-term learning exhibited in the third round of interviews raise some important issues for educators about the accepted means of assessment.

6.6 Overall summary

The extent and persistence of conceptual change among the participants in this study clearly differed between individuals, however two dimensions appeared significant in promoting or constraining change.

Firstly, the quality of the participant's foundations in the topic of acids and bases from secondary and university chemistry appeared to shape the development of contextual discrimination. Those participants who demonstrated a strong conventional conceptual framework at the beginning of the study appeared to develop more well-defined contextual discrimination than those who exhibited a weak, fragmented or anomalous initial framework, irrespective of the small group in which they worked. A reasonably strong foundation in secondary level chemistry was assumed knowledge for

IPS, and the teaching was designed to contrast the conventions of pharmacy with those learned in chemistry in order to promote contextual discrimination and conceptual change. Participants with a weak background in chemistry therefore needed to learn not only the new pharmacy conventions, but also those of chemistry, in addition to the discrimination between them, during the teaching period. Learning by conceptual change implies that a foundation exists as the basis for comparison and contextual discrimination, and conceptual change teaching which emphasised differences between the two contexts was probably not optimal in the absence of this foundation. Such teaching effectively required participants to learn two parallel sets of concepts simultaneously, which would almost inevitably lead to some conceptual confusion and distortion. This pattern was observed for a number of participants, most noticeably Larry, Jasmine and Alicia. In contrast, participants including Janine, Geoffrey and Emma who displayed a robust initial conceptual framework developed greater discrimination between the contexts of pharmacy and chemistry, although to some extent this discrimination could be classified as compartmentalisation.

A strong foundation could then be postulated to affect conceptual change learning in different ways. Firstly, it could enhance conceptual change if the participant was able to contrast chemistry concepts easily and clearly with the alternative versions from pharmacy. Alternatively, it could hinder conceptual change if the chemistry concepts were too firmly entrenched to allow the possibility of considering other possible meanings

Similarly a weak foundation could also be hypothesised to have two effects. Conceptual change may be perceived to be promoted if the original conceptual framework is easily discarded in favour of a more useful or practical alternative, or it could be hindered because the foundational concepts were not sufficiently coherent as to allow the development of an understanding of the differences between chemistry and pharmacy.

The second dimension of significance was the group in which each individual participated, which appeared strongly correlated with the persistence of learning. Participants in the transient change group in general demonstrated short term learning of pharmacy conventions with respect to concepts which differed between chemistry and pharmacy, and those which were unique to pharmacy. However, minimal persistence was observed of pharmacy conventions which conflicted with those of chemistry, and significant deterioration was apparent in a number of cases with respect to the unique material. In contrast, members of the persistent change group displayed persistence of most of the concepts which were apparent in the short term, both those which were consistent with conventions and those which were anomalous or idiosyncratic.

An error made by all members of the PC group highlighted the importance of expert modeling of conventions, and opportunities to practice using them in relevant situations. Participants in this group all retained to the end of the study the notion that bases must have higher pK_a values than any acids, including weak acids. This concept appeared to have developed during the teaching semester, although it was not prominent at the time of the examinations, possibly because students

had been practicing the assignment of pKa values and had trained themselves to reject their intuition. By the end of the study, all participants articulated the erroneous underlying notion of the relationship between acids and bases, which was clearly grounded in chemistry understanding. In order to promote appropriation of the conventional concept, intervention by the tutors during the workshops would have been necessary to provide input for internalisation and subsequent externalisation of the counter-intuitive concept, however this did not occur as the tutors did not at any stage diagnose this specific difficulty.

On the surface, the TC group appeared to have undergone greater conceptual change at the time of the second interviews, probably because they were more adept at preparing for exams and had higher aspirations than the PC group. The TC group was clearly more focused on performance than learning for retention, and had adopted specific strategies to secure their success in the examination. Interestingly, these strategies were closely reflective of those suggested by Posner et al (1982) in the earliest descriptions of conceptual change, who postulated that students might avoid conceptual change by attempting to assimilate new knowledge into pre-existing conceptual structures, resolving conflict by compartmentalising the knowledge, ignoring the existence of anomalous data completely or rejecting it as erroneous or irrelevant. In this case, Geoffrey, Larry and Lucy focused on memorisation and compartmentalisation strategies as tools for remembering rules, and Emma adopted survival strategies designed to compensate for her reduced study opportunities, while Janine revealed that she did not really believe the pharmacy conventions. In all cases, material which had either been memorised, or which conflicted with the 'right' versions in pharmacy, was rapidly discarded after completion of the examinations. In contrast, the PC appeared to be more focused on their own learning and helping each other to learn, and less on performance for the exam, and as a consequence there was less evidence of memorisation and strategy use simply for the purpose of achieving high marks, and greater evidence of conceptual change learning.

Since the outcomes of conceptual change learning were strongly related to membership of either the TC or PC group, the processes which occurred within the two groups were of considerable interest in terms of their capacity for promoting or constraining change. These processes are analysed in chapter 7.

CHAPTER 7 GROUP PROCESSES AND CONCEPTUAL CHANGE

LEARNING

“Collaboration might productively be thought of as involving a dual-problem space that participants must simultaneously attend to and develop: a *content space* (consisting of the problem to be solved) and a *relational space* (consisting of the interactional challenges and opportunities).” (Barron (2003, p.310, author’s italics))

“...to understand the nature of productive collaboration, we need to articulate how social goals and discourse practices interact with knowledge-building processes that lead to coconstruction of understanding.” Barron (2003, p.309)

7.1 Introduction

The previous chapter has outlined the conceptual change outcomes for each participant by focusing on the personal plane (Rogoff, 1998), and has revealed significant commonalities amongst members of each group. The current chapter focuses on the processes underlying conceptual change, and explores the interpersonal plane in order to discover possible sources for these commonalities.

Barron’s notion of dual-problem space (Barron, 2003) provides the framework for the chapter. The first section deals with the content space, and describes the extent and quality of talk about acids and bases within the workshops, while the second section focuses on the relational space by exploring the social and interactional dynamics of both groups. In the latter section, data are gathered from both the workshops and individual student interviews. The chapter concludes with a brief discussion of the perceived impact on group functioning of the presence of the recording equipment.

7.2 The content space – talking about acids and bases within workshops

In order to promote conceptual change through appropriation by transformative internalisation and externalisation, significant ‘talk’ is a critical element of the learning process. Talk is simultaneously an externalisation by the speaker and resource for internalisation by others, and thus the extent to which each group discussed the actual content, and the nature of the discourse is explored to elucidate affordances and constraints on the conceptual change process. Both quantitative and qualitative aspects of discourse are considered.

The extent of the discourse

A number of quantitative measures can be calculated for the discourse of each group during workshops, and while they represent only a limited perspective, they provide useful insight into the differences between the two groups in the study. Individual turns within each workshop were coded

according to the primary function of the turn, and graphs of numbers of turns are presented below. A brief description of each code, together with sample turns is included in Table 7.1.

Code description	Sample turns
<p>CALC = Calculation Turns were coded as CALC if they related to the carrying out of a calculation, including discussion about the appropriate choice of approach or equation, the mechanics of the arithmetic, the use of calculators, the answers as calculated, and comparison of answers between participants.</p>	<p>Three point eight minus four point two, alternate log to the power of ten, that, right, so, therefore (Larry 2.1174)</p> <p>OK. So work out the moles, right? I got point zero zero one six. Lots of sixes (Veronica 2.147)</p>
<p>EXPL = Exploratory Turns were coded as EXPL if they involved exploration of ideas or approaches, where participants were attempting to work out approaches to tasks. This code included speculation rather than certainty (the latter was coded REAS), and could involve either individual exploration or a more collaborative approach by more than one participant.</p>	<p>But then, why can you work with S up here and you can't work with S down here? (Janine 1.247)</p> <p>With this question does it mean there's like, not enough? Like it hasn't dissolved properly? (Isabelle 2.2109)</p> <p>For example, increasing the pH, is that what you were getting at? (Jasmine 2.2117)</p> <p>I think before it's in the water, it should be un-ionised, don't you reckon? (Veronica 2.391)</p>
<p>OFF = Off task Turns were coded as OFF if they involved reference to individuals or activities not directly related to the workshop and its associated tasks.</p>	<p>I've gotta study for Chem tomorrow. Oh actually, when we go home, can I photocopy your Chem book? Someone's Chem book? For tomorrow? (Lucy 2.1235)</p> <p>Anybody want some mints? (Denise 2.220)</p>
<p>PROC = Procedural Turns were coded as PROC if they related to the method of carrying out the workshop tasks, including regulation of the activities and inquiries about task requirements.</p>	<p>Oh are we doing the last one are we? Excellent. The last question? (Geoffrey 1.817)</p> <p>What are we writing here? (Denise 3.1008)</p>
<p>REAS = Reasoning Turns were coded as REAS if they involved individuals attempting to request or give reasons. This included reasoning about the method of approaching a problem, the meaning of answers, requests for explanation, the provision of explanations and subsequent agreement or disagreement with the explanation offered.</p>	<p>Well, because, if this is at pH less than nine point six, if that's at pH less than nine point six, then that will be ionised. So eight point'd be that. No, no, eight, no no sorry, that will, that won't be ionised. OK (Geoffrey 2.886)</p> <p>Why would you say that's ionised? Sorry, can you explain that to me? (Jasmine 2.1183)</p> <p>If you square at the beginning, put it in, the answer you get you square root it. (Alicia 1.404)</p>
<p>RECL = Recall Turns were coded as RECL if they indicated that the participant was recalling, or attempting to recall, material relating to the task at hand. This code was also used when participants read material from written sources.</p>	<p>No sodium salt, that means um, remember how the bases, um can become, when they're, when they're in the salt form, right? If it's a salt form with a cation, it must have been an acid? And if it's a salt form with a base, it must, no, a salt form with an anion it must have been a base? Remember how we did that? So you just look for the acids and the base and you've got them in the right place. (Janine 2.1226)</p> <p>"Acid drugs form salts with metals such as sodium or potassium, while basic drugs form salts with anions such as chloride." (Kellie 2.1413)</p>

<p>REFL = Reflection Turns were coded as REFL if they involved reflection about the workshop or task.</p>	<p>I'm doubting everything now, that I've thought (Larry 1.902)</p> <p>Ohh, yeah, that's right, anyway. It makes sense because you worked it out numerically, and it turned out to be the same as that. Very close, anyway (Jasmine 2.1856)</p> <p>But I don't even know what I did. I thought there was something else to do (Isabelle 3.350)</p>
<p>STDY = Study Turns were coded as STDY if they involved discussion about the conduct of the research study, for example scheduling of interviews, and general comments about the study.</p>	<p>I don't wanna do it after the exam though (Lucy 1.2)</p> <p>Yeah, but there's another interview next year (Veronica 3.729)</p>
<p>UNCO = Uncoded Examples of uncoded talk included inaudible turns, and individual, usually brief, turns which could not be interpreted within the context of an ongoing dialogue.</p>	

Table 7.1: Code descriptions for analysis of workshop discourse. (Note: when the tenor of a particular discussion was generally in either the EXPL or REAS mode and the discussion was coherent and flowing, sequences of turns were assigned the same code.) Sample turns are identified as (student name workshop.turn)

The total number of turns during each workshop, and the breakdown by codes are presented in Figures 7.1 and 7.2.

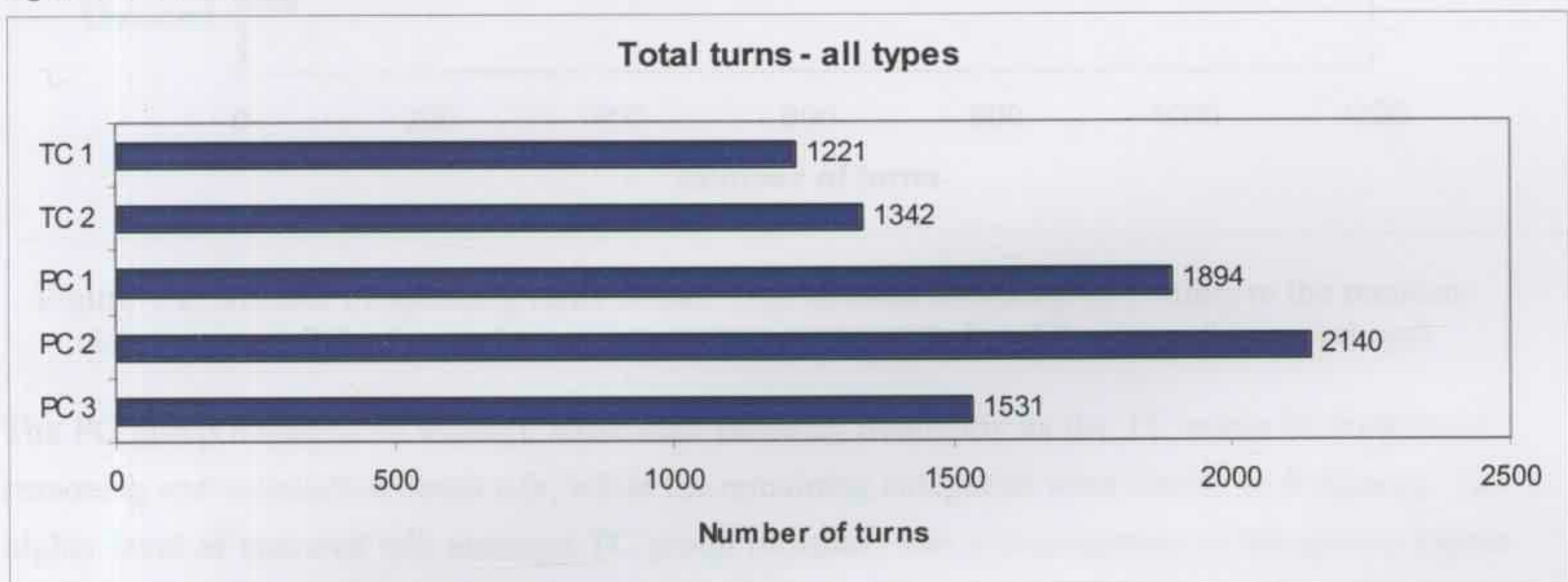


Figure 7.1: Total speaking turns in each workshop (TC refers to the transient change group; PC refers to the persistent change group; 1, 2 and 3 refer to the workshops)

Members of the PC group articulated more turns than members of the TC group in each workshop, which was consistent with the length of time each group remained in the workshop (TC average 76 minutes; PC average 117 minutes). More importantly for the promotion of conceptual change, the types of turns differed significantly between the two groups as illustrated in Figure 7.2.

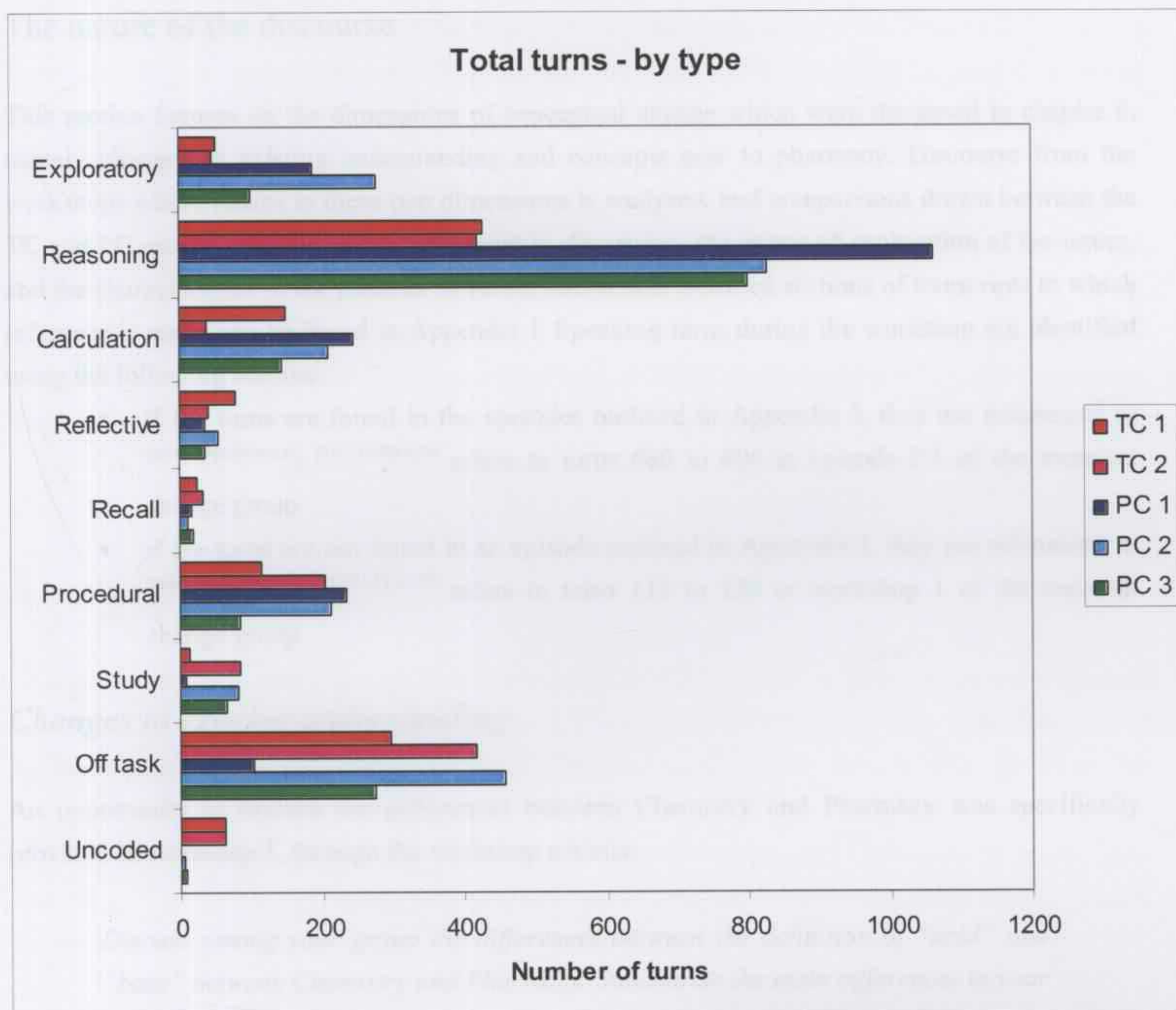


Figure 7.2: Number of speaking turns of each type in each workshop (TC refers to the transient change group; PC refers to the persistent change group; 1, 2 and 3 refer to the workshops)

The PC group engaged on average more than twice as frequently as the TC group in exploratory, reasoning and calculation based talk, while the remaining categories were similar in frequency. The higher level of uncoded talk amongst TC group members was a consequence of the greater extent of self talk, particularly brief comments, by these participants. These comments were usually decontextualised and thus unable to be coded.

Exploratory and reasoning discourse are likely to be the most productive for promotion of conceptual change, thus the higher frequency of these patterns of discourse among PC group members suggested that their externalisations were likely to provide more effective resources for internalisation of appropriate concepts by other members of the group. However these quantitative measures are simply indicative only, and analysis of the nature of the discourse itself is necessary in order to infer evidence of the relationship between discourse and conceptual change.

The nature of the discourse

This section focuses on the dimensions of conceptual change which were discussed in chapter 6, namely changes to existing understanding and concepts new to pharmacy. Discourse from the workshops which relates to these two dimensions is analysed, and comparisons drawn between the TC and PC groups with respect to time spent in discussion, the extent of exploration of the issues, and the characteristics of the patterns of verbal interaction. Selected sections of transcripts to which reference is made can be found in Appendix I. Speaking turns during the workshop are identified using the following scheme:

- if the turns are found in the episodes outlined in Appendix I, they are referenced as (groupepisode:turns). (TC2.1:680-686) refers to turns 680 to 696 in episode 2.1 of the transient change group
- if the turns are not found in an episode outlined in Appendix I, they are referenced as (groupworkshop.turns). (TC1.115-129) refers to turns 115 to 129 in workshop 1 of the transient change group

Changes to existing understanding

An opportunity to discuss the differences between Chemistry and Pharmacy was specifically provided in workshop 1, through the workshop activity:

Discuss among your group the differences between the definition of "acid" and "base" between Chemistry and Pharmacy. Summarise the main differences in your own words.

Further opportunities to explore changes in understanding arose during other activities in both workshops 1 and 2.

Transient change group

The transient change group spent less than one minute on the specific activity outlined above, before deciding to abandon the remaining activities and move directly to the page which was to be submitted for feedback. During this short period, some discussion took place about the differences in both the nature and strength of acids and bases between Chemistry and Pharmacy. Short discussions also took place later in workshop 1 and during workshop 2. Three episodes were identified across the two workshops.

Episode TC1.2 (51 seconds)

All four students participated briefly in a discussion about whether the dissociation of acids and bases was different in Chemistry and Pharmacy. Larry and Geoffrey claimed that it was the same,

but Janine initially challenged their assertion and Lucy was not certain. After looking at her lecture notes, Janine subsequently agreed with Larry and Geoffrey, and Lucy eagerly suggested recording this information ^(TC1.2:696-715). No exploration of the concept occurred, as Larry, Geoffrey and Janine accepted their own ideas, and Lucy was happy to accept Janine's authority.

All four students were also briefly involved in discussing the different definitions of strength in Chemistry and Pharmacy, but no consensus was achieved. Larry articulated the notion that a different extent of dissociation was important, but did not explain his ideas, while Janine appeared to be talking to herself rather than responding to the comments of the others. Geoffrey ended the discussion with the statement '*that's enough to find the correct answer*' ^(TC1.2:695), effectively precluding further exploration of the concept, and limiting the opportunities for development of contextual discrimination.

Episode TC2.1 (32 seconds)

While attempting to identify ingredients in a tablet as either acidic or basic, all four participants interacted about the nature of sodium carbonate. Larry, with the weakest background, claimed it to be acidic, while Geoffrey was adamant that it was basic. Janine agreed with Geoffrey but erroneously suggested that it was considered basic only in Chemistry and not in Pharmacy. None of the others challenged Janine's assertion, and appeared content to move immediately to the next question ^(TC2.1:679-692). The lack of discussion permitted an incorrect assumption to remain unchallenged, constraining the development of discrimination between the two domains.

Episode TC1.3 (31 seconds)

Geoffrey took the lead in a discussion with Lucy about the characteristics of acids and bases in which only those from Chemistry – corrosiveness, taste and feel – were mentioned. There was no evidence that either student realised that these were not relevant in Pharmacy, and indeed Lucy commented that she needed to remember these characteristics for her next interview. It is significant that Geoffrey identified only these physical characteristics in his third interview (chapter 6). Neither of the other participants intervened in this dialogue, as both were working independently on other activities, thus the opportunity for collaborative conceptual discourse was lost. Rather, the exchange reinforced prior understandings and thus constrained the development of contextual discrimination.

In summary, very little TC group workshop time was devoted to exploration of the differences between Chemistry and Pharmacy, and the development of contextual discrimination. Janine and Geoffrey appeared to confirm their previous understandings, while Larry and Lucy remained tentative and willing to accept the assertions of the others. The discourse provided limited resources for transformative internalisation, and contained few externalisations, thus the appropriation of contextual discrimination was significantly constrained.

Persistent change group

The persistent change group spent two minutes discussing the specific activity outlined above, before deciding to ask for assistance. While waiting for assistance they began the subsequent activity, and never actually returned to the questions they wanted to ask the tutor. Two episodes were identified: although they represent continuous discourse, the focus of each was distinct.

Episode PC1.3 (47 seconds)

All five¹⁶ students were engaged in this discussion, although the majority of the discourse was carried out by Jasmine and Kellie. The group briefly explored the differences in definition between Chemistry and Pharmacy, and came to the consensus that the same definition, that of Bronsted-Lowry, applied to both domains. Denise, Veronica and Alicia made minimal contributions but appeared willing to accept the authority of the others.

Episode PC1.4 (73 seconds)

Denise took more of a leadership role in the subsequent discussion of differences in the concept of strength between Chemistry and Pharmacy, although Jasmine, Kellie and Veronica also contributed suggestions. A number of ideas were offered:

- that the difference in strength between the domains related to the extent of dissociation (PC1.4:1039-1043)
- that the definition of strength in Pharmacy was based on pK_a (PC1.4:1044-1046, 1056)
- that the major difference in the definitions of acids and bases between Chemistry and Pharmacy was actually the different definitions of strength (PC1.4:1047-1056)

Unfortunately the discussion did not reach consensus, nor was a tutor asked for assistance or confirmation, however the raising of the issues provided valuable input for transformative internalisation, particularly since the ideas themselves were appropriate.

In summary, although a similar amount of time was devoted by both the PC and TC groups to the topic, the discourse of the former was more open-ended and exploratory, which afforded fewer constraints to conceptual change than the more closed and bounded discourse of the latter. Within the PC group, no individual was afforded greater authority than the others, whereas Janine and Geoffrey appeared to assign themselves authoritative roles within the TC. Given the brevity of discussion of this topic by both groups, it is difficult to draw definite conclusions about the relationship with the changes observed in the interviews, but it is apparent that PC members were at least exposed to a wider range of ideas than their counterparts in the TC.

¹⁶ Isabelle was ill, and was absent from workshop 1.

Concepts new to pharmacy

Considerably more workshop time was devoted to these new concepts:

- in workshop 1, the assigned activities included discussion of the methods of identifying acids and bases, in particular differentiating them from similar non-acidic/basic molecules, and exercises involving application of these methods to specific molecules
- in workshop 2, the assigned activities included calculations relating to the extent of ionisation and the pH/pKa-dependent solubility of acidic and basic drugs
- in workshop 3, the assigned activities focused on the pH/pKa-dependent movement of acidic and basic drugs between different solvents, however these are not analysed in this chapter

In this section, episodes are drawn from the discussions surrounding the identification of acidic and basic drugs based on their functional groups, and those relating to the dissociation equilibria. For each group specific episodes from workshops 1 and 2 have been identified as critical, and a brief outline of each is included in Appendix H. The section is then structured around the identification of phenols, amines and amides, molecules with both acidic and basic groups, and dissociation equilibria.

Transient change group

Identification of phenols, amines and amides

Only minimal discussion occurred regarding the criteria for identifying OH groups as phenols. Janine was the first to begin the activity and thus also the first to mention the group, but she simply stated that codeine contained a phenol ^(TC1.4:756-761) without discussion. In fact she was incorrect as she mistakenly classified an aliphatic ring as benzene, and the lack of discussion provided no opportunity for her to reconsider her suggestion. Larry subsequently (correctly) identified the OH groups on dopamine as phenols, but was contradicted by Janine who suggested that they were actually benzoic acid. On reviewing her lecture notes as a consequence of the challenge to her thinking, Janine recognised her error, but no further discussion ensued ^(TC1.4: 899-920). The paucity of externalisations resulted in limited resources for transformative internalisation of the concept by other members of the group, and thus limited potential for conceptual change.

Discussion surrounding the criteria for identifying and differentiating amines and amides was limited to episode TC1.4, although passing mention was made of these groups in other episodes. Janine was again the first to mention the group ^(TC1.4:761-765), as she identified the nitrogen in codeine as an amine, and importantly stated the appropriate criterion, namely that it '*has to be sp³, right?*' ^(TC1.4:763). However, again, discussion was minimal, as Larry and Lucy assented in single words, and Geoffrey was working independently on an earlier question. When Geoffrey reached the same point, he also appeared to classify the nitrogen as amine, but in addition he classified codeine as

basic (TC1.4:794). None of the others explicitly articulated the latter point since Janine remained unchallenged about her suggestion that codeine also contained a phenol.

Discussion about amines also occurred in relation to diazepam and lignocaine. An exchange between Janine and Larry (TC1.4:774-801) revealed some conceptual confusion on Janine's part as she used a different, and inappropriate, criterion for classifying the nitrogen in diazepam as amine: '*it's connected to another carbon so it's got three bonds, so I'd say it's a base. So we'll circle it and we'll go base*' (TC1.4:774). Larry's corrective response echoed Janine's previous classification by means of sp^3 hybridisation (TC1.4:782, 788), but she apparently needed confirmation from her notes (TC1.4:793-793) before accepting his correction (TC1.4:797, 799, 801).

The final discussion of amines occurred in the context of Janine checking her answers with those of Larry (TC1.4:861-880), who had classified lignocaine as basic. Geoffrey joined briefly in the exchange to point out that Larry had incorrectly suggested both nitrogens in lignocaine were amines, and Janine completed the rationale by pointing out that one of the nitrogens was attached to a benzene ring (TC1.4:877) and was therefore double bonded. Presumably this statement implied that the criterion of sp^3 hybridisation was not met, but Janine did not make this concept explicit.

In summary, more discussion occurred about nitrogens than about phenols, but the discourse was rarely conceptual in nature. In most cases, individuals simply stated their ideas with little or no explanation, and disagreement was generally resolved by reference to lecture notes rather than by exploration through discourse. The significance of sp^3 hybridisation was highlighted, but no details of the means of recognising sp^3 hybridised carbons were explicitly described beyond a single explanation provided by the tutor (TC1.5:1043), which was not reiterated by any student. Further, no descriptions of the salient features of amides were clearly articulated, again apart from one comment by the tutor (TC1.5:1038), which was again not echoed by any of the students. As a consequence, appropriation of the concepts underlying the recognition of amines and amides was constrained by the dearth of externalisations which could have stimulated transformative internalisation.

Classification of molecules with both acidic and basic functional groups

The two molecules amoxicillin and dopamine contained both acidic and basic functional groups, and thus should have been classified by the students as neither acidic nor basic. In addition, codeine was incorrectly classified as containing both an acid and a base. Codeine and dopamine were the subject of disagreement, which was ultimately resolved by the intervention of the tutor, however no comparable discussion occurred about amoxicillin.

The initial discussion focused on codeine (TC1.4:815-848), which had been accepted by Larry as containing both a phenol and an amine, and which he suggested was classified as neither acidic nor basic (TC1.4:815). He was immediately and forcefully challenged by Janine (TC1.4:820), but was able to

defend his position with a clear rationale based on the authority of the lecturer ^(TC1.4:821). This declaration provoked a division of opinion, with Geoffrey backing Janine, and Lucy backing Larry ^(TC1.4:824-831). Referral to lecture notes ^(TC1.4:832-834) provided Larry with evidence, and Geoffrey took advantage of the serendipitous proximity of the tutor to seek clarification ^(TC1.4:835-846). Confirmation of Larry's understanding caused Janine to listen to the tutor without comment, and to write this new information rapidly into her lecture notes.

The tutor's explanation was clearly sufficient for Janine, and she externalised her transformed understanding in a subsequent self-directed comment about dopamine ^(TC1.4:939-943). The transformative nature of her appropriation of the concept was underlined by her extension of the idea to include the concept that the relative number of each type of functional group was irrelevant to the classification ^(TC1.4:939). Unfortunately for the promotion of conceptual change among the whole group, only Larry heard her comment, and his only response related to pronunciation.

Geoffrey also appeared to appropriate the tutor's explanation, because he externalised the concept several times in seeking confirmation from both Larry and Janine ^(TC1.5:992-1007). Lucy remained unconvinced ^(TC1.5:1010), but eventually articulated the reason as a question ^(TC1.5:1016). However it was subsequently clear that Lucy and Geoffrey did not fully appreciate the tutor's explanation, because they later changed their classification of dopamine to basic ^(TC1.6:1089-1104). Although Larry and Janine were concurrently working on a different question, they were drawn into the discussion, with Larry exhibiting signs of frustration over the alternative suggestions ^(TC1.6:1114), and Janine providing a succinct explanation which closely reflected the pharmacy conventions: '*Yeah, we've got that, we've got a base and two acids which made it neither*' ^(TC 1.6:1118). Further comments by Geoffrey clarified the problem: Geoffrey had not at any point articulated his concept of phenol, and was of the belief that '*you don't count these [phenols] as acidic*' ^(TC1.6:1119). It was not clear whether he believed that they were basic, however Lucy articulated this belief explicitly ^(TC1.6:1124), and the confusion thus generated triggered a request for adjudication from the tutor ^(TC1.6:1125-1126). The tutor responded to Lucy's assertion and Larry's refutation ^(TC1.8:1149-1150) by affirming Larry's understanding, but unfortunately no further conceptual discourse followed apart from a final comment of confirmation by Lucy ^(TC1.8:1166).

On the basis of the extent of discussion of this issue, it could be predicted that group members would have had a reasonable opportunity to appropriate the concepts, however evidence from chapter 6 suggests that this expectation was not well realised. An explanation may lie in the focus on seeking external authority, rather than sustained engagement in collaborative discourse, to resolve disagreement or confusion. While lecture notes and the tutor were able to provide resolution and clarity, the scarcity of extended exploratory and explanatory discussion significantly hindered appropriation of the conceptual basis for the ideas which were confirmed.

Dissociation of acids, bases and molecules with both types of functional group

There was general agreement during the first workshop among Larry, Geoffrey and Janine about the process of writing dissociation equilibria, however Lucy did not articulate her ideas and it was difficult to ascertain her depth of understanding. Geoffrey suggested that ‘*You start from the lowest pH don't you? When you're doing dissociation equilibria?*’ (TC1.5:988), Larry concurred that ‘*[you] start the process with all protons attached, start with deprotonation, the deprotonation of the functional groups from lowest to highest pKa*’ (TC1.5:991), and Janine queried ‘*Do you start from the lowest pH and work up?*’ (TC1.5:1016a). However, only one further comment was made during the remainder of this workshop, when Janine uttered a self-directed comment (TC1.5:1033). Larry attempted to carry out the task but was frustrated, and his only comment was about the difficulty of drawing the diagrams (TC1.5:1057). Additional discourse made it clear that Janine and Larry had attempted the three dissociation equilibria independently, and that Janine did not trust Larry's answers to be submitted as representative of the group (TC1.6:1087, 1090, 1093-1095). Interestingly, however, when Janine checked Larry's final version (TC1.8:1128-1145), she discovered errors in her own reasoning, and copied Larry's version back onto her worksheet. She did not share these insights with the rest of the group.

The task was revisited in the second workshop in the context of questions asking about the relative abundance of ionised and unionised forms of the molecules at specific pH values. The students appeared to have retained little understanding of the task from the previous workshop, suggesting that Lucy and Geoffrey did not actually attempt it. The molecules under consideration were naproxen, lignocaine, ibuprofen, amoxycillin and ticarcillin.

Lucy, Geoffrey and Larry articulated their ideas when drawing the dissociation of the easiest molecule, naproxen, but Lucy was initially tentative (TC2.3:762) and did not receive an immediate response from the other members of her group before being drawn into other activities, and Larry began by posing a question only to himself (TC2.3:765). Subsequently, however, the three engaged in a productive exploration of the task, and co-constructed an appropriate response and explanation (TC2.3:770-772). They remained tentative, and sought confirmation in the previous week's corrected answers (TC2.3:817-825) and were reassured that their original conclusions were correct (TC2.3:823-831).

Only perfunctory comments were made by Lucy in relation to the dissociation of lignocaine (TC2.3:833-841), and ibuprofen (TC2.3:852-862), and neither Larry nor Geoffrey attempted to address these molecules, although it was clear that Janine had completed naproxen, lignocaine and ibuprofen by herself. The discourse was dominated by the dissociation of amoxycillin, which appeared to cause significant confusion. It is likely that the prominence of amoxycillin was a result of Janine's greater difficulties with this molecule than any of the others.

Janine's approach in assigning the pKa values¹⁷ for amoxicillin (TC2.3:741-767) was to articulate her ideas to herself, but with sufficient volume that the others could hear and answer. The others were, however, working on different issues: Larry and Lucy were working on naproxen, but independently of each other, and Geoffrey was attempting to understand the structure of amoxicillin as it was drawn¹⁸. Janine's self-talk was generally appropriate, but the lack of interaction with other students constrained the opportunities for meaningful appropriation of her conclusions. Janine continued in the same pattern as she moved onto thinking about the state of ionisation at pH 7 (TC2.3:773-797), but again did not engage in discourse with other members of the group. Her comments nevertheless provided insight into her appropriation of the concept of ionised/unionised, and they revealed an idiosyncratic approach. She identified the ionisation of amoxicillin group by group rather than by drawing the sequential dissociation equilibria of the molecule as a whole, and while she was successful in assigning the correct state of ionisation for each group, she concluded erroneously that the molecule was half ionised and half unionised (TC2.3:797) at the pH specified in the question. When challenged by Geoffrey (TC2.3:800, 803) she modified her answer but did not appear to accept his opinion that the molecule was more unionised than ionised. Her conclusion was idiosyncratic because she did not acknowledge that the presence of any charge on a molecule resulted in that molecule being ionised, and only a later interaction with the tutor about a different issue allowed her to revise this conclusion.

Larry, Lucy and Geoffrey engaged briefly in discourse about the ionisation of amoxicillin (TC2.3:863-886), and interestingly Lucy actually articulated the appropriate idea when, observing the diagram from the previous week's workshop, she suggested '*well at pH seven, maybe it's probably, it's gonna be just in the middle, coz it's in the middle*' (TC2.3:864). Her comment was ignored by the other two, as Geoffrey made a counter suggestion using similar logic to Janine (TC2.3:879-883), and Larry remained unconvinced by both suggestions (TC2.3:884). While Geoffrey talked himself through his approach to the problem, and Lucy watched him (TC2.3:898-917), Larry instead briefly consulted Janine, who directed him to a table in the lecture notes (TC2.3:901-920). This table appeared to channel Larry into the same line of reasoning as Janine and Geoffrey, and while Larry read and wrote independently, Geoffrey continued to lead Lucy through his reasoning (TC2.3:952-965). Janine, although by this stage considerably further advanced in the worksheet, interjected to correct their ionisation of bases (TC2.3:966-983). Interestingly, while this created confusion for Geoffrey, Lucy appeared to perceive this as corroboration of her own thinking (TC2.3:1000), and the explanation she provided to Larry (TC2.3:1007) suggested that she had internalised the discourse to some extent. This exchange appeared to terminate the consideration of amoxicillin, regrettably without a clear consensus.

The discussion surrounding the dissociation of amoxicillin was reasonably extensive, occupying a period of approximately 13 minutes from beginning to end, however the discourse was poorly coordinated because the group was rarely working on the same problem. Some exchanges created conditions for co-construction of concepts, and for their appropriation through transformative

¹⁷ She actually described them as the pH values (TC2.3:741) but the context made it clear that she was referring to pKa.

¹⁸ There was an error in the worksheet, where one of the bonds in the amoxicillin structure had been omitted.

internalisation and externalisation, but the paucity of exploratory discourse limited the utility of these opportunities.

The dissociation of ticarcillin was only addressed briefly. Janine was the first to reach the question, and she completed it with ease and with minimal, self-directed comment ^(TC2.3:799-813). 12 minutes later, Lucy initiated discussion with Larry and Geoffrey ^(TC2.3:1032-1048) that led them to the conclusion that it was '*half and half*' ^(TC2.3:1042, 1046), however it was not clear how this conclusion was reached.

Group members appeared to be satisfied with their answers and their reasoning, and did not seek assistance from a tutor in relation to the details of the equilibria. Janine however struggled with the calculation of the ionised percentage for amoxicillin, and summoned a tutor just as the other three reached the end of their consideration of ticarcillin ^(TC2.3:1053-1102). Although the tutor initially addressed her explanation only to Janine, and focused on the arithmetic aspects, she addressed the remaining group members ^(TC2.3:1076) when she realised that the group had failed to understand the key aspect of ionisation, namely that '*just one charge is enough to make the whole molecule ionised*' ^(TC2.3:1070-1072). The behaviours of all group members, including watching, listening and writing, indicated that the tutor's general explanation gained and maintained their interest as she modeled and expounded the appropriate discourse, both for the ionisation ^(TC2.3:1079-1085) and more generally the classification of molecules ^(TC2.3:1093-1101). While the group members appeared to accept the explanation however, only Janine subsequently externalised her understanding ^(TC2.3:1123).

In summary, the discourse in which members of the TC group engaged while attempting to solve problems relating to functional groups and their dissociation was in large part unlikely to promote effective appropriation of the concepts under consideration. The discourse was poorly coordinated, as participants worked at different paces, and the preferred option was consultation of the authorities (lecture notes and the tutor) rather than seeking to explore difficulties through exchange of ideas. The perceived credibility of opinions was unequal, with the result that appropriate comments were disregarded if they were offered by the individual with the lowest recognised status, Lucy. Interactions with tutors provided expert modeling of the discourse, but little if any discussion developed as a result of the tutor's explanations. Only Janine was likely to engage in subsequent externalisation, but generally to herself. As a consequence, the potential inherent in the environment for learning through conceptual change was seldom realised.

Persistent change group

Identification of phenols, amines and amides

The PC group engaged in extensive discussion about the nature, identification and characteristics of these functional groups. With approximately 30 minutes remaining in the first workshop, they agreed to begin completing the back page to be submitted for feedback. All five group members

participated in this activity, although Alicia's participation was largely tacit and silent. When assessing the first molecule, codeine, Denise initially classified the OH group as neutral (which was correct) but immediately changed her mind and classified it as basic, confusing it with the hydroxide ion ^(PC1.5:1082). This began an extended discussion encompassing both phenols and hydroxide ions, as the group attempted to resolve their conceptual confusion ^(PC1.5:1083-1144; 1158-1169). Denise continued to insist that OH groups were basic ^(PC1.5:1084, 1086, 1091, 1096, 1137), but Jasmine and Veronica countered by focusing on phenols ^(PC1.5:1087, 1089). The latter argument appeared to be persuasive, although Denise continued to struggle, and her difficulties were not completely resolved by this discussion. Having concluded that the OH was not basic, the group moved on to debating whether it was acidic or neutral. Veronica's initial thought was that the OH was a phenol ^(PC1.5:1089), but she immediately changed to classifying it as neutral ^(PC1.5:1092-1094) on the basis that the ring to which it was attached was aliphatic rather than benzene (the appropriate rationale). Her initial suggestion appeared to strike a chord with both Jasmine and Kellie, however, and a wide-ranging exploration of the concept ensued. Ideas which were raised included:

- the possibility that the definition of phenol was different in Chemistry and Pharmacy ^(PC1.5:1098), which was countered by Alicia ^(PC1.5:1101)
- the suggestion that alcohols had not been mentioned in Pharmacy ^(PC1.5:1102), which was countered by a reference to the lecture notes ^(PC1.5:1144)
- the means of recognising benzene rings and differentiating them from 'normal' aliphatic rings ^(PC1.5:1124-1132)
- the idea that there were more acids in pharmacy than in Chemistry: '*I just always thought H plus is acidic*' ^(PC1.5:1165)
- the recognition that some, but not all, OH groups could be basic ^(PC1.5:1163, 1166)

As a result of this discussion, a common conclusion was reached, that although phenols were acidic, the OH in codeine was not a phenol because it was attached to a ring which was not benzene. Engagement in coordinated exploratory discourse had therefore resulted in the co-construction of the appropriate convention, and the repetition of ideas provided greater opportunities for appropriation of the group conclusion.

Denise, however, continued to struggle, and after a short period of reflection returned to her original idea that all OH groups were basic ^(PC1.5:1206, 1209). Rather than reiterating the previous argument and conclusion, Jasmine added an additional argument with which Denise was expected to be familiar, namely that, in Chemistry, OH groups which were alcohols were also weak acids ^(PC1.5:1210). This argument appeared finally to satisfy Denise and when Veronica followed up Jasmine's suggestion ^(PC1.5:1218, 1224), Denise was able to state that '*I've changed my mind again*' ^(PC1.5:1125). She appeared to experience no further difficulties during the workshops, and her interview responses (chapter 6) strongly supported the inference that she had effectively appropriated and retained the concept of phenols as weak acids.

Although group discussion was able to facilitate co-construction of an appropriate concept of phenol, considerable difficulties were experienced in the recognition and interpretation of the characteristics and relevant structural features of functional groups containing nitrogen. In particular, a focus on the presence of lone pairs on a nitrogen channeled discussion in idiosyncratic directions, and ultimately left the PC group without complete resolution of the differences between amines, amides and other nitrogen-based groups.

In the context of the long discussion about whether codeine contained a phenol, the presence of its amine was not recognised and codeine was confidently classified as neither acidic nor basic. Denise's recognition of an amine ^(PC1.5:1183) appeared to point her in a productive direction, but the comment was made while referring to lecture notes, rather than looking at the molecules on her worksheet. No amines were initially detected in lignocaine either, however comparison of the structure with those of her lecture notes led Denise to notice the nitrogen at the right hand end ^(PC1.6:1339), and discussion which followed her comment led to a correct consensus that it was basic ^(PC1.6:1340-1355). No clear rationale, apart from comparison with molecules in lecture notes, was articulated for this consensus, and it appeared that the best explanation that group members could devise involved a reference to lone pairs, although they were not certain if this applied only to Chemistry or to Pharmacy as well ^(PC1.6:1349-1350).

Consideration of diazepam ^(PC1.5:1226) introduced the concept of amides, but did not distinguish between amides and other non-basic nitrogens as activity revolved around comparing diazepam with illustrations in lecture notes rather than explicit discussion of relevant structural features ^(PC1.5:1252-1263). The amide in lignocaine was readily identified, and Veronica articulated the beginnings of a discussion about the identifying criteria with her comment '*that's an amide, because it has double bonds*' ^(PC1.6:1338). Further progress in recognising the structural features was made when Denise asked Jasmine to draw the full structure of phenacetin ^(PC1.6:1371-1382), which provided a clear representation of the amide functional group as a nitrogen attached to a carbonyl. Jasmine followed the drawing of her diagram with an explanation which indicated that the presence of the '*N...next to a C double O*' ^(PC1.6:1387a-1388), rather than the presence of a lone pair ^(PC1.6:1384-1386), was the critical feature of an amide.

Discussion about chloroquine was extensive and exploratory, but rather confused, and although a number of issues were raised, little consensus was reached ^(PC1.6:1391-1471). The major issues were:

- no argument that the nitrogen at the right hand end was an amine ^(PC1.6:1394-1397)
- explanations by Veronica to Jasmine ^(PC1.6:1398-1406, 1417-1425) that the nitrogen attached to the two benzene rings was not basic because of the double bonds in the benzene rings
- a counter argument by Denise that both nitrogens were basic because both had lone pairs ^(PC1.6:1443-1445)
- clarification from Veronica that the relevant double bonds were not between the carbon and nitrogen, but from the carbon (which was attached to the nitrogen by a single bond) to other atoms ^(PC1.6:1452-1469)

Jasmine appeared to grasp the last point, and when seeking clarification from the tutor about how to word her ideas appropriately ^(PC1.6:1518-1523), was able to articulate Veronica's explanation very closely ^(PC1.6:1521), suggesting some level of appropriation of the concept.

The group was happy to conclude that chloroquine was basic ^(PC1.6:1470-1471), but the conflict between double bonds and lone pairs as critical structural features was not resolved, and the concept of sp hybridisation was not yet mentioned. Nevertheless the free exchange of ideas provided abundant resources for transformative internalisation, although the potential for idiosyncrasy was clearly evident.

sp hybridisation was finally raised when the group reached oxazepam ^(PC1.6:1563-1621). Although this molecule was structurally similar to diazepam, the group was now better equipped to recognise that the two non-basic nitrogens were different in nature, a distinction they had been unable to make for diazepam. The amide grouping was identified immediately ^(PC1.6:1563), but when Kellie suggested that the nitrogen double bonded to the carbon was also an amide ^(PC1.6:1564-1565), she was refuted by both Denise and Jasmine because there was no oxygen atom involved ^(PC1.6:1566-1570). This paved the way for the introduction of sp hybridisation ^(PC1.6:1571), and an exploration of the meaning and significance of this feature ^(PC1.6:1577-1590), however the discussion was still confused. Jasmine in particular struggled to grasp the new information, and continued to be confused by the placement of the double bonds ^(PC1.6:1591-1600), suggesting that her previous externalisation ^(PC1.6:1521) had not resulted from complete appropriation. The opportunity to revisit an issue of concern was, however, likely to reinforce the new concepts she was encountering and promote conceptual change.

By this point, therefore, the PC group had raised many ideas and suggestions about the identification and structural characteristics of amine and amides, but little consensus had been reached, and conceptual confusion was clearly evident. They continued with the final molecule, amitriptyline, where they easily identified the amine ^(PC1.6:1605-1606), still without a clear rationale, but continued to struggle with the other nitrogen. In this context, Denise argued for both the lone pair ^(PC1.6:1611-1613) and hybridisation rationales ^(PC1.6:1617-1619), suggesting that she was experiencing, and indeed externalising, the process of conceptual change as she spoke. Finally, the tutor was called, and during her interaction with the group ^(PC1.6:1625-1666), clarified, either by modeling the appropriate discourse herself, or affirming the appropriate discourse of the student:

- the structural features of an amine ^(PC1.6:1639-1641)
- the structural features of an amide ^(PC1.6:1642-1647)

Unfortunately, however, the heart of their difficulties with nitrogens which fitted neither of these categories was not resolved, and they continued to rehearse their previous debate ^(PC1.6:1673-1699) before effectively agreeing to disagree and wait for the following week's feedback ^(PC1.6:1700). Denise continued to display evidence of a change in her conceptual understanding ^(PC1.6:1673-1677), but the lone pair argument was still regarded as an option by Jasmine ^(PC1.6:1674).

A final twist to this debate arose in the last few minutes of the workshop, when Jasmine was copying out a neat version of the sheet to be submitted for feedback. She challenged their previous classification of diazepam as neither acidic nor basic, because she claimed that one of the nitrogens was basic ^(PC1.8:1871-1890), and persuaded the others to change their answers. The group remained uncertain, however ^(PC1.8:1888), but were happy to learn from their answer even if proved incorrect ^(PC1.7:1889).

Evidence from chapter 6 suggests that the discourse surrounding nitrogens in this workshop may have contributed to some extent to persistent conceptual change in relation to identification of different nitrogen-containing groups for all but two of the group members. Jasmine still retained vestiges of the lone pair argument, and Kellie struggled to differentiate amides from other non-basic nitrogens, but the other four experienced little, if any, difficulty.

In summary, coordinated discourse about the nature and identification of phenols resulted in a clear consensus about this functional group, and evidence of appropriation of the concepts surrounding it. In contrast, although extensive discussion occurred about the different types of nitrogen, consensus and conceptual change towards conventional understanding were less apparent. Nevertheless, the breadth of the discourse provided the potential for significant transformative internalisation, which could be channelled towards the conventions with the input of expert modeling by tutors, and some evidence of persistent conceptual development was observed in later interviews with group members.

Classification of molecules with both acidic and basic functional groups

Only dopamine was specifically identified as neither acidic nor basic on the grounds of possessing both types of functional groups ^(PC1.6:1472-1511). The phenols and amines were easily identified by Veronica ^(PC1.6:1473), and after a short debate about the possibility of a molecule containing two phenols ^(PC1.6:1474-1480), consensus was reached about the nature of the groups. However, the group members were uncertain about the relationship between strong bases and weak acids, and offered two possible scenarios:

- Denise suggested that the presence of the strong base overrode the presence of weak acids, resulting in a basic molecule ^(PC1.6:1483-1485)
- Veronica questioned whether two weak acids overrode one strong base, which was refuted by Kellie and Denise ^(PC1.6:1487-1489)

One of the tutors was in close proximity, and her opinion was immediately sought. Jasmine and Alicia had been working silently on the same question, but as the tutor's explanation proceeded ^(PC1.6:1490-1511) all group members quickly began to pay attention. The tutor indicated that the molecule was neither acidic nor basic according to the pharmacy conventions, but her explanation appeared to introduce a confounding aspect when she indicated that '*you don't know if one is stronger than the other*' ^(PC1.6:1508). Although she was clearly responding to the question of which of

the acidic and basic groups was stronger overall, her wording was ambiguous, and tended to validate the students' perception that relative strength was an important determinant of the classification of these molecules. However, while this aspect was subsequently externalised as Jasmine was rewriting the group answers onto the back page^(PC1.8:1901), it did not appear to be the dominant idea^(PC1.8:1898-1907), and the more conventional explanation was later reinforced by the other tutor^(PC2.2:1237).

Evidence from chapter 6 suggests that significant conceptual confusion remained for at least three group members about this concept. Although most were able to recognise that the presence of both types of group rendered a molecule neither acidic nor basic, only two were able to provide the conventional reasoning for their classification.

Dissociation of acids, bases and molecules with both types of functional group

The PC group discussed this concept in two major episodes, one in each of workshops 1 and 2. During the first workshop, only four students remained, because Isabelle was absent and Denise had left early for paid work, however all six students were present during the second workshop.

The initial attempt at drawing the dissociation equilibria during the first workshop proceeded relatively logically, although not always accurately. Jasmine continued in her role as scribe, while Kellie and Veronica provided most of the spoken input and Alicia was generally content to watch, with occasional comment.

The dissociation of ibuprofen was carried out rapidly and accurately^(PC1.7:1719-1734), with the major topic of discussion whether it was acceptable to abbreviate the molecular structure. The equilibrium for lignocaine was completed with similar ease, however the group incorrectly added the proton to the right hand side rather than the left, thus the equilibrium represented an association rather than a dissociation^(PC1.7:1735-1764).

More time was spent on amoxicillin^(PC1.7:1766-1848), but the students continued to work methodically, with Jasmine and Kellie recognising that the presence of three functional groups necessitated three steps in the dissociation process^(PC1.7:1768), and Veronica that they needed to begin with all protons attached^(PC1.7:1784). As the exchange proceeded, each student focused on completing her own worksheet, thus eye contact was minimal, however the discussion itself was coordinated and constructive. The most significant issues were canvassed, including:

- the need to commence with the lowest pKa and work to the highest
- the concept that each step involved the entire molecule, rather than only one functional group
- the fact that dissociations were cumulative^(PC1.7:1816-1823)

Through their discourse, the group members reached consensus on each aspect, and achieved the correct structures, with the exception that they repeated their earlier error in relation to the dissociation of amines. On receiving their corrected sheet the following week, however, they recognised their mistake ^(PC2.2:1010, 1024), and incorporated the correction into their subsequent work.

During the second workshop, the PC group spent more than twenty minutes discussing the state of ionisation of five molecules at specific pH values ^(PC2.2), and while considerable confusion in their thinking was revealed by their discussion, the extent of engagement and the modeling of pharmacy conventions by the tutors eventually allowed each participant to transform her understanding of a number of central concepts. The most significant concepts explored were those of ‘protonation’ and ‘ionisation’, with emphasis on the latter.

The episode involved all six students, however the discourse was considerably less coordinated than any other recorded for this group. Initially the lack of coordination arose because subgroups within the PC were working on different molecules (naproxen and lignocaine), however later discourse was complicated by individuals revisiting earlier aspects of the debate. Rather than following the convolutions of the discourse chronologically, the rest of this section traces developments in the two key concepts of protonation and ionisation.

The meaning of protonation

Convention: A molecule is protonated if it is an acid or conjugate acid of a base, and contains a proton which can be lost in the dissociation equilibrium.

Although less discussion focused on this concept than on ionisation, the roots of significant conceptual confusion were evident in the short interchange around protonation ^(PC2.2:1032-1049). This term had already been used by both Veronica and Denise ^(PC2.2:1024, 1025, 1031), but Alicia opened discussion on its meaning by suggesting that it was equivalent to ‘basic’ ^(PC2.2:1032). Although Veronica agreed with her, a range of additional ideas were articulated as possibilities, with Kellie offering either that it meant simply containing a proton ^(PC2.2:1035), or having gained a proton ^(PC2.2:1037), and Jasmine agreeing with the latter that protonation implied addition of a proton ^(PC2.2:1046), and moreover that the proton brought a positive charge ^(PC2.2:1049). Unusually for this group, this multiplicity of ideas was not further discussed, although the subsequent discussion of ionisation may have clarified some of the confusion.

The meaning of ionisation

Convention: The process of ionisation means the formation of ionic species, that is those species which contain at least one charge, either positive or negative.

When Kellie asked for a definition of ionisation ^(PC2.2:1055), she received conflicting responses from Veronica – that it meant having lost a proton ^(PC2.2:1056) – and Jasmine – that it meant having gained a proton ^(PC2.2:1060). At least some of the confusion about this concept can be explained by the fact that some members of the group were considering naproxen and others lignocaine, but the lack of understanding was clearly more fundamental. Denise indicated that ionisation meant going ‘*into the different ions*’ ^(PC2.2:1057), which was an appropriate explanation of the process, but her later comments suggested that she had conflated the process of ionisation with the state of ionisation. With respect to the former, she articulated her Chemistry understanding that when ‘*it’s ionising, it’s going to the ions*’ ^(PC2.2:1188), and she focused on the fact that the products of an acid dissociation in Pharmacy always involved the production of an hydrogen ion ^(PC2.2:1202). However she failed to recognise that the state of ionisation referred only to the acidic or basic molecule, and that this molecule could be ionised or unionised after it had lost its proton. As a consequence, she conflated the concept of ‘ionised’ with that of ‘protonated’, and attempted to persuade the others in her group to adopt her interpretation. Some of the others were not convinced, however, and Jasmine in particular indicated that she was ‘*really worried about this now*’ ^(PC2.2:1080) as it seemed not to make sense. She sought an explanation about lignocaine from Denise ^(PC2.2:1183-1206), where the opposing views were most clearly stated. Jasmine suggested that presence of the NH^+ conferred a state of ionisation ^(PC2.2:1200), but Denise confidently stated that ‘*that’s [NH⁺] un-ionised, cos it’s still attached. When it ionises, it breaks up into like, H plus and then the other thing*’ ^(PC2.2:1202). All members of the group apart from Isabelle were closely listening to this exchange.

The serendipitous arrival of the tutor to change the audiotapes permitted a first opportunity to resolve the confusion, but the tutor was clearly not aware of the fundamental discrepancy between the students’ perceptions of the meaning of ‘ionised’. As a consequence, her explanation of the dissociation of naproxen ^(PC2.2:1085-1120) addressed only part of their problem. All students participated in the interaction with the tutor, and their subsequent externalisations ^(PC2.2:1125-1129, 1154-1159, 1248-1257, 1349-1353) suggested that the exchange had clarified the process of dissociation, and the conventional way of comparing pH and pKa to ascertain the form of the molecule which predominated at specific pH values. However it was not until two later interactions with the tutors that the difficulties with ionised and unionised forms were resolved.

The first of these interactions occurred in response to a question from Isabelle about the corrected dissociation of amoxicillin on the previous week’s submission. Although the exchange began only between Isabelle and the tutor, Denise and the others gradually engaged with the discussion. The critical moment in the discourse occurred when the tutor explained that ‘*as soon as you’ve got one charge on a molecule, that makes it ionised*’ ^(PC2.2:1227), thus making the explicit, but until then missing, link between charge and ionisation of the molecule. This comment clearly sparked the emergence of changed understanding as evident in the students’ tentative comments both in the presence and absence of the tutor ^(PC2.2:1242-1309). Isabelle was the first to articulate her ideas ^(PC2.2:1251, 1255) in the context of ticarcillin, but Veronica subsequently returned to lignocaine and was now able to express the correct answer ^(PC2.2:1290). Jasmine remained confused and asked Denise for assistance

(PC2.2:1265), thus providing Denise with opportunities to externalise the changes in her understanding (PC2.2:1266, 1309) and to rehearse these ideas within ongoing discourse (PC2.2:1266-1309). Kellie and Alicia appeared to accept the tutor's explanation, but Jasmine wanted additional confirmation and called the other tutor (PC2.2:1317). The group's second interaction with a tutor about states of ionisation served to reinforce the concepts introduced in the first interaction (PC2.2:1319-1333), however the tutor became momentarily confused (PC2.2:1328), and to clarify the situation led the group through an externalisation of the logical process she used to determine the state of ionisation of a molecule at any pH (PC2.2:1347-1354). This explanation served not only to resolve the lingering confusion about lignocaine, but also provided clear modeling of the reasoning underlying the approach to solving the problem.

That group members retained these transformed concepts for at least a week was evidenced by a short exchange in the third workshop (episode PC3.1). In the latter, while discussing the effect of pH on the partition coefficient of ibuprofen, Veronica, Denise and Kellie discussed the state of ionisation at pH 2, and decided that it was unionised because the pH was lower than the pKa and the drug itself was an acid. Supporting evidence of the long term persistence of this transformation is found in their interviews in chapter 6.

In summary, the discourse in which members of the PC group engaged while attempting to solve problems relating to functional groups and their dissociation contained many features likely to promote effective appropriation of the concepts under consideration. For the majority of the time, discourse was coordinated and constructive, as the participants tended to work simultaneously on the same problem. An exception occurred when the group was working on the state of ionisation at specific pH values, because of the conceptual confusion surrounding critical terms, but once the confusion had been resolved, coordinated discourse returned. Participants were willing to engage in extended exchange of ideas before consulting the tutors, and often rehearsed the explanations modeled by the tutors in later discourse. Importantly, the ideas of all members of the group were accorded equal status, and all were considered able to provide useful input into the discussion. As a consequence, the learning environment created by the discourse of this group proved to be a fertile ground for transformative internalisation and externalisation, and co-construction of new conceptual understanding.

7.3 The relational space – interactions and group dynamics

As outlined in chapter 3, conceptual change is expected to be promoted by the presence of 'progressive discourse' (Wells, 1998, p. 8), which is characterised by a common commitment among all participants to engage in discussions which work towards a satisfactory joint understanding, are based on an examination of evidence, expand the range of propositions, permit critical analysis of beliefs, and build on previous speaking turns. Inherent in progressive discourse is the creation of a collaborative culture, and the development of intersubjectivity, or shared thinking (Rogoff, 1998), whereby joint understanding of the task and its goals among the

participants creates a common ground for initiating co-construction of a solution, and participants enter into each other's frame of reference (Tudge & Rogoff, 1989). Other types of discourse, which are characterised by less collaboration and different aims and goals among the participants, are less likely to promote conceptual change. In this context, the discourse encompasses not only what is actually uttered by the participants, but the interpersonal relationships and interactions in which the utterances are embedded.

This section explores the nature of this discourse by focusing on the culture which was created and revealed in the workshop setting, in particular exploring the extent to which discourse was progressive or otherwise, and the development of intersubjectivity. For each group, the interpersonal plane (Rogoff, 1998) is described and analysed under five headings:

- participation in discursive interactions
- interpersonal behaviours
- group culture
- intersubjectivity
- roles of the tutors

It is important to note that a comprehensive analysis of the workshop discourse is impossible, since a total of 386 minutes of workshop activity was recorded. The intent in this section is not to analyse individual turns in detail, but in general to use conversations and interchanges as the units of analysis, with the aim of illustrating characteristic patterns of interaction and discourse for each group, and thus identifying the major affordances and constraints to conceptual change learning. The omission of a particular type of interaction does not imply that it was never observed, but rather that it was not a distinguishing characteristic of the group's behaviour.

The latter half of the section complements the discursive analysis by focusing on the interpersonal and social relationships which existed and developed within each of the two groups. Data from the student interviews were examined to reveal each individual's perspective on the functioning of his or her group¹⁹.

¹⁹ In this section reference is made to the episodes outlined in previous sections, however additional material is sourced from other parts of the workshop discourse. In the case of the latter, not all of the actual discourse is included in Appendix I or the text. In addition, some of the discourse is from exercises and activities only peripherally related to acids and bases. They are included as evidence of the existence of particular types of interactions within the groups, and because the whole context of the workshops is important in setting the culture.

Transient change group

Participation in discursive interactions

The most common type of discursive interaction was dyadic, with two individuals either working on the same problem, or engaging in conversation. Triadic and tetradic interactions also occurred, but with lower frequency, and usually involved either disagreement or off-task activity. Tacit participation, involving an individual watching and listening, but not contributing verbally, was also evident.

Dyadic interactions

Dyadic peer tutoring, exploratory talk, unchallenged agreement and unresolved debate were commonly observed. Occasionally the dyad expanded momentarily to include a third and possibly fourth member, but the nature of the conversation was essentially dyadic. Tacit participation also coincided with dyadic conversation on occasion.

Dyadic peer tutoring

Dyadic peer tutoring was characterised by the provision of information by one student to another without significant discussion or joint construction of an answer. The term 'peer tutoring' is used in a broad sense to include both examples of one student providing 'expert' didactic assistance to another, and examples of assistance given in response to an initiating question.

The peer expert

The expert role was usually filled by Janine, either by appropriating the role for herself or being granted it by the other students, and Larry was usually the recipient of her tutoring. In workshop 1, Larry was unable to calculate correctly even after several attempts.

- Larry I still get the wrong answer
 Janine Woops! Can I have a look?
 Janine Did you change it into moles already?
 Larry Yep
 Janine Um, OK, right, looks that, you've got them wrong like all you're doing is that OK
 Janine So, your twenty three over three oh eight? So, three oh eight?
 Larry Yup
 Janine Yep? Right so you've ??? got all that done. Two point eight eight, minus two, never mind my maths
 Larry But it's in milligrams though
 Janine That should be ten to the minus three not minus six
 Larry It's milligrams
 Janine No, milligrams per mil is the same as grams per litre
 Larry Oh, OK, grams per litre!
 Janine Yep
 Larry There you go. It's all good ^(TC1.115-129)

Larry's self-directed comment that he had still been unsuccessful triggered a response from Janine who offered her expertise, since she had successfully completed the question and was confident of her ability to solve the problem. Interestingly Larry did not *ask* for assistance – possibly because he did not wish to lose face by appearing to be helpless – but he was happy to accept Janine's direction and correction of his error. Janine was also quite forthright in offering assistance which reinforced her expert status in the eyes of the others.

Janine again assumed the role of self-designated expert to ensure that the back page which was submitted by the group for formative assessment was 'correct' according to her understanding and standards. As a consequence, she appropriated it from Larry, who had completed it, and compared his answers with the ones she generated (TC1.6:1087-1095; TC1.7:1128-1143, Janine/Larry only). While checking, Janine's comments were all self-directed, and Larry was at the time engaged in off task activity with Lucy and Geoffrey.

Janine's expertise was not challenged by Larry at any point, and Lucy and Geoffrey were willing to add their names to the work done by Janine and Larry. Janine's self-image as expert and authority was demonstrated in her comment above that '*I knew I needed to check yours*' (TC1.7:1139).

Janine's authority was not merely self-designated however, as the other students deferred to her on several occasions. For example, Larry and Geoffrey sought Janine's assistance in relation to the definition of a parameter, and accepted her word without seeking to confirm from another authority (lecture notes or tutor):

Larry The solubility product constant K, or is it Q? Q
 Geoffrey Q? No. I don't know, ask Janine
 Larry Which one's the solubility product constant, is that Q or?
 Janine K
 Larry K. Ksp?
 Janine Ksp
 Larry Ksp (TC1.138-144)

Although Janine was usually the most capable member of the group in solving problems, she was not always correct, and when she assumed the role of peer expert under this circumstance, she had the potential to convince the others to replicate her error.

Janine I don't know why you're working with K_1 and K_2 when we're working with solubilities, you're calculating with solubilities.
 Larry Sorry?
 Janine You're working with the wrong equation. You're supposed to be working with S_2 and S_1 . Same thing but if you're using the totally wrong variable you'll probably get it wrong. It's not K_2 , K_2 is the equilibrium constant, we're talking about solubilities
 Larry OK, so I just put it there
 Janine S_1 and S_2 . Same with that question (TC1.199-203)

Janine's assured tone of voice and confident use of language appeared to convince Larry and he wrote on his worksheet as Janine suggested. In fact, Janine's choice of equation was still inappropriate and her tutoring did not bear fruit either for herself or for Larry. Eventually they were forced to seek assistance from the tutor.

Answering a question

A number of peer tutoring episodes were initiated by a direct question. Early in workshop 1 Lucy sought assistance from Larry:

- Lucy How do you do this one? K_1 ?
 Larry What?
 Lucy How do you get K_1 ?
 Lucy How did you get that number?
 Larry It's wrong. Number of moles equals mass over molecular mass. The amount says two point oh eight
 Lucy Yeah
 Larry Milligrams, divided by that
 Lucy Oh, OK
 Larry So you get number of moles (TC1.102-110)

Interestingly she had to ask three times and point to his worksheet before Larry replied, suggesting that his assistance was somewhat grudging. He finished what he was writing before looking at her worksheet and pointing to information which he perceived as useful on her worksheet. Larry's brief explanation appeared to satisfy her immediate dilemma and she proceeded to write purposefully. It was not clear that she understood why Larry carried out the calculation, however, and intersubjectivity cannot be inferred.

Not all such episodes involved grudging assistance however. Later in workshop 1 Larry was more accommodating of Lucy's request for assistance, possibly because he appeared to be confident of his approach to solving the problem, and he assisted her in a peer tutoring interaction which subsequently expanded to include both Janine and Geoffrey.

- Lucy Hon, what you get for the first bit?
 Larry Which bit?
 Lucy That bit
 Larry Well you know that weight per volume is grams in a hundred mils, so there's that many grams in a hundred mils
 Lucy Right. So you work out, so that's the number of, so you just work out the amount in moles?
 Larry Yep.
 Larry That's in a hundred mils and you want it in a litre don't you?
 Lucy Oh, OK
 Larry You have to convert it to litres, Geoff?
 Janine Yeah, you do
 Geoffrey Yeah
 Larry So you just times it or you divide by ten
 Janine Divide by point 1, which is the same as timesing by ten (TC1.165-177)

Peer tutoring exhibited some characteristics of progressive discourse in that it was apparently intended that all participants reach a common understanding, and each turn built on previous turns, however it was rarely characterised by critical analysis of a range of options. Since one person usually provided the answer, co-construction of understanding was therefore limited.

Exploratory talk

On occasion, none of the students was able to solve a particular problem, and discussion involved an attempt to explore where they had erred. After a sustained period of largely individual activity, it became clear that none of the group was able to solve a calculation exercise individually. Janine appeared not to want to be the first to acknowledge that she was stumped, but admitted it when she was asked by Larry.

- Larry What did you get?
 Janine The wrong answer
 Larry What? Two point four six times ten to the negative five? That's what I keep getting!
 Janine Yeah, that's fine if maybe they ask us for the K_{sp} which is just this squared, but then, it's not right
 Larry Five point nine eight
 Janine Yeah. And the answer's, the answer's two point five three times ten to the minus ten. Coz you know why K_{sp} is K squared, it's sp
 Larry Yeah. Because you do that little equation thingy and it's
 Janine Yeah. So why, um?
 Lucy Ask Erica.
 Janine Geoffrey, did you get the right answer?
 Geoffrey Um, I'm still doing it ^(TC1.188-198)

This interchange focused on the failure of Janine and Larry to achieve the correct answer to a numerical problem as printed on the worksheet. Lucy was a tacit participant and Geoffrey remained outside until he was addressed directly. Janine and Larry briefly explored the relationship between different equations, but were unable to diagnose their errors through their dialogue. Lucy's suggestion to ask for assistance was initially ignored, but Janine subsequently picked it up later in the episode and the tutor was summoned.

A second example of exploratory talk occurred when Larry and Lucy attempted to find a way to solve a later calculation problem. As they appeared unable to resolve their difficulties, Janine interjected towards the end as Larry dismissed Lucy's contributions to the exploration:

- Larry Here we go
 Larry No, van't Hoff isochore
 Lucy Yeah but it still might work. Pull it out
 Larry No it doesn't work.
 Larry Does this, does delta G, no it's delta H. But can you work out delta H from delta G?
 There's not enough room anyway
 Lucy Use delta G first
 Larry OK

- Lucy Here's a delta G for dissolution compared to water. That
- Lucy Well, then, if. Don't you have to work out the solubility of that? Isn't that what we did on the back here? Here we go, yeah I told you, use this one
- Lucy Actually, maybe you don't
- Larry I don't?
- Lucy No, look, here,
- Lucy therefore the solubility of caffeine at twenty five degrees is that, you CAN do it. Solubility. Gsol
- Larry We don't have enough information
- Lucy We don't? Well, we've got T,
- Janine I don't know how to show you what we have to do
- Lucy we've got G
- Larry With this stuff?
- Janine Yes, yes
- Larry I don't think we have enough information
- Lucy Yeah, we've got G we've got R we've got T (TC1.304-327)

Larry and Lucy were willing to explore the possibilities for solving the problem, but their efforts were poorly coordinated and ultimately unfruitful. Larry tended to hold Lucy's opinions and suggestions in low regard, and in this case when she displayed hesitancy (*Actually maybe you don't*), he sought a more valued opinion, that of Janine. Somewhat ironically, Lucy was the only one on the right track and it would have been interesting to see if the students could have solved the problem by following up on her suggestions. Unfortunately, her insights were never revisited. What actually followed was a period where Janine dominated the discussion, apparently explaining to Larry and then Lucy, but probably articulating her thinking for her own benefit.

Thus, although it had the potential to be progressive, ultimately most of the exploratory talk was poorly productive, as the students' status relationships interfered with effective collaboration and resulted in asymmetrical interactions. Intersubjectivity may have been evident on occasion, but it rarely produced a ZPD (chapter 8).

Unchallenged agreement

A number of exchanges served to confirm students' ideas and understanding through concurrence of utterances. The externalisations of one student accorded with the understanding of the other, and frequently the second student repeated part of the original externalisation. This type of interaction differed from peer tutoring in that it was more symmetrical, with both participants contributing to the discussion, and one not being perceived as the authority. This concurrence was able to consolidate new understanding or reinforce prior knowledge, or perpetuate misconceptions or errors. The key characteristic was that the ideas expressed by one participant were not challenged by the other. Whether this was productive or counterproductive depended on the extent to which the original ideas were appropriate within the context.

Consolidation of new understanding through unchallenged agreement occurred as Janine, Larry and Geoffrey discussed the identification of phenacetin, ibuprofen and lignocaine (TC1.4:855-865). All three

students had worked independently to achieve the answers that they now shared, and the discussion served to confirm that each was correct in their identification of the molecule as a whole (it was not possible to identify whether they had correctly assigned the acidic group in ibuprofen and the basic group in lignocaine). The ability to classify these molecules was new since it involved application of concepts appropriate to the Pharmacy context, and this brief interchange suggested that the three students had appropriated these concepts sufficiently to enable them to solve this type of problem.

The latter conclusion is supported by a later exchange between Janine and Larry. While Geoffrey and Lucy were engaged in an arm wrestle and Chinese handcuff, Larry and Janine worked steadily through the rest of the structures with minimal discussion and little eye contact ^(TC1.4:978-987, Janine/Larry only).

<p>Janine Acid, yeah?</p> <p>Larry That one's nothing is it?</p> <p>Janine Which one?</p> <p>Janine Yeah, it's neither</p> <p>Larry Err. That one is</p> <p>Larry Are the carbons in a benzene ring sp^3 hybridised? No?</p> <p>Janine Sorry?</p> <p>Larry Are the carbons in the ...</p> <p>Janine No, they're not, because of the double bond. It's sp^2 hybridised. Anyway, it's the double bond</p>	<p>This comment refers to cefoxitin.</p> <p>These comments relate to oxazepam.</p> <p>These comments relate to amitriptyline.</p>
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It might be argued that some degree of progressive discourse was present in this disjointed exchange, however this was countered by the presence of long pauses between comments and the lack of evidence of the joint construction of solutions or concepts.

Prior knowledge was reinforced in a discussion between Lucy and Geoffrey about the physical characteristics of acids and bases ^(TC1.3). This exchange was detrimental to conceptual change learning about acids and bases, since it reinforced concepts which were relevant to the Chemistry context rather than to Pharmacy. Indeed Lucy's final comment ^(TC1.3:750) indicated that she had not developed significant contextual discrimination, since she believed that memory of these physical characteristics would be helpful for her performance in the second study interview. Further, in Geoffrey's case, these physical characteristics remained dominant in his conceptual understanding throughout the study, and in the final interview (chapter 6) he continued to externalise these features as characteristic of acids and bases.

Perpetuation of error occurred when Janine and Larry were working on identifying acidic and basic structures on the back page. While considering codeine they identified two groups, one as a phenol and one as an amine, and then reflected upon the three groups which were of relevance in the topic

overall (TC1.4:756-774). Larry agreed with Janine's incorrect assignment of the OH as a phenol without argument or challenge.

Again, although some aspects of progressive discourse were apparent, the failure to challenge prior beliefs or to consider alternative options limited the potential for co-construction of concepts and thus constrained conceptual change.

Unresolved debate

On occasion, the students began a discussion which had the potential to become productive through debate about the concepts involved. Usually this failed to occur as a consensus was not reached and the potentially fruitful debate concluded without resolution of the differing opinions.

In episode TC1.2, all four students briefly considered the activity which asked the students to "Discuss among your group the differences between the definitions of 'acid' and 'base' between Chemistry and Pharmacy." This is one of the key conceptual areas of the topic, and the activity was designed to encourage students to externalise their understanding in order to help clarify their ideas for themselves as well as to provide input for internalisation by the others in the group. Only two ideas were expressed in this interchange, the first by Larry (TC1.2:690), and the second by Janine (TC1.2:697, 699). Janine's suggestion was challenged by both Larry and Geoffrey as being the same in both Pharmacy and Chemistry (which it is) but she was adamant that it was not the same and retreated from the discussion to consult the authority of her lecture notes. At no stage in the remainder of the workshop did she defend her statement, although she located some material which seemed to back her up. In fact, a thorough reading of her notes would have confirmed the assertion made by Larry and Geoffrey, but if she found this, she did not externalise it during the workshop.

Geoffrey's support of Larry appeared to be based on understanding gained prior to the workshop and he was strong in his affirmation: 'I said it's true' (TC1.2:706), but Lucy appeared to be out of her depth and her contribution was limited to suggesting that they write down what Janine had said. This is consistent with her stated method of writing things down in the workshop and trying to understand them later.

The potential existed in this exchange to delve below the superficial and to grapple with the ideas which were in contention, however there was no apparent will amongst the group members to engage further with the topic once Janine had stated her disagreement with Larry and Geoffrey. The presence of different perspectives was potentially an effective stimulus to learning, but in this case the difference of opinion was left unresolved and an opportunity for learning was abandoned after only 24 seconds of discussion. Perhaps the fact that there was no obvious "problem" to solve devalued the activity in the estimation of the group members, particularly Janine and Larry. Interestingly (and unfortunately), at no stage did the group or any individual member appear to

focus on the actual topic of the question, namely the differences between Chemistry and Pharmacy. Little evidence of progressive discourse was apparent in these types of interactions.

Triadic and tetradic interactions

Interactions involving more than two participants tended to involve argument. As previously described, in episode TC1.4 (TC1.4:815-834), Janine and Larry disagreed about the classification of codeine, and Lucy and Geoffrey were drawn into the argument as they each supported one protagonist. They argued again about the nature of phenol groups, and the consequences for the classification of dopamine (TC1.6:1101-1126). Dopamine had previously been discussed by Janine and Larry, and they had come to the correct conclusion that it was neither acidic nor basic because it contained both types of functional groups, however Geoffrey and Lucy challenged their assertions. Both of these arguments became somewhat heated, as the irritation of at least one group member was clearly evident on each occasion. In the first instance Janine was derisive about Larry's assertion, which was subsequently confirmed by the tutor as correct. In the second instance, Larry became annoyed with the argument, and his comments were spoken in a particularly irritated tone of voice. Janine also responded in a superior tone, since she and Larry had agreed both on their answers and on the reasoning. Lucy and Geoffrey, on the other hand, had not been involved in discussion with either Larry or Janine about this concept, and had developed idiosyncratic and contradictory ideas.

Tacit participation

Tacit participation often coincided with other types of interactions. Lucy was the most regular tacit participant, frequently observing and listening to what was occurring but contributing little verbal input. Since she was naturally talkative and put in comments when she could, Lucy's tacit participation was generally a consequence of uncertainty or poor comprehension of the discussion. However, her tacit participation was not always a sign of lack of understanding. In an episode involving an extended one-on-one interaction between Larry and the tutor about algebraic rearrangement, Lucy was silent but active, appearing to follow the verbalised reasoning, and writing animatedly on her worksheet.

Lucy was also a tacit participant in the exploratory discussion between Larry and Janine about their inability to solve an exercise in workshop 1, and her participation led her to make the suggestion to consult a tutor since she could see that no solution was likely.

- | | |
|--------|--|
| Larry | What did you get? |
| Janine | The wrong answer |
| Larry | What? Two point four six times ten to the negative five? That's what I keep getting! |
| Janine | Yeah, that's fine if maybe they ask us for the K_{sp} which is just this squared, but then, it's not right |
| Larry | Five point nine eight |

- Janine Yeah. And the answer's, the answer's two point five three times ten to the minus ten. Coz you know why Ksp is K squared, it's sp
- Larry Yeah. Because you do that little equation thingy and it's
- Janine Yeah. So why, um?
- Lucy Ask Erica^(TC1.188-196)

In summary, the styles of participation in discursive interactions among the TC group rarely met the conditions for progressive discourse which promoted conceptual change. Elements such as turns which followed in logical sequence were frequently present, but there was little evidence of evaluation of more than one alternative, or a real commitment on the part of all participants to seek joint understanding. The discourse involved the provision of explanations, rather than exploration, and at best, the discourse could be described as coordinated rather than collaborative. However, many of the interactions were not able to be described even as coordinated, since the speaking turns of the participants tended to reflect their focus on individual work.

Interpersonal behaviours

Apart from peer tutoring interactions, the behaviours exhibited by the TC group within workshop can be classified as primarily self-focused or off-task. Even the exploratory discursive interactions described in the previous section were only partially other person focused, since in most cases at least some of the participants were interested mainly in developing their own understanding.

Janine, Larry and Geoffrey all displayed self-focused behaviours, although to different extents and in a variety of ways. Lucy was considerably less self-focused, and was the most willing to engage in interactions with the others, however she was also the most likely to engage in off-task behaviours.

Self-focused behaviours

Five types of self-focused behaviours were apparent in the TC groups' interactions: brusque responses, early disengagement from interactions, ignoring others, working alone and unwillingness to share.

Brusque responses

On numerous occasions, a request for assistance was met with a response which suggested that the request was an unwelcome interruption. Frequently Lucy was brushed off with a brusque answer which rarely met her needs. For example, after spending some time looking at her work, Lucy broke a ninety-second silence with a question, but the responses she received from Geoffrey and then Larry were brief, and they seemed reluctant to interrupt their trains of thought.

- Lucy Is this the same thing?
- Geoffrey Um, I'm not sure yet
- Larry Yeah, it is

- Lucy Same for everyone else?
 Larry Yeah. (To Geoffrey) What's Ag weigh? Hundred and seven point eight,...thirty five point three five I think. Thirty five point four five. Oh, hang on (TC1.154-158)

Lucy was clearly seeking significant assistance but the others were dismissive of her questions. Geoffrey did not look up at all, and Larry looked only briefly at Lucy's worksheet as he replied, before seeking information about the molecular weight of silver chloride from Geoffrey.

Lucy was not, however, the only recipient of brusque and essentially unhelpful responses. When Larry was struggling with algebra, he sought assistance from Janine.

- Larry So that's the negative log
 Janine No, pKa is the negative log of Ka. When they give log of that, that weird looking thing is the negative log of that
 Larry The negative what?
 Janine Um, oh, OK. Just hold on. (to herself) (TC1.403-406)

Janine did initially respond, but once she made one comment she was not willing to continue conversation with Larry as she preferred to return to her own work.

Ignoring the other

During workshop 1, all four students were attempting exercise 2, but initially no assistance was provided in response to questions posed by two of them in sequential turns.

- Geoffrey Does that mean you do logarithms both sides of the equation?
 Janine Can you take the negative logarithm of that? What happens to that? I don't know. Oh. No, I still don't know (TC1.372-373)

Both questions invited responses, but none were forthcoming. Geoffrey and Janine were further advanced in this multi-part question than Larry and Lucy, which might explain the latter pair's lack of response, but Geoffrey and Janine were working on the same part.

In episode TC1.4, Lucy made several unsuccessful attempts to interpose herself into the interactions between Janine and Larry about the completion of the back page. She was struggling with the material but offered to be the scribe, and on occasion attempted to introduce a new line of conversation, albeit not always seriously. On each occasion she was ignored completely or was treated with indifference:

First attempt

- Janine Well, that's a phenol group, hold on. So what's the? OK
 Larry Phenol?
 Janine There's only two acids and a base that we have to know anyway.
 Lucy Can I do it on mine?

Larry Yeah
 Janine The acid is the phenol and the base is that, um, amine group, right?
 Lucy Yep
 Janine Which has to be sp^3 , right?
 Larry Yep
 Lucy Yep
 Janine And the um
 Larry Car..box..ylic acid
 Janine phenol, oh, and the carboxylic acid
 Lucy carboxylic acid yeah? Is that the strong one?
 Janine Oh, all right. I'll just go have a look. Um,
 Larry The first one, the OH ^(TC1.4:756-771)

Lucy's offer to fill in the answers on her sheet was met with an offhand response from Larry, but both he and Janine continued working on their own sheets, effectively dismissing Lucy's offer. Lucy's attempt to contribute her ideas about the carboxylic acid group was completely ignored as Janine continued to speak only to Larry.

Second attempt

Janine This is an acid
 Geoffrey Oh. It's connected to that carbon there
 Janine and that's nothing. OK what else have we got
 Geoffrey But it's next to an O.
 Janine This one's, one two, three, this one's a base
 Lucy The leg bone's connected to the (laughs)
 Janine Yep?
 Lucy shoulder bone
 Larry The carbon's not an sp^3 hybridised carbon
 Lucy I'm going insane. I've had too many hours of uni today
 Janine Is it only supposed to be connected to a carbon which is sp^3 hybridised? I'll check that
 Larry Yeah
 Lucy I think, Larry, we should change the number of hours for first years. Or maybe second years.
 Larry N is attached to only H or sp^3 hybridised carbons ^(TC1.4:774-788)

Again, all of Lucy's attempts to break into the conversation were ignored. She initially tried humour, picking up on the concept of connection, but when that failed she changed the topic to the perceived excessive workload they were all experiencing. Even this attempt at mutual commiseration did not gain her entry into the interaction.

Third attempt

Larry So I think there's none of them
 Janine Yeah. This isn't it. OK
 Lucy This one? Are you sure that's the right one?
 Janine So there's none.
 Lucy What's that, the base?
 Janine None

Lucy Babe, you have to do it in pink pen.
 Larry No.
 Janine We have to give reasons ^(TC1.4:796-804)

Lucy's questions were addressed to Geoffrey who ignored her, and her comment to Larry who also ignored her as he responded to Janine. Lucy made further occasional attempts to re-enter the discussion as it proceeded, but she became discouraged by the continual rebuffs, and her attempts eventually petered out.

Disengaging early

This behaviour frequently occurred when an explanation was being given, usually by the tutor, and one or more students disengaged from the interaction before the end of the explanation in order to pursue his or her own activity. Commonly it was Janine who displayed this behaviour. Janine clearly grasped ideas more quickly than the others on most occasions, and when she had heard what she thought she needed for herself, she 'wasted' no time in applying it. On occasion she disengaged from an interaction which was one-on-one, leaving the tutor explaining to nobody in particular. Sometimes other members of the group joined the interaction, but this did not always occur.

In workshop 1, Janine was struggling with the different ways of using a particular equation and was confused when a method which had been successful for one problem was unsuccessful in one which she perceived to be similar. She engaged in a one-on-one interaction with the tutor, who began to explain the reasoning.

Janine So we're supposed to be working with K_{sp} and not S .
 Tutor Yeah
 Janine But then, why can you work with S up here and you can't work with S down here.
 Tutor The difference is that one's nonionisable, so it doesn't form ions, and that one, um, forms ions, silver chloride forms ions in solution
 Janine All right
 Tutor So the difference is what the, what form the equilibrium constant takes. In the top one, the equilibrium constant is just equal to solubility. In the bottom one, solubility is not the equilibrium constant. The van't Hoff isochore is always about equilibrium constant, so you've gotta try and work out in each situation what the equilibrium constant is ^(TC1.245-250)

Janine disengaged partway through the tutor's final explanation in order to correct her answer and solve the problem correctly – which she achieved. Disengagement from an interaction in order to pursue one's own work is not necessarily unproductive, although it may be considered more polite to listen until the speaker finishes. However here Janine's failure to focus on the whole of the explanation resulted in an inability to transfer her reasoning to a subsequent problem. She used enough of the explanation to finish the task at hand but did not seek to understand the underlying principle. She was satisfied with associating the state of ionisation with using either S or K_{sp} in the equation, without making the connection that both were equilibrium constants. When she came to a near transfer problem, where the state of ionisation was not explicit, she again struggled:

- Janine But you don't have all that information? Like for this one?
 Tutor No but you don't need to.
 Janine So you can put that, like K_{sp} into that equation?
 Tutor Yeah.
 Janine Yeah, I didn't realise that.
 Tutor Equilibrium constants, whatever the equilibrium constant happens to be, can go into those equations.
 Janine OK
 Tutor Yeah, so that's right. I mean what you calculated there is K_{sp} , but I've asked you for solubility
 Tutor So K_{sp} for a salt like that, what would it be as a function of solubility?
 Janine S^2
 Tutor S^2 , yep. So solubility then is, like you've done there, the square root of K_{sp} . So it's the same principle again, if you've got a salt form, if it ionises, then the equilibrium constant that you're dealing with is K_{sp} , um, and that's usually, it's gonna be solubility squared ^(TC1.456-470)

Janine's admission that she did not realise the significance of equilibrium constants confirmed that she had not listened to the tutor's previous explanation. As the unifying concept of equilibrium constants was repeated, Janine appeared to grasp the idea, however she repeated her previous behaviour by disengaging from the final explanation of this exchange also.

Geoffrey also disengaged from a one-on-one conversation with the tutor, although he did it explicitly by interrupting the tutor's utterance and bringing it to a premature conclusion:

- Geoffrey Erica?
 Geoffrey You know how we're taking the square root, if it's salt
 Tutor Yeah
 Geoffrey Say if it's sodium, sodium chloride, take the square root but what if it's something like copper chloride?
 Tutor Then you would have to take
 Geoffrey Cube root?
 Tutor Yeah, do whatever it is that, to make it the whatever it is
 Tutor You'd have to divide it by four, would it be?
 Tutor You got K_{sp} would be
 Tutor copper concentration times chloride concentration squared and the chloride ion concentration is two times S . So whatever the K_{sp} expression would be, you
 Geoffrey Oh, OK ^(TC1.498-519)

This exchange suggests that Geoffrey was attempting to understand the principles behind the problems, but he was satisfied with only a partial and somewhat disjointed explanation from the tutor. He disengaged from the discussion before she finished her explanation and it was not clear whether he understood, or lost interest. Perhaps the complexity of the explanation stifled his interest, or perhaps he was disappointed that his somewhat naïve suggestion of 'Cube root?' was not accepted.

Working alone

Janine, Larry and Geoffrey demonstrated a distinct preference for working alone and at their own pace. Janine was almost invariably the first to finish a particular activity, and moved to the following activity without checking to see if any of the others might want some assistance. Her focus was on her own achievement, making comments such as '*Oh wow! I got it right!*' (TC1.95) and '*I know what I'm doing wrong*' (TC1.185) rather than sharing her insight with the others. Even when she was working 'with' another student such as Larry, she tended to break off potential conversations by reverting to her own resources and as a result co-construction was rarely achieved. Larry also engaged in similar behaviour but to a lesser extent. Geoffrey was often a little behind the others and his comments occasionally caused some confusion when he referred to problems which were not current for the others. On occasion one student looked at another's worksheet and made adjustments to their own without verbalisation.

On several occasions the work was uncoordinated because the students were working on different parts of the worksheet. One example occurred in episode TC1.4 (814-817), when Geoffrey asked Lucy for her opinion about Valium, and suddenly realised that the other three were working on the back page.

Sharing behaviours

A characteristic of this group was that they did not each bring all of the necessary artifacts for completing the workshop problems, and thus needed to borrow them from each other. Lucy was the most generous, lending pens, pencils, eraser and lecture notes. Geoffrey never brought his lecture notes and needed to borrow someone else's on a regular basis. On most occasions, sharing of resources was amicable, but on occasion tensions arose as individuals either took each other for granted, or behaved selfishly with their own possessions.

When Lucy attempted to borrow Larry's calculator, admittedly without asking as she simply reached out to it, he extended his hand over it with his fingers clawed, and she immediately released it back to him. He did not, however, use it immediately. On another occasion Geoffrey asked Janine if he could borrow her lecture notes. She agreed, but asked for them back after only 30 seconds: '*Can I have my handouts back so I can work out what I need?*' (TC1.214), and her reason for reclaiming them strongly suggested an entrenched self-focus.

Perhaps the most telling episode came late in workshop 1 where the students were attempting to complete the back page in order to hand it in and leave the workshop. Geoffrey opened the exchange by suggesting that Larry hand his sheet in as it was very neat, but he reacted violently and negatively. Instead, he reached out to pick up Janine's pencil (it had an eraser on the end and he had used it before), but she snapped at him '*Bloody hell, bring your own along*' (TC1.889). Although she eventually allowed him to borrow the pencil, she did not do so in a particularly

friendly manner. Lucy joined in with her complaint about a similar situation: '*See Janine, see Janine you know how I feel now because... Because no, see Janine knows how I feel because I've got Geoffrey borrowing three pens at a time, and I've got Larry taking all my bloody rubbers... Why don't I just buy you a set of coloured pencils to go with it, you moron?*' (TC1.890-894). The latter was spoken to Larry, and while Lucy was joking, she was only partly joking, because she refused to allow Larry to look in her pencil case as she spoke. Larry laughed off the potentially inflammatory incident, and the situation appeared to resolve with all four students eventually smiling at each other. However, this section of dialogue exposed some of the underlying tensions within this group, which were increasing as the end of semester approached.

Off-task activity

Lucy was easily distracted, and on a number of occasions engaged in behaviour which was playful or designed to amuse herself and others. Her most common play involved a partly full water bottle which she placed on her ear and rocked from side to side: according to Lucy, '*It's fun, and I'm like, it's feels like I'm swimming and you're in the water*' (TC1.577). She attempted, usually successfully, to draw Larry and Geoffrey into this activity.

Towards the latter stages of workshop 1, when her attempts to become involved in the completion of the back page had been ignored or rebuffed by the others, Lucy sought alternative forms of distraction. While Larry and Janine were discussing phenols and other matters, Lucy engaged Geoffrey in an arm wrestle. Geoffrey willingly responded to Lucy's suggestion '*Do you want to have an arm wrestle?*' (TC1.924), and they played two rounds, both of which were won rapidly by Geoffrey. Larry was briefly interested in their activity, but otherwise Larry and Janine ignored what Lucy and Geoffrey were doing. Geoffrey attempted to return to working on his back page after the arm wrestling, but Lucy was still distracted, and after approximately 15 seconds of looking around the room, she again addressed Geoffrey with a suggested distraction. Geoffrey agreed to allow her to show him the 'Chinese handcuff', which was a complicated interweaving of fingers between the two of them. It was not clear if he was just humouring her, but this seemed likely because he did seem to be trying to do his work, while Lucy was showing no real signs of diligence. As the Chinese handcuff finished, Geoffrey indicated his desire to continue working as he picked up on a comment from Janine about dopamine. Lucy laughingly commented '*No. No work for Geoffrey*' (TC1.980), but he pulled free of her and managed to resume solving the structural identification problems.

During the second workshop, Lucy brought an envelope of photographs with her, and on three occasions was able to distract Larry and Geoffrey with them, as they were taken at an event where all four students were present. Janine was briefly drawn into one of the exchanges, but in general continued to work while the others were distracted.

Off-task talk was often mocking, albeit apparently in a friendly way, and often involved criticism of other individuals, either members of the group or mutual acquaintances. In workshop 1, Lucy, who appeared distracted, bored and confused about the material in the workshop, initiated a conversation which engaged all four students about a college social function which was imminent. Some time later, when Janine left the table to visit the bathroom, Lucy and Larry engaged in an extended off-task exchange about mutual friends, social activities and holidays which included disparaging comments such as '*she was being a real bitch to everyone. She was good, but she's a racist. She was talking about how they pumped you up at some parties, and that sort of stuff...she was so mean, and so that's why, everyone liked her and stuff, but she was really mean. And so, um by schoolies, everyone was sick of her, and we were calling her a gnome*' (TC1.628). Geoffrey appeared to be trying to work but was repeatedly drawn into the conversation. At various points Lucy and Larry also made half-hearted attempts to return to their work, but the off-task conversation reclaimed them quickly on each occasion. When Janine returned, she joined the off task conversation as the others recounted the topics of conversation pursued in her absence. In workshop 2, off-task talk involved a discussion of the incident which resulted in Geoffrey having his head shaved, questions about the requirements for their current Chemistry assignment and several graphic and colourful discussions which related to individuals' drinking habits and the consequences of overindulgence in alcohol.

Group culture

The ways of participating in discourse, and interpersonal behaviours together contributed to the creation of a group culture, operating on the interpersonal plane. In the case of the TC group, this culture was characterised as individual and competitive, poorly supportive, task-focused and poorly persistent.

Individual and competitive

Overall the culture was individualistic, with each student working alone until called upon to provide assistance or needing assistance him- or herself. Janine, Larry and Geoffrey appeared comfortable with this approach, but Lucy often seemed lost or distracted or disinterested. The culture had a competitive undercurrent – Janine admitted failure only as a last resort and tended to do so only when another student was also unable to solve the problem.

Both Janine and Larry liked to see themselves as competent students. Janine in particular perceived herself as academically superior to the others (chapter 6). She was very certain of herself in many situations, and even when she was wrong her assurance sometimes persuaded the others to agree with her. Larry was willing to argue for his own understanding on occasions, and when he did he was usually correct. If he was vindicated, for example by the tutor, he displayed triumphalist actions such as raising his fist and articulating victory.

An example of Janine's assertiveness when she was in error is found in episode TC1.4 when Larry revisited his original classification of codeine. Having (incorrectly) identified two functional groups – phenol and amine – on the molecule, he classified the molecule as a whole as neither acidic nor basic ^(TC1.4:815). This classification is correct when there are both acidic and basic functional groups present in the same molecule, so the conclusion that he drew was valid, although on flawed grounds. Janine, however, somewhat arrogantly challenged his conclusion ^(TC1.4:820) as she refused to consider that her memory or understanding might be incomplete ^(TC1.4:822, 825, 828). Although Larry justified himself on the authority of his lecture notes ^(TC1.4:832), it is not clear whether Janine would have accepted Larry's assertion since the material that he was reading as evidence to support his opinion was hand written by him during the lecture rather than printed on the lecture outline. Fortunately the tutor arrived at this point to change the audiotapes and Geoffrey immediately asked for adjudication ^(TC1.4:835).

This incident suggested that Janine regarded herself as highly competent in the particular activity of identifying acidic and basic groups, and once she had made up her mind, she appeared unwilling to change it. Some of the tensions which characterised this group were also apparent, as their attitudes towards each other were revealed.

The serendipitous arrival of the tutor allowed the situation to be addressed and the argument resolved ^(TC1.4:835-847). Interestingly it was Geoffrey and not Janine who engaged with the tutor in this interaction. Although Janine was vehement about her opinion, she did not seek to argue with the tutor, either because she was unwilling to display ignorance, or she was persuaded that Larry had indeed written down something in lectures which she had missed. It is likely that she was listening to the tutor but she did not at any stage acknowledge that she was in error in relation to this concept. It is interesting to speculate how the previous discussion may have progressed without the serendipitous arrival of the tutor.

Janine's assertiveness was also seen when she insisted on checking the answers written by Larry on the back page which was to be handed in as the 'group' effort (episode TC1.7). Since she and Larry had worked independently, she perceived a need to ensure that the answers which were submitted were in accord with hers. As they waited for a tutor to arrive to assist with another issue, Janine compared her answers with Larry's ^(TC1.7:1128-1143), and commented somewhat patronisingly that '*I knew I needed to check yours*' ^(TC1.7:1139).

The competitive nature of the group was also highlighted in episode TC1.8. The tutor had been called to adjudicate an argument about the nature of phenols and dopamine, and although she stood between Janine and Larry, it was Lucy who asked the question. This is interesting as it may suggest that neither Larry nor Janine was keen to let the tutor know there had been confusion.

Lucy	Can we just ask again, to be absolutely certain that dopamine is basic
Larry	But if it's got the two phenol groups on it, so it has an acid and a base so it's neither.
Tutor	Um, I hate to agree with Larry, but he is correct.

Lucy Ahhh!
 Janine Yay! ^(TC1.8:1149-1153)

The tutor's expression was almost apologetic, but Larry looked at Lucy with a smug grin as she exclaimed in mock horror, and Janine looked up in triumph. Larry raised his fist above his head and bounced up and down in his seat. It is likely that the triumph reflected not only the tutor's confirmation that they understood the material, but also an element of victory-in-competition, the importance of which cannot be underestimated.

Poorly supportive

Interpersonal interactions apart from peer tutoring were not particularly supportive. Lucy needed to ask for assistance several times, and did not always receive an answer. When she did, the answers did not appear to promote her learning, and she was frequently forced to resort to copying answers without apparent understanding.

Further, when assistance was given, no verbal thanks were given, supporting the notion that the culture was not supportive. For example, Larry seemed well satisfied with the assistance offered by Janine in relation to a calculation ^(TC1.115-129), but did not offer her any thanks. Nor did he thank Lucy when she diagnosed his error in using the wrong temperature scale ^(TC1.99-101).

Within the group, contributions from group members were valued to different extents. Janine was usually seen as the highest authority, and her opinion was sought on occasion as the arbiter. She also appeared to regard herself as the authority, which is in line with her apparent desire to avoid being seen as ignorant and lacking in knowledge or problem-solving ability. Larry and Geoffrey appeared to value each other's opinions to a similar extent, although they were not averse to arguing. Lucy's opinions were universally disregarded. In a number of situations she was actually correct, or at least on the right track, and the others ignored her to their detriment. She did not usually force her opinions on the others – with some notable exceptions – possibly because of her experience of being ignored on a regular basis. As a consequence, she retreated into a subservient role, when at the end of the second workshop she comments: *'How about I write everyone else's names and SIDs on there? I'm really good at doing that. I do it every week. I think I'd get a hundred percent in the exam if I could write everyone's names and SIDs in the exam'* ^(TC2.1228-1230).

The poorly supportive nature of the group is also clearly seen in the interpersonal behaviours described above, including brusque responses, ignoring the other, disengaging early and working alone.

Task-focused

The culture was strongly focused on completing the task, and this was apparent in a number of ways. In both workshops, the students automatically gravitated to the completion of the back page,

although they only completed it in the first one. Lucy was willing to copy down the working in order to keep up with the others, although in her interviews she indicated that she would aim subsequently to understand it in other settings. The questions which were designated as for group discussion simply were not attempted as they did not appear to be valued in themselves since they did not contribute to the task of solving problems.

During workshop 1, Lucy articulated a desire to leave but this was countered by the need to complete the task: *'Ohh, boys! Look, it's four o'clock. I wanna go home. Oh, no we have to hand something in. Why don't we do that first?'* (TC1.709). Although this suggestion was initially ignored, it was soon picked up by Larry:

- Larry Let's turn to the back page so then some of us have the option to leave if we want to.
 Lucy Like me? I'm gonna go get a killer python and go to bed.
 Janine Why can't you leave?
 Larry Sorry?
 Janine Nothing.
 Larry Why can't we leave?
 Janine Yeah.
 Lucy Coz we have to do this.
 Larry We gotta detach this (TC1.719-727)

Completion of the back page engaged the group for approximately 16½ minutes and involved more than 34% of all of the spoken turns in the workshop. In itself, completion of the back page was not problematic, but it was intended to be completed after consideration of the questions earlier in the workshop. The back page contained a selection of the workshop questions and was submitted for formative assessment and diagnosis of student difficulties. It is interesting but unsurprising that this task commanded the most concentrated activity since it needed to be handed in, and the failure to complete it would be noticeable to the tutor. Other activities were not assessed so failure to complete them would be able to be hidden.

Poorly persistent

Persistence can be considered in the context of individual problems, and within the workshop overall. As has been described above, the task-focus which prevailed among this group frequently resulted in persistence with a problem only for as long as it took to achieve the correct answer, rather than for all members to have the opportunity to understand the underlying principles and processes. In terms of completing the workshops themselves, the TC group rarely stayed until the end of the two hour session, and in the two workshops under consideration, remained for 75 and 77 minutes respectively. As a consequence, they did not finish the activities within either workshop, although it is likely that they attempted them subsequently in preparation for examinations. In the case of the second workshop, they completed only the first activity and approximately a quarter of the back page, omitting the best part of four activities. They were easily persuaded to leave early by Janine's comment after 70 minutes in the first workshop that *'now we've been here long enough... I*

mean when you've got two hours' worth and you leave after an hour it's a bit dodgy. If you leave with 45 minutes to go, that's not so bad (PC1.1073-1079). During the second workshop, Larry indicated that he needed to leave 45 minutes early for a job interview (TC2.1158-1160), and Lucy chose to leave at the same time despite not having completed the back page. Geoffrey remained slightly longer, commenting '*I want to do this last page before we go*' (TC2.1326), but he was easily dissuaded by Janine who suggested '*Don't worry about it*' (TC2.1327). Since the group did not submit the back page from this workshop they did not receive feedback the following week. Not only were they less focused on the learning aspects of the workshop, apart from Janine their enthusiasm for finishing the task itself had also waned by this time.

Intersubjectivity

Intersubjectivity, or shared thinking (Rogoff, 1998), was apparent on occasion during the workshops, but it was not a strong characteristic of the TC's interactions. Intersubjectivity may be apparent when the discussion includes features which suggest shared understanding, either of the problem or the approach to solving it, including:

- joint attention to the interaction by the participants
- tacit understanding, where the individuals do not need explicit speaking turns to understand the other's perspective or utterance
- coordination of turns where sequential turns are closely related, and coordination of ideas (Barron, 2003)
- co-construction of solutions or concepts (Barron, 2003): distributed cognition where each individual contributes pieces of the whole and no individual may have been able to construct the whole by him or herself
- using an artifact as a "centre of coordination" (Barron, 2003), and joint attention to that artifact
- co-regulation of the interaction rather than domination by one individual

Several of the types of TC group interactions outlined above involved the potential for intersubjectivity, particularly exploratory talk and peer tutoring, but many tended to inhibit the development of intersubjectivity. The latter included unchallenged agreement, one-sided interchanges, unresolved debate and self-focused behaviours. Intersubjectivity was apparent also in some episodes of tacit participation. Further, intersubjectivity was evident also in off-task behaviours and discussions, primarily through tacit understanding.

Joint attention

Within the workshop students attracted each other's attention in a number of ways, by comment, question, gaze, or by physical contact (eg tapping on arm), however maintaining joint attention was often problematic. When solving a problem, all individuals had a tendency to 'drop out' once their

own needs had been met, and to focus then on their own work, with Janine and Larry most prone to this behaviour. This left a less confident or more confused partner, usually Lucy, still at a loss.

Discussion with evidence of intersubjectivity

A number of interchanges which provided evidence of intersubjectivity are briefly described below. In general, periods of intersubjectivity were rarely sustained beyond a minute, and many were shorter. Since intersubjectivity involves both words and actions, brief descriptions of the accompanying actions are provided with some of the transcript excerpts.

One interchange in which intersubjectivity was apparent occurred as Larry and Lucy engaged with the complexities of algebraic rearrangement of the Henderson-Hasselbach equation.

Lucy	Ohhh	Larry and Lucy look closely at
Larry	Do you get it?	Lucy's worksheet.
Lucy	Yeah, yeah, so what's that? Negative log of K?	Lucy writes rapidly, and speaks as
Larry	Take that	she writes. Larry looks alternately at
Lucy	Do you put it in a box?	his worksheet and Lucy's as he
Larry	What?	guides her and corrects her as she
Lucy	And then you have plus	makes 'errors', which are not always
Larry	No, it's minus	errors on her part!
Larry	You go negative and positive for the log A minus, plus	Initially Larry points at something on
Lucy	Why? Why do you? You're dividing by it, aren't you?	Lucy's worksheet, and Lucy joins
Larry	Yes, but the log that's here is negative. That times that	him shortly afterwards as they
	is the log of that becomes a negative log	discuss the mechanics of algebraic
Lucy	Should be a plus	rearrangement. Lucy continues to
Larry	What do you mean?	write as they discuss.
Lucy	Well she said it should be a plus	
Larry	It should be a plus but because of the negative there	Lucy has finished writing but they
	it's a negative	continue a vigorous discussion which
Lucy	Then this one down here is a plus	ends with Larry's triumphant "Yes!"
Larry	Yeah. Yes! ^(TC1.499-525)	as both agree on the solution to the
		problem.

In this episode, intersubjectivity was apparent in the words and gestures (joint attention to the worksheet, pointing), and the coordination of speaking turns where the comments of one student were followed up and built upon by the other.

Intersubjectivity was also apparent when Larry and Janine engaged in an exploratory discussion about the nature and identification of phenols which involved both conceptual and practical

aspects. The discussion took place in the context of looking at dopamine, which has two phenolic groups in its structure.

- Larry OK, if the OH is attached to a benzene ring, is that OK?
- Janine I don't think so. I'll just go look it up.
- Larry I'm doubting everything now, that I've thought
- Janine So am I.
- Janine How annoying!
- Larry Yeah, it's OK
- Larry I think
- Larry No that's the wrong one
- Janine No, because it's benzoic acid then
- Larry It's phenol
- Janine It's not a phenol, it's benzoic acid isn't it?
- Larry No, it's a weak acid, it's phenol
- Oh, sorry. Oh phenols are O H attached to a benzene ring. Oh, I'm forgetting everything now. So if it's not attached to a benzene ring then it's not an acid. ???
- Janine That's right. Coz it's got to be attached to a benzene ring, not any ring.
- Janine So this one's a base
- Janine Ohhh
- Janine Forgot what a phenol was.
- Larry I reckon I could be wrong all the time
- Janine So this one is an acid, and this one is an acid, yeah?
- Janine Yeah, there's two acids (TC1.4:899-936 – Larry/Janine only)

Janine and Larry converse without eye contact as they are both reading their individual lecture notes. Their frustration is evident.

Janine looks briefly at Larry before returning her gaze to her notes.

Larry finds what he needs in his lecture notes and points it out to Janine, but she does not look where he is pointing; rather she continues to read her own notes until she confirms for herself what Larry has said.

Both students write on their worksheets, apparently correcting their previous annotations.

Through discussion and consultation of lecture notes, Janine and Larry constructed a joint understanding of phenols which was consistent with the Pharmacy perspective. Interestingly, Larry opened the exchange with an appropriate definition, thus the discussion appeared to consolidate his initial understanding. Janine initially disagreed with Larry's position, but through coordinated discussion of ideas, repetition of explanations and reference to her lecture notes she also became able to articulate an appropriate description of phenols from the context of Pharmacy.

A third instance of apparent intersubjectivity occurred as Larry and Janine admitted that they were unable to solve a particular calculation, and engaged in extended discussion about the answer and the equation:

Larry	What did you get?	Larry leans over to look at Janine's working.
Janine	The wrong answer	Janine picks up Larry's worksheet and checks his working and Larry looks for assistance from his lecture notes. Lucy looks up as the interchange progresses but makes no attempt to contribute to the discussion, perhaps because she does not have the solution either.
Larry	What? Two point four six times ten to the negative five? That's what I keep getting!	Larry lifts his gaze from his lecture notes and joins Janine in focusing on his worksheet.
Janine	Yeah, that's fine if maybe they ask us for the Ksp which is just this squared, but then, it's not right	Lucy's suggestion is made towards Janine but neither Janine nor Larry acknowledges it as they continue to contemplate Larry's worksheet.
Larry	Five point nine eight	
Janine	Yeah. And the answer's, the answer's two point five three times ten to the minus ten. Coz you know why Ksp is K squared, it's sp	
Larry	Yeah. Because you do that little equation thingy and it's	
Janine	Yeah. So why, um?	
Lucy	Ask Erica. (TC1.188-196)	

The joint focus on Larry's worksheet (Barron's "centre of coordination"), and the coordinated speaking turns suggested that they were sharing their thinking, however they did not resolve the problem, as they were unable to move from their recognition of their error to a correct solution.

Much tacit or unspoken understanding was assumed in many of the exchanges: in some cases it was clear that the tacit understanding and thus intersubjectivity was present. For example, tacit understanding was evident in a brief exchange between Lucy and Larry which involved Lucy identifying an error made by Larry in his calculation of temperature:

Larry	Oh shit. I got that one wrong.
Lucy	No that's not supposed to be thirty five and fifty. It's supposed to be in Kelvin
Larry	I always do that. (TC1.99-101)

Lucy did not need to specify that Larry had used the Celsius temperature scale, since her reference to Kelvin was sufficient for him to recognise his error.

Absence of intersubjectivity

While intersubjectivity was present on occasion, there were numerous exchanges where it was clearly absent. For example, in episode TC1.1, Lucy attempted to apply the information which she had read in her lecture notes, but was unable to do this without assistance. When she indicated that she was 'stuck' (TC1.1:56), the responses from Larry and Geoffrey were not helpful since they did not seek to understand where she was experiencing difficulties, but simply repeated what she had

already read. The absence of shared thinking led her to resort to copying the others' answers with the hope that she would be able later to work out what they had done. On other occasions, assistance was provided, but the student providing the assistance rarely sought to ascertain if the other had understood, and as a consequence, intersubjectivity was either not apparent or its presence could not be established with certainty.

In a number of exchanges, intersubjectivity was not evident despite the contributions of multiple participants. For example, in episode TC1.4, all four students contributed comments to a consideration of phenacetin, lignocaine and chloroquine.

Janine	This one's neither is it?	Janine looks at Larry as she asks this question but he does not look up and she quickly drops her gaze to her own worksheet. Lucy and Geoffrey are working independently. As Larry makes his next comment, again without looking up, Janine glances over to his worksheet, then points to where she believes he has made an error, probably in relation to lignocaine. They look at his answer for a few seconds, before Lucy turns to him and asks her question. As Lucy looks on, Larry erases one of his circles, and Janine moves onto the next structure. Janine's self-directed comments are probably made in relation to chloroquine, which has a similar group to the one in lignocaine. However, the comments made by the other students in this short section cannot be easily attributed to any of the structures as they do not articulate in sufficient detail.
Larry	What?	
Janine	Phenacetin's neither. Yeah	
Larry	And that one they're all basic. It's a very strong base.	
Janine	That's not basic, it's a benzene ring. Meaning one of them would be double, bonded.	
Lucy	Ohh. Which one's that?	
Larry	I think it's that one.	
Janine	It's base	
Larry	O H (silly voice) But	
Janine	That's not either, for the same reason	
Larry	Damn!	
Geoffrey	It's not acidic?	
Lucy	Oh well	
Janine	So it's still a base. ^(TC1.4:873-885)	

This interchange demonstrates the low level of verbal discussion which was often associated with solving the problems of identification and assignment of the acid or basic nature of the drugs by this group. Intersubjectivity, as demonstrated by joint attention and the coordination of utterances, was not evident. Although 'discussion' was occurring, students were not contributing significant resources for transformative internalisation by others, nor did their utterances demonstrate

significant transformation in externalisation. Further, there was only momentary coordination of attention, and for much of the interchange, each individual was focused on his or her own worksheet. Although some tacit understanding may have been involved, the solutions were not co-constructed. In addition, both Larry and Janine demonstrated a strong task focus, indicating that they believed that the important thing was to get the correct answer rather than to develop a shared understanding of the material.

Roles of the tutor

The primary functions of the tutors within the workshops were to be a source and model of appropriate discourse, and to provide structured guidance to the students in appropriating and using this discourse within the relevant contexts. The tutors were expected to adopt a number of roles and engage in a number of practices in fulfilling these functions including asking leading questions, suggesting initial steps to a problem solution (Chaiklin, 2003), reformulating expressions, requesting elaborations, summarising discussions, modeling appropriate discursive practices (Wells, 1999a) and diagnosing sources of error. Each workshop was staffed by two tutors, and in the case of the TC and PC groups, the same two tutors were involved, one of whom was the researcher. Both tutors were very experienced, and were aware of the expectations placed upon them. However, the extent to which they were able to fill these roles and meet the expectations depended largely on the students, since the workshop design primarily involved the student groups seeking assistance from the tutor rather than the tutor providing unsolicited assistance.

The TC group interacted exclusively with the tutor-researcher, although this was apparently coincidental. 13 minutes were spent in interactions with the tutor in workshop 1 and 11 minutes in workshop 2, comprising 15.7% of the time actually spent in their workshops. This relatively high proportion suggested that potential existed for the tutor to play an important role in promoting conceptual change. The following section analyses the nature of the interactions of the tutor with the TC group.

Initiation of the interactions

The tutor visited the group on eight occasions during the two workshops. On three occasions, the visit was at the request of Janine, on two occasions Lucy raised her hand to attract the tutor's attention, on one occasion Geoffrey took advantage of the arrival of the tutor to change the audiotapes to ask a question, on a further occasion Geoffrey approached the tutor at another table and the tutor returned with him, and the final occasion involved an unsolicited visit to check on the progress of a small experiment involving dissolution of an aspirin tablet in different volumes of water.

Tutor discursive behaviours

The tutor engaged in many of the behaviours appropriate to the role of the tutor as outlined above, and examples of these behaviours are described in the following sections under the general categories of ‘asking’, ‘explaining’ and ‘adjudicating’.

Asking

Asking leading or conceptual questions

Examples of questions designed to elicit consideration of the conceptual underpinnings of the problems included:

- asking ‘*Well what do you think is the critical issue to remember, like the fundamental issue that I’ve been trying to expound?*’ (TC1.264) in the context of an interaction about the choice of values to use in a particular equation
- asking ‘*what do you think might be the difference between calling something morphine and calling something sodium cromoglycate?*’ (TC1.434) in the context of an interaction about the choice of values to use in a second equation

Several of the calculation exercises within the workshops were intended to illustrate more than the arithmetic manipulations necessary to reach a numerical answer, and these questions focused on uncovering the principles underneath the calculations. As described below, these questions did not always elicit the desired responses, however, as Larry had a tendency to reply facetiously.

Asking for elaborations

When students offered their own ideas, the tutor sought to encourage them to elaborate. For example, when Janine suggested that the difference between morphine and sodium cromoglycate could be ‘*a salt thingie*’ (TC1.435), the tutor responded with ‘*Yes, so could well be. So what would be the implication or the consequence of having a salt?*’ (TC1.436). Similarly, when it was suggested that Janine believed a value given in a question was an unionised solubility (TC2.420–422), she was asked to elaborate (TC2.423).

Diagnosing error

Many of the tutor interactions resulted from difficulties in achieving the correct answers to calculation questions, and thus a key role was in the diagnosis of error and suggestion of more productive approaches to solving the problems. In general the tutor used questions to ascertain the nature of the problem or the progress made. For example, when the students were struggling with a calculation error in the first workshop, she began by asking ‘*what happens when you square that?*’ (TC1.223) and ‘*you sure that molecular weight’s correct?*’ (TC1.227). In relation to the difficulties with

assignment of the value of unionised solubility, the tutor began by asking 'OK. What've you, what've you thought so far?' (TC2.414) and 'What, you've worked out...what's that do you think?' (TC2.417).

Explaining

Modeling appropriate discursive practice

In order to model appropriate discursive practices, the tutor often offered longer explanations, both conceptual and problem-solving. For example, in explaining why amoxicillin was neither acidic nor basic, she suggested that '*It's neither because it doesn't behave like an acid, so it doesn't have acid solubilities, doesn't have base solubilities, it's kind of hybrid. So you can't say, at pH below its pKa, then it's unionised, you can't say that, coz it's got basic properties as well. So it's got both, properties of both, so it makes it neither, in its pure form. Make sense?*' (TC1.4:842-846). This explanation focused on the reasons for not classifying the molecule as either an acid or a base in order to emphasise the concept that molecules with both types of functional groups needed to be considered as a whole.

The same underlying principle was addressed in an explanation of the means of evaluating the ionisation of molecules with both acidic and basic groups (TC2.3:1060-1085). The question was originally asked by Janine, and the explanation was therefore initially addressed to her: '*because, if the carboxylic acid group's a hundred percent ionised, then the molecule is ionised...because just one charge is enough to make the whole molecule ionised*' (TC2.3:1067-1072), however the tutor expanded to include the whole group by commenting that '*this is worth listening to*' (TC2.3:1076), and explained: '*The way that it works is, this is what happens to it as the pH increases from really, really low to really high. OK? At really low pHs it's ionised through, um, the amino group, then as you go up pH a bit, it becomes ionised at the carboxylic acid group and stays ionised at the amino group. Then it loses its ionisation at the amino group, but it's still ionised at the carboxylic acid. And then even higher, it's ionised at the carboxylic acid and the phenol. So the relevant thing is that on each of these forms, there is a charge. So each of those forms is fully ionised. It doesn't matter that the ionisation type changes from being a plus to a plus and a minus, to a minus, to two minuses. Each one of those forms is ionised. So this molecule, is ionised, fully ionised, at all pHs. There's no form that you can find once you put it into solution, there's no form it can take which doesn't have a charge somewhere on it*' (TC2.3:1079-1085).

In both of these explanations, and in others, the tutor sought to express ideas and concepts which were consistent with pharmacy conventions, and to highlight the critical issues. Unfortunately from the perspective of appropriation of these concepts, only Janine subsequently externalised the modeled discourse, and only to herself.

Suggesting a starting point

In addition to providing the answers, the tutor sometimes attempted to stimulate the students' thinking by suggesting a starting point rather than providing the entire explanation at first. For example, when Janine indicated that she did not know the value of solubility (S), the tutor modeled the appropriate place to begin solving the problem:

- Tutor You don't know S. OK, how much aspirin is there in a tablet?
 Janine That's, OK. So there's three hundred milligrams
 Larry Milligrams
 Janine and
 Tutor How much water are you trying to dissolve it in?
 Janine Forty mils ^(TC2.432-437)

On occasion she also suggested where to look in the lecture notes or worksheet in order to find a possible method. For example, when the students were struggling to differentiate between morphine and sodium cromoglycate, she suggested that they '*have a look at the previous page*' (TC1.440)

Contextualising questions within pharmacy

When the possibility arose, the tutor also attempted to locate the question within the wider context of pharmacy. In relation to the effect of water volume on the dissolution of the aspirin tablet, the tutor explained that '*the next question then says well what happens if you're stingy with water and you don't want to, you're not gonna put it in forty mils, you're only gonna put it in ten mils. See this is something that like, patients will um, have control over, OK, so, what you've worked out then is that to dissolve it, to an even higher concentration the pH has to be even higher. Otherwise it won't dissolve, you just get this grotty while stuff floating around. And patients don't like this. You see the reason why people buy Aspro Clear is that a) it tastes nice and b) it's fizzy and c) there's no grotty white stuff floating in the solution, it's all dissolved. Huge amount of technology involved in actually getting all the things in the tablet to dissolve, so patients are happy*' (TC2.485-502).

Adjudicating

Many of the tutor interactions were initiated in order to resolve disagreements or disputes, and therefore the interaction began with an affirmation of one side of the disagreement. Whether the interaction progressed beyond this affirmation was dependent on the extent to which the students were interested in the explanation or simply the resolution of the argument.

Student behaviours in interaction with tutor

In general, the students appeared to value the assistance of the tutor, although they tended to pay attention primarily when their particular needs were being met. Janine and Geoffrey were the most

likely to disengage from the interaction once their questions had been answered, although on occasion it was apparent from later interjections that Janine continued to listen. Geoffrey clearly did not continue to listen once he had disengaged, however, and on at least one occasion asked a question which had recently been answered by the tutor. Lucy listened to the tutor for most of the interactions, but the extent to which the tutor's explanations were of assistance to her was unclear.

Interactions with the tutor provided opportunities for the competitive side of group members to be displayed. When Larry's opinion about molecules with acidic and basic functional groups was vindicated at the expense of Janine's, he raised his hand in triumph and Janine appeared slightly disgruntled (TC1.4:820-836). However when both were proven correct about dopamine (TC1.8:1149-1155), both were happy to celebrate their 'victory'.

Janine appeared to be reluctant to display any ignorance or inability to solve problems to the tutor, and adopted a defensive tone when implying that she had carried out a calculation correctly and that the answer on the worksheet might not have been correct. She made comments such as '*that's what we did and the answer's wrong*' (TC1.243) and '*I got nine point five six, she's got nine point eight. I think her numbers are a little bit suss actually. Coz I'm using, like in memory and stuff so, I think she's rounded off... There's somethin' wrong with the last one!*' (TC1.360-364). Her individual interactions with the tutor often focused on procedural rather than conceptual issues, for example, the method of writing the answer to the question rather than the underlying principles: '*Um, should we do it via pH, like that? But not this time, OK. But I know what they are anyway. It's just a matter of calculations. So do you, what, do you go, do you go through and look which is the acid and which one's the base and you eliminate it there?*' (TC2.613-619).

Larry tended to react facetiously when he was not certain of the appropriate response to a leading or conceptual question. He responded to the tutor's question '*what do you think is the critical issue to remember, like the fundamental issue that I've been trying to expound?*' (TC1.264) with the laughing answer '*memorise all of it*' (TC1.265). Similarly when the tutor asked '*what would be the implication or the consequence of having a salt?*' (TC1.436), his response was '*it'd be salty*' (TC1.437).

In summary, the student behaviours largely emphasised their focus on task completion rather than conceptual understanding, and thus as a group they failed to take full advantage of the tutor's assistance. They appeared to regard the tutor primarily as a source of information, in the sense that she was perceived as a provider of the correct answer, rather than as someone who could explain the relationship between the assigned workshop activities and the broader context of the topic, and they did not demonstrate interest in exploring the ideas beyond what was defined narrowly by the workshop exercises.

Persistent change group

Participation in discursive interactions

In contrast to the TC group, in which dyadic interactions were the most common, interaction patterns in the PC group were considerably more fluid in nature and involved most or all of the group members. Within a larger interaction, parallel conversations in dyads and triads occurred occasionally, but the most common conclusion to an interaction was a group decision or action. Tacit participation was also evident, particularly by Alicia and Isabelle.

Fluid interactional patterns

The interactional pattern observed consistently within the PC group began with each student involved in individual work as she attempted the problem in silence, and proceeded into discussion as one or more individuals asked questions or raised issues. Once discussion had been initiated, most or all of the students engaged with it, either by contributing verbally or in tacit participation. This pattern was observed in episodes of peer tutoring, exploratory talk and co-construction of conceptual understanding, as well as interchanges involving a mixture of different styles of discourse.

An example of the fluid nature of the typical interaction is found in episode PC1.5⁽¹⁰⁷³⁻¹¹⁸⁸⁾. The group was working in a coordinated manner^(PC1.5:1073-1078), and as the episode began, each student was looking at her own worksheet. The first interaction was initiated by Denise, who commented that the OH group was neutral^(PC1.5:1080), and engaged all five participants in discussion for 1 minute^(PC1.5:1080-1113). At this point, the conversation split, with Jasmine asking each student in turn for their student numbers for the back page²⁰, Veronica and Kellie engaging in discussion about the difference between aliphatic and benzene rings^(PC1.5:1114-1124), and Alicia listening to the latter. Denise^(PC1.5:1125) and Jasmine^(PC1.5:1143) subsequently joined the ring discussion, and all remained engaged until consensus was reached about the nature of the OH group^(PC1.5:1143-1169). Each then returned to individual work before the next issue was raised by Veronica^(PC1.5:1171). This issue was quickly resolved^(PC1.5:1171-1181), and individual work recommenced. Jasmine and Alicia jointly attended to Jasmine's lecture notes as they identified an amide group^(PC1.5:1185), and the other three students joined in confirming their finding^(PC1.5:1185-1188).

This pattern was repeated consistently throughout both workshops. Triggering comments and questions were articulated primarily by Jasmine (eg. PC1.5:1201, 1236; PC1.6:1391; PC2.2:1134), Veronica (eg. PC1.5:1218; PC1.6:1359), Kellie (eg. PC1.5:1251; PC1.7:1735), and Denise (eg. PC1.6:1339, 1371, 1472), but Alicia also contributed occasionally (eg. PC1.6:1441). As indicated above, the characteristic types of interactions included peer tutoring, exploratory talk and co-construction of conceptual understanding.

²⁰ These turns have been omitted from the transcript of the discourse for ease of reading.

Peer tutoring

Peer tutoring within the PC usually occurred in response to a question raised by a member of the group, and it was a feature of this group that they were consistently willing to display their lack of understanding by asking many questions. Peer tutoring sometimes occurred in the context of dyads, but also in larger clusters, up to and including the entire group. It was different in character from that observed in the TC group, in that no individual was perceived to be more or less capable than any other of assuming the role of 'expert', nor did anyone take on the tutoring role exclusively. All members of the group at some stage acted as the peer tutor, although Veronica, Jasmine and Denise were more forthright in offering their ideas than Kellie, Isabelle or Alicia.

Veronica as tutor

At the beginning of episode PC1.5, Veronica was the first to recognise that the OH group in codeine was not a phenol, and she led Kellie and Denise through her reasoning ^(PC1.5:1111-1133), focusing on the fact that the ring in codeine was not a benzene ring because it did not have a circle drawn in the middle. She was animated as she pointed to Kellie's worksheet, and used a persuasive tone indicating her strong conviction that she was correct. In episode PC1.6, after a group discussion of amines and amides, Jasmine asked Veronica about the attachment of nitrogens to benzene rings, and Veronica responded with an explanation that the double bond was not from the nitrogen to the ring ^(PC1.6:1452-1469). All students were attending to her explanation, which she reinforced by pointing to Kellie's worksheet which was visible to all of them. Veronica was a clear speaker, expressing her understanding in language which was both simple and appropriate to the pharmacy context, and she readily offered her assistance frequently throughout both workshops.

Jasmine as tutor

In workshop 1, Jasmine explained to Kellie and Alicia how to calculate K_{sp} and how to use it in calculations relating to the solubility of ionic substances ^(PC1.1:360-389). Jasmine's explanation began by ascertaining the exact difficulty experienced by Kellie ^(PC1.1:361), and partway through the exchange, she again checked Kellie's understanding ^(PC1.1:371). Jasmine herself was not confident of the full explanation, and referred to '*explanations from before*' ^(PC1.1:373) to supplement her account, however she was enthusiastic and inclusive in her attempt to communicate her rationale for answering the question the way she did.

In workshop 1, Denise asked Jasmine for assistance in drawing the detailed structure of phenacetin, and Jasmine obliged by explaining as she drew, and also giving her rationale for identifying the molecule as neither acidic nor basic ^(PC1.6:1371-1389). She wrote on Denise's worksheet as both Denise and Alicia watched closely, although only Denise asked for clarification ^(PC1.6:1383). Jasmine was able to illustrate and explain the structural basis for classifying the nitrogen as part of an amide rather than an amine, and Denise appeared to be satisfied with Jasmine's assistance.

Denise as tutor

Denise took the role of tutor in workshop 2 when asked by Jasmine to explain ionisation and protonation ^(PC2.2:1182-1199). Denise commented that both nitrogens in lignocaine were ionised, which appeared to confuse Jasmine. Denise and Jasmine looked together at Jasmine's worksheet as Denise pointed to various items, and Isabelle listened without looking closely at the worksheet. Isabelle's comments suggested that she supported Denise's interpretation, and although, as has already been discussed, Denise's reasoning was incorrect, Jasmine was clearly willing to listen to her and take notice of what she said. As this exchange concluded, the tutor began a dialogue with Isabelle, to which the other students gradually attended, and after listening to the tutor explain the correct approach, Denise was now willing to articulate her new reasoning in response to Jasmine's later question ^(PC2.2:1265-1268). Denise was enthusiastic about sharing her ideas when she believed she had grasped a concept, although she was not always correct in her understanding.

Kellie as tutor

Kellie was more reticent about taking a leadership role in explanations, and tended to become involved in more collaborative interchanges. However, when she was confident, she was able to contribute in a peer tutoring role. Early in workshop 2, she identified where Veronica erred in a calculation of solubility, and explained how to carry out the remainder of the calculation ^(PC2.1:421-448). The discourse was primarily between Kellie and Veronica, although Jasmine made a number of comments. As the interchange began, Veronica and Kellie were interacting, with the other four students working individually. Kellie's comments were made in response to Veronica's, either a question or a statement which was incorrect, and with her assistance, Veronica was able to complete the calculation. This exchange is characteristic of Kellie's more diffident participation in discourse. She was naturally softly spoken, and appeared to prefer the more talkative members of the group to take leadership roles.

Isabelle as tutor

Isabelle displayed a preference for working alone, although she willingly participated in discussion when asked, and was often listening to the conversation of the group. Occasionally she took the initiative and offered an unsolicited contribution, for example in workshop 2, when she achieved the answer to exercise 1 before any of the other group members.

- Isabelle Veronica, I got the concentration.
 Jasmine What did you get for the concentration?
 Isabelle I got four point two times ten to the minus
 Jasmine Two.
 Denise Yeah.
 Jasmine Yep, yep, I got that too.
 Isabelle Oh, OK. And then, you have the Henderson Hasselbach equation
 Jasmine Which one?

- Denise But we don't have the concentration of the ionised form.
 Jasmine Yeah, the A minus, huh.
 Isabelle If you take any chemical species and you put it in water.
 Isabelle And then you... Oh, sorry, but it's not fully ^(PC2:475-486)

Later in the workshop, Jasmine asked Isabelle for her answers to the ionisation question, suggesting that although Isabelle was generally quiet, her opinion was valued. Discussion between Jasmine, Denise, Kellie, Veronica and Alicia appeared to result in a tentative consensus, however Isabelle had not been involved and Jasmine sought to ascertain her independent understanding. Isabelle was happy to share her answers ^(PC2.2:1295-1310), confirmed all but one of the group's conclusions, and was happy to accept correction for the one error she had made. As described in chapter 6, Isabelle lacked confidence in her ability which constrained her from overly assertive expression of her ideas, and she was therefore more likely to respond rather than initiate an exchange.

Alicia as tutor

Alicia was the quietest member of the group, and rarely put herself forward as an expert, however towards the end of workshop 2, she took the lead in explaining to Jasmine how to interpret information in a calculation question.

- Alicia OK. Ohhh. I dunno, cos it says here. Like, this bit, if you see the pKa.
 Kellie Here for this bit, um,
 Alicia It gives you the pKa.
 Kellie the implicit information is that it doesn't mention pH.
 Alicia But in this case, I just thought that
 Alicia But from that, they worked out that, um, the pH was one
 Alicia And so you compare pH with the pKa.
 Jasmine Oh, and then you work out from there.
 Alicia Yeah.
 Jasmine Use that table thing.
 Alicia If it's ionised or un-ionised.
 Jasmine Oh, OK. So, do they give us similar information?
 Alicia I think, yeah, they gave us pKa. They gave us the concentration, but yeah,
 Jasmine But they didn't give us
 Alicia They didn't give us within water.
 Jasmine Ohh ^(PC2.1971-1990)

In addition, she was consulted several times by Jasmine for her opinion. In workshop 2, Jasmine attempted to sketch a solubility curve as Alicia watched. Jasmine turned to Alicia to ask 'So, roughly like that?' to which Alicia assented '*I think so*' ^(PC2.1673-1674). Later Jasmine asked her how to work out a solubility calculation:

- Jasmine Yeah, how did you answer that, Alicia?
 Alicia Oh, well, um, OK. Dunno. I just put the pH of these, three point eight or something. So they gave us the pKa, they told us it's acidic and they gave us the solubility.
 Jasmine So you don't need the concentration of the hydrochloric acid?
 Alicia I dunno. Cos in here, they just gave us the pH, so... I'm not sure ^(PC2.1718-1721)

Alicia appeared to be more comfortable interacting one-on-one with Jasmine than interacting with the other members of the group, either individually or with the group as a whole. She was clearly hesitant about asserting herself, which was probably a consequence of her lower confidence with the material (chapter 6). However, with Jasmine's support, she was able to contribute appropriately.

In summary, members of the PC group adopted the role of peer tutor interchangeably when they were either asked directly or had achieved a particular insight which they wished to share with the rest of the group. The interactions were more symmetrical than those of the TC group, since it was apparent that no member of the PC group regarded herself as an expert, although several were more confident in contributing. Peer tutoring within the PC group was characterised by a greater level of explanation than that within the TC group where Janine tended simply to provide answers, and by repetition of ideas and concepts, both of which provided greater opportunities for transformative internalisation and externalisation. The interactions were also more closely aligned with progressive discourse, since many involved more than two participants, thus facilitating exploration and critical analysis of a wider range of options. However, since the students were not experts, the potential existed for peer tutoring to produce conclusions which were incorrect or idiosyncratic, and this potential was realised more frequently in the PC group than in the TC group where Janine was generally correct in her assertions.

Exploratory talk

Exploratory talk among the PC group frequently displayed most or all of the characteristics of progressive discourse. Two examples serve to illustrate this observation. In the first example, from workshop 2 ^(PC2.3:1917-1959), Jasmine, Kellie and Veronica explored the relationship between the acidic and salt forms of phenobarbitone, with the immediate trigger for their explanation outlined in the question read out by Kellie: “*To which form or forms of the drug does this solubility apply?*” ^(PC2.3:1917). A range of alternative explanations was proposed and evaluated as the discussion proceeded. Jasmine firstly introduced the idea of molecular weight ^(PC2.3:1920-1926) but subsequently focused additionally on structure ^(PC2.3:1930) by identifying the hydrogen which was lost from phenobarbitone to form its salt. Kellie introduced the concept of ionisation ^(PC2.3:1931) which stimulated Jasmine's externalisation that the salt had been formed by the replacement of hydrogen by sodium ^(PC2.3:1934). Veronica introduced the question of the nature of the charge ^(PC2.3:1939), and Kellie suggested the idea of a swap between the two ions ^(PC2.3:1947), leading Jasmine to formulate her conclusion that the salt form was unionised ^(PC2.3:1948). Veronica offered the alternative explanation that the creation of a charge resulted in an ionised form ^(PC2.3:1950, 1954), but was convinced by Jasmine's argument ^(PC2.3:1955-1957). Exploration of all these ideas, and how they interrelated, provided significant resources for transformative internalisation and externalisation, however they did not reach a conventional conceptual understanding, despite a further 6 minutes of subsequent discussion, and a tutor was not asked for assistance.

The second example involved a discussion in the first workshop about a question posed in a quiz which the majority of students answered incorrectly^(PC1.2:806-871). The question required students to carry out an algebraic rearrangement of the Henderson-Hasselbach equation, and because of the low success rate in the quiz, a question exploring the process was included in the workshop. As the interchange began, the five students were reflecting upon the fact that they all answered incorrectly, despite being confident that they were correct. Denise opened the discussion by suggesting that their error lay in a failure to recognise an algebraic change to the equation^(PC1.2:806), which spurred Kellie to ask about the consequence of changing the sign of a logarithm^(PC1.2:810). Denise continued to suggest how the equation had been manipulated^(PC1.2:813-817) and, together with Jasmine, why they had been deceived in the quiz^(PC1.2:820-822). Denise further suggested a means of avoiding this error in future^(PC1.2:829), but Jasmine was keen to explore the fundamentals further, and this engaged the group for the remainder of the episode^(PC1.2:830-871). In this instance, not only were resources for transformative internalisation and externalisation apparent in the interchange, the students were able to reach consensus on the conventional explanation.

As outlined in chapter 3, progressive discourse is characterised by a common commitment among all participants to engage in discussions which work towards a satisfactory joint understanding, are based on an examination of evidence, expand the range of propositions, permit critical analysis of beliefs, and build on previous utterances (Wells, 1998). These two examples provide evidence that the PC group engaged in progressive discourse as they explored the concepts under discussion. There is clear evidence that members of the group were committed to assisting each other to understand, by providing explanations and building arguments based on coordinated speaking turns. Different opinions were welcomed, and were considered on their merits, before the most promising line of thinking was pursued. Suggestions were not accepted uncritically, but reasons were sought for the points of view which were expressed. Exploration of the ideas did not, however, invariably lead to an appropriate conclusion, as illustrated in the first example, where an idiosyncratic interpretation was developed, thus highlighting the importance of linking student discourse to that of the expert tutor.

Co-construction of conceptual understanding

One of the characteristic features of the discourse of the PC group is that they were committed to a thorough consideration of new ideas, and to building a clear understanding of those concepts which they valued. They spent time in discussion, and revisited ideas until they were satisfied with their joint construction of the concept. An illustration of this approach is found in the development of their understanding of the OH group as encountered in Pharmacy.

The discourse relevant to the co-construction of this concept occurred during episode PC1.5, and encompassed five sub-episodes, which are analysed to illustrate the co-constructive process.

Sub-episode 1 (PC1.5:1080-1096)

This discourse introduced the primary reasons why members of the group found the OH group problematic, in that it could be neutral, basic or acidic depending on its molecular context. Denise initially suggested it was neutral, but immediately 'corrected' herself to indicate that it was basic, citing as her rationale the fact that hydroxide groups were basic. This represents the conceptual foundations gained in Chemistry, and is indeed one of the consistent notions expressed by Pharmacy students over many years. Jasmine countered with the notion of OH group as phenol, and thus as weak acid, but while she appeared to accept the possibility that the group was a phenol, Denise remained convinced that it was still basic, and reiterated this belief twice (PC1.5:1091, 1096).

Sub-episode 2 (PC1.5:1137-1144)

After a short discussion which concluded that the ring to which the OH is attached was not benzene, and therefore the OH was not a phenol, Denise continued to insist that it still must be basic. Veronica used the evidence of her lecture notes to counter this argument and to argue that in codeine the OH group was an alcohol, and therefore neither acidic nor basic.

Sub-episode 3 (PC1.5:1158-1166)

Kellie now joined Veronica in recognising that the OH was an alcohol and therefore neutral, and Denise was beginning to develop discrimination between different OH groups, as she commented '*Oh, so it's only like, NaOH's that are basic*' (PC1.5:1163), a development which was echoed by Jasmine (PC1.5:1166). Further, Denise was beginning to recognise that there were more possibilities for acids as she reflected '*I just always thought H plus is acidic*' (PC1.5:1165).

Sub-episode 4 (PC1.5:1198-1211)

The group returned again to codeine to confirm its nature, and Veronica stated the jointly constructed concept that '*hydroxyl groups, um are not basic, nor are they acidic*' (PC1.5:1204). Alicia and Kellie concurred with Veronica, but Denise again raised her previous Chemistry beliefs that '*I thought that whenever you have an OH attached to something, it makes it basic*' (PC1.5:1209). Jasmine added the final element to the concept by reminding Denise that not all OH groups in Chemistry were basic (PC1.5:1210), which appeared to persuade her.

Sub-episode 5 (PC1.5:1218-1225)

Veronica re-stated the jointly constructed understanding (PC1.5:1218), because she was uncertain if Denise was still struggling, however the discussion appeared to have convinced Denise of the validity of the new concept and she indicated that she had changed her mind (PC1.5:1225).

Thus extended and repeated discussion provided the resources for each member of the group to appropriate, at least to some extent, the differences between the nature of OH groups depending on

their molecular context. It was a joint activity, with input from all group members, and consensus was achieved that:

- OH was basic if it was an hydroxide ion
- OH was acidic if it was a phenol, and a phenol required the OH to be attached directly to a benzene ring
- OH was neither acidic nor basic if it was an alcohol

This consensus was entirely consistent with pharmacy conventions, and represented clear evidence of conceptual change. Although it is likely that members of the group reinforced their understanding in preparation for the examination, chapter 6 provides abundant evidence that this change persisted to the end of the study, and the externalisations of the group members bore a striking resemblance to the discourse of this interchange.

A second example of joint construction of a new concept is found in the group's discourse about the dissociation equilibria of amoxicillin (PC1.7:1766-1848). Both of these examples display the characteristics of progressive discourse, and both also involve coordinated externalisations which provide resources for, and evidence of, transformative internalisation.

Tacit participation

Alicia spent most of the workshop as a tacit participant in discussion, as she lacked the confidence to assert her opinions on a consistent basis. As outlined above, she was more comfortable with a dyadic interaction, preferably with Jasmine, next to whom she sat in every workshop. Isabelle, whose preference was to work alone, also participated tacitly on occasion, but she was slightly more confident in offering her opinion.

Interpersonal behaviours

The majority of interpersonal behaviours exhibited by members of the PC group were cooperative rather than self-focused, and were directed towards ensuring that each member of the group was able to participate and learn effectively. Most of the time during the sessions was spent on the tasks assigned for the workshop, but some off-task activity was also evident.

Cooperative behaviours

The cooperative nature of the group members' behaviour was manifest in coordination of effort, responding to others, consideration of others' understanding, an inclusive environment and a willingness to share.

Coordination of effort

In contrast to the TC group, who tended to work independently and at different paces, the PC group consistently worked contemporaneously on each activity, and numerous examples of this practice have been described above. Although each worked alone for part of the time, individual work was generally a prelude to group activity. This coordination of effort was manifest in coordinated discourse, which facilitated the co-construction and appropriation of conceptual understanding. Occasionally, while working on a multi-part activity, individuals briefly lost synchronicity (eg PC1.5:1226-1229), however their propensity for discussion generally brought them back together within a short period of time.

Responding to others

The discourse of the PC group was marked by a willingness to respond to any question or issue raised by any other member of the group. Again, numerous examples of this behaviour have been described above, and it stands in contrast to the difficulties experienced by Lucy in having her questions answered on occasion. Significantly, responses to questions tended to be given in detail rather than briefly, and to result in discussion rather than exist as a question-and-answer interaction.

Consideration of others' understanding

In addition to the provision of explanations and reasoning, group members tended to confirm whether other members had understood before moving ahead in the discussion. The question '*does that make sense?*' was asked three times (PC2.1374, 2021, 2042), '*do you get it?*' was asked on four occasions (PC1.397, 632, 962; PC2.1930), and '*do you understand?*' on three occasions (PC1.363, 1441; PC2.846) in comparison to the solitary '*do you get it?*' (TC1.502) by Lucy in the TC group. The group was eager to reach consensus, rather than to leave any member struggling.

Inclusive environment

Although Alicia and Isabelle tended to remain on the periphery of discussions, and to act primarily as tacit participants, they were actively included in the group work, usually by Jasmine. Isabelle was regarded as a valuable member of the group, despite her own reservations. In the second workshop, Jasmine asked '*What do you think, Isabelle?*' (PC2.1408) about the formation of salts of acids and bases, and as Isabelle was beginning to pack up towards the end of the session, Jasmine exclaimed '*Oh don't go Isabelle. We need your brain*' (PC2.2081). During the first workshop Jasmine lamented Isabelle's absence, suggesting that '*we need Isabelle*' (PC1.585) when the group was struggling with a calculation. Alicia was also treated as a valued member, with Jasmine telling her '*I'm relying on you, Alicia*' (PC1.926), and consulting her for assistance about the precipitation of salts (PC2.2083-2090). As indicated previously, Alicia appeared to be comfortable interacting with Jasmine, and Jasmine's behaviour towards her was probably significant in putting her more at ease.

A further instance of the inclusive environment created within the PC group involved the return of the corrected feedback sheets in workshop 2. Since Isabelle had missed the previous workshop, she did not receive a copy, and Jasmine was quick to reassure her that she was '*in our group anyway*' (PC2.904), and that '*we'll tell Erica to get another one*' (PC2.917) for her.

Willingness to share

In contrast to the TC group, members of the PC group were happy to share their possessions, and on no occasion was a request to borrow pens or notes answered grudgingly. Veronica offered to lend pens to Denise and Kellie (PC1.37-43), and lent Jasmine her ruler (PC2.1545-1547), while Alicia lent Denise her 'orange book' (PC1.186-188). They were also more likely to thank the lender, and also to thank each other for assistance, with thanks being offered on 27 occasions by the PC group in comparison to 16 by the TC group.

Off-task activity

The PC group engaged in very little off-task activity, although a number of passages of off-task talk were interspersed throughout the workshops. The only off-task activity occurred at the beginning of workshop 1, when Denise showed Alicia some photographs of her birthday party, however Alicia returned them after only one minute, and they were not brought out again.

Off-task talk in general was less mocking and more friendly than that of the TC group, and while both groups discussed social activities and mutual friends, the conversations in the PC group lacked the underlying critical and derogatory nature which underpinned much of the TC group conversations. During the first workshop, topics of discussion included boys, sunscreen agents, sore throats and calculators in examinations, while they discussed mutual friends, a party, group assignments and Denise's employment in the second. In general, the off-task talk appeared to serve as a brief attention break during the workshop activities, and when it occurred, most of the students participated before returning to work.

Group culture

The discursive participation and interpersonal behaviours within the PC group resulted in the creation of a qualitatively different culture from that of the TC group. The PC culture was characterised as collaborative, supportive, learning-focused and persistent.

Collaborative

The patterns of participation in discursive activity and the interpersonal behaviours described in previous sections created a collaborative rather than competitive culture. Little, if any, evidence suggested that any participant was motivated by a desire to appear more competent or

knowledgeable than any other, nor was there evidence of triumphalism when an individual's suggestion was proven correct. The hallmarks of this collaborative culture were the prevalence of progressive discourse and co-construction of understanding, together with the supportive environment created by an awareness of the needs of other participants.

Supportive

A culture of supporting others was clearly evident in the cooperative behaviours described in the previous section, where individuals were willing to offer assistance and share resources. Even sections of the off-task talk were supportive in nature. For example, during workshop 1 a discussion arose about whether students were permitted to use their own calculators during the end of semester examinations. All five students participated in the discussion either verbally or tacitly.

- Denise Um I think I read about it in the information booklet. Otherwise people could be taking their calculator in.
- Kellie But we took it into the Stat one.
- Denise I don't know, it just says there. Well maybe just for certain tests. That's where I read it. It says the uni will provide you with calculators and then like some special name. And it you want to find out more about it, you can go to the student centre.
- Kellie Do you have the timetable?
- Veronica What?
- Kellie You know, for the final examination?
- Veronica Yes
- Kellie Specific examinations.
- Denise Oh that's only for specific examinations
- Kellie Yeah
- Denise How about Pharmacy?
- Kellie Pharmacy, no
- Denise Ah that's all right then ^(PC1.709-725)

Since the question had arisen, the group decided to settle the issue so that all were aware of the requirements. Veronica lent Kellie her copy of the examination timetable, in which she read to the rest of the group her finding that individuals were permitted their own calculators in Pharmacy examinations.

Later in the same workshop, Jasmine and Veronica commiserated over their irritable coughs, and Jasmine offered Veronica a cough lolly.

- Veronica Have you still got that itchy throat thing?
- Jasmine Yes.
- Veronica It's so annoying.
- Denise Did you get it on the cruise?
- Jasmine Yeah. Well, after the cruise. Do you still have it?
- Veronica Yes.
- Jasmine Do you want a lolly?
- Veronica Oh, it's OK.
- Jasmine Later, huh?

Veronica Yeah
 Jasmine I'll have to have one soon (PC1.1240-1250)

In both of these examples, even though engaged in off-task talk, group members demonstrated concern for others, thus reinforcing the supportive nature of the group culture.

Learning-focused

As was the case with the TC group, the PC group was eager to finish the workshop activities and in both workshops under consideration omitted activities in order to complete the back page, however they were also aware that the purpose of the workshops was to facilitate their learning, and were willing to spend sufficient time on an activity in order to explore it thoroughly. For example, in workshop 1 they spent 27 minutes discussing the identification of functional groups and classification of molecules as acidic, basic or neither (compared with 9 to 11 minutes by members of the TC group, depending on the extent of their off-task activity). Further, the repetition of questions such as '*do you get it?*' and '*do you understand?*' which were designed to elicit and ascertain the comprehension of others, underlined the focus on learning and understanding. As a group, they were aware that it was possible to learn from errors:

Jasmine Is that right?
 Alicia I think so, yep
 Kellie OK, yeah
 Jasmine We'll probably get it wrong, but, oh well.
 Veronica We will learn from it.
 Alicia Yeah (PC1.1385-1390)

They were particularly interested in the feedback that they would receive on the answers submitted each week, and were willing to include responses about which they were uncertain in order to gain clarification (PC1.6:1687, 1700).

The consequence was that they did not finish all of the activities in most of their workshops, and this was acknowledged by group members in their interviews (chapter 6). However the majority believed that spending the time covering the material thoroughly was beneficial, both at the time of the workshops and later when engaged in private study (pages 246-250).

The learning focus of the group was expressed most clearly by Veronica who explained '*you're trying to understand it, which is good. But I can understand it now because people've been explaining it*' (PC2.618).

Persistent

The PC group displayed significantly greater persistence than the TC group, both with individual activities and with the workshop as a whole. As has been described, they sought to complete each

activity to the point where they understood it, and were willing to persist even if only one member was still uncertain (eg PC1.5:1080-1225). This persistence was critical as an affordance of conceptual change, since it created an environment in which transformative internalisation and externalisation were encouraged. Further, the prevalence of exploratory and progressive discourse allowed the group to uncover the critical aspects of their understanding difficulties and to seek to resolve them. For example, in workshop 1, they spent almost 7 minutes attempting to understand how to apply a particular equation to free energy and solubility calculations, and the range of possibilities that was suggested led them eventually to the critical issue, articulated by Jasmine, which was the importance of learning how to distinguish between molecules which ionised in solution from those which did not (PC1.649).

The PC group was also more persistent in remaining for the duration of both workshops, leaving after 113 and 121 minutes respectively. Denise left early on both occasions in order to travel to her paid employment, but none of the others suggested leaving before the two hours was complete. Although they found it necessary to omit some activities in order to complete the back page, they did so from necessity rather than choice, and in contrast to the TC group, submitted the completed sheets at the end of both workshops.

Intersubjectivity

Intersubjectivity, or shared thinking (Rogoff, 1998), was a strong characteristic of the PC group's interactions. All of the previously outlined features of intersubjectivity (page 208) were apparent in the interactions of the PC group, particularly joint attention, coordination and co-construction, and co-regulation. Tacit understanding was also apparent, both in on-task and off-task talk, although it was most obvious in the latter where mutual acquaintances and activities formed the basis for conversation. Some discussion occurred without apparent intersubjectivity, but these occurrences were generally brief and not significant.

Joint attention

All group members responded to questions or comments addressed to them, and rarely were physical actions such as tapping the arm necessary to attract attention. Group discussions were commonly accompanied by either sustained eye contact or joint focus on an artifact such as one individual's worksheet, lecture notes or calculator, and on many occasions, participants leaned towards each other in order to concentrate to a greater extent on that joint focus. Occasionally neither eye contact nor joint focus was maintained throughout the entire interaction, however in these cases group members were almost invariably focused on the same question in their individual worksheets, and so were effectively engaged in joint attention.

Coordination and co-construction

The coordination of speaking turns and co-construction of understanding and solutions to assigned problems have been discussed above, and were prominent characteristics of the PC group's interactions.

Co-regulation of interactions

Although not explicitly described above, co-regulation was implicit in many instances of exploratory and progressive discourse, as regulation of the discussion and activities tended to flow from consensus. Agreement of other group members was sought before moving from one activity to the next, for example when deciding to start the back page.

- Kellie Oh, we have to do this.
 Denise What is it?
 Veronica Oh, quick, do it.
 Jasmine Oh, no!
 Kellie It's double sided, as well.
 Denise Oh my God.
 Alicia This is all right
 Jasmine Oh that's good. I like these ^(PC1.1066-1073)

The co-regulation was real in the sense that alternatives were considered ^(eg PC1.5:1226-1229), and when one member was not ready, the group waited.

- Jasmine Whatever. Oh. Okay, shall we go on?
 Veronica Please.
 Denise Wait a second.
 Denise Ah!
 Jasmine Got it?
 Denise I keep on getting this number. Like, this, all the time.
 Jasmine What is it?
 Denise Let me just check your working out.
 Jasmine Yeah.
 Denise Oh that's why. I just did something dumb.
 Denise Oh, sixty. Er. I've been using the enthalpy for this problem.
 Veronica Oh. Oh no.
 Kellie From the other question?
 Denise Yeah, like the twenty-four point five. How dumb is that? ^(PC1.484-497)

Co-regulation was also evident in the completion of specific activities. For example, when deciding how to describe the nature of chloroquine on the back page, Jasmine, Denise, Veronica and Kellie all contributed ideas, and Jasmine took all into account ^(PC1.6:1687-1700).

Roles of the tutor

As indicated previously, the primary functions of the tutors within the workshops were to be a source and model of appropriate discourse, and to provide structured guidance to the students in appropriating and using this discourse within the relevant contexts. The PC group interacted with both tutors in both workshop sessions. 15 minutes were spent in interactions with the tutor in workshop 1 and 17 minutes in workshop 2, comprising 13.4% of the time spent by the PC group in the workshops. Thus the times spent with tutors by both TC and PC groups were comparable, suggesting that similar potential existed in both groups for the tutor to play an important role in promoting conceptual change. The following section analyses the nature of the interactions of the tutors with the PC group.

Initiation of the interactions

The tutor-researcher visited the group on eight occasions during the two workshops, and the other tutor on four occasions. On three occasions, the interaction was initiated by an explicit group decision, and on another by Jasmine as a consequence of fruitless collaborative effort to solve a calculation question. Five interactions were initiated by individuals (Jasmine, Denise and Isabelle), and three by the arrival of the tutor to change tapes or move papers from covering the microphone.

Tutor discursive behaviours

With some exceptions, both tutors engaged in similar discursive behaviours with this group to those of the researcher-tutor with the TC group. The PC group was more likely to ask longer questions, outlining their progress and their difficulties, and to request broader explanations than the TC group, thus the tutors' responses needed to encompass the breadth of their inquiries.

Asking

In general the tutors asked fewer questions of this group than of the TC group, because the PC participants had often reached the point of formulating their own questions. In addition, while they needed assistance on occasion with calculations, the PC group asked more conceptual questions than the TC group, reflecting their greater learning focus.

Asking leading or conceptual questions

Leading questions were used by the tutors when the students expressed difficulties in achieving the correct answers to calculation questions. For example, when the students were unable to achieve the appropriate answer using the Henderson Hasselbach equation, the tutor used three questions to ascertain the extent of their progress: 'OK, how far did you get?' (PC2.509); 'Do you know which formula you have to use?' (PC2.514) and 'OK, what's the first thing you need to know?' (PC2.522).

Similarly, conceptual questions were used to probe the understanding which the group had reached prior to requesting the assistance of a tutor. During episode PC2.2, after extensive discussion among themselves and with the tutors about the meaning of ionised and unionised, Jasmine requested that the tutor finally confirm the articulation of their newly formed concept of ionised (PC2.2:1319-1321). The tutor began by asking for their ideas: *'What's the definition of something being ionised?'* (PC2.2:1322), and was able to assent to the response *'Is it charged?'* (PC2.2:1323). Later in the same interaction, the students appeared convinced of the tutors' explanations, but struggled to articulate the rationale for the classification of molecules as ionised or unionised at particular pH values. To assist them, the tutor led them through the logical reasoning processes involved with a sequence of questions (PC2.2:1347-1358). A further opportunity for a conceptual question arose in the discussion of the algebraic manipulation of the Henderson Hasselbach equation, when the tutor asked *'What do you think I'm trying to get at there, like with that whole question?'* (TC1.986).

The tutors also responded with questions in response to conceptual questions raised by the students, particularly when they raised issues which had not explicitly been covered in lecture material. During the first workshop, the students experienced difficulties with calculations relating to solubility, but spent a considerable period discussing the topic before asking for input from a tutor. As a consequence, the initial student question was conceptually sophisticated and allowed the tutor to respond with questions which broadened the students' perspectives. The prior discussion between the students also permitted them to engage in a brief episode of progressive discourse with the tutor by picking up the argument and moving it in an appropriate direction.

Jasmine And then that equals to K_{sp} , and that's why if you want the solubility for that you square root it. But how did you know that is like an ionisable drug?

Tutor OK. That's the heart of the question, is what the equilibrium constant is equal to depends on whether it's ionised or not. So you need to go on some clues that you might have in the question. Here I've told you morphine, and the other two, sodium cromoglycate, thiopentone sodium. Is there any of those three suggest anything in particular?

Tutor About ionisability.

Tutor You've got a sodium salt.

Jasmine That will probably ionise.

Tutor That would probably ionise. So you've got here two sodium salts: sodium cromoglycate, and sodium thiopentone. But with morphine, it doesn't say anything about salts. It doesn't have any indication that it's a salt.

Jasmine Oh. Cos this has got two words, kind of.

Tutor Well, yes, and you recognise one of them as a cation,

Jasmine Yeah, yeah.

Tutor a small cation. And you're used to seeing those as, um salts. So, I mean you'd be used to sodium chloride, sodium sulphate, those sorts of things.

Jasmine Yeah

Tutor So, when you see sodium salts, or chlorides, or sulphates, or nitrates, or bromides or anything that you're used to seeing as a salt form, you can say that's going to form ions when it dissolves. And so in that situation, the equilibrium constant will be what?

Jasmine K_{sp}

Tutor It'll be K_{sp} when it forms ions, yeah? When you've got something like morphine, it doesn't have any indication with it that it's going to form ions in solution. So you can't assume that it's going to. So the equilibrium constant.

Denise That's why you don't have to square root it.

Tutor That's why you don't have to take the square root in that situation ^(PC1.664-679)

Asking for elaborations

In general the tutors did not ask the students to elaborate, because the students often offered their own spontaneous elaborations. A later section describes the tendency of members of the PC group to articulate their understanding of the tutors' explanations and discourse in their own words without prompting.

Diagnosing error

Fewer interactions involved diagnosing errors than was the case for the TC group, however the tutor was able to assist Isabelle with the arithmetic of a solubility calculation:

Isabelle I'm using three point three.

Tutor Ah, ha. Yep. So that's, is that for S?

Isabelle Yeah.

Tutor OK, so what you'll need to do here, it'll be one gram divided by one eighty. And that will change it, that will get it to

Isabelle that will be one gram, instead of three point three

Tutor Yep.

Isabelle divided by one eighty

Tutor Yep.

Isabelle so that gives you the moles.

Tutor Yep ^(PC2.696-721)

Explaining

As indicated above, the PC group frequently formulated conceptual questions before requesting the assistance of a tutor, and thus the tutors engaged to a greater extent in explanations than in leading questions. For example, Jasmine attempted to explain the reasons for using a particular value in a calculation, but it was clear that not all of her peers followed her reasoning. When the tutor was summoned, the group request was phrased as follows:

Jasmine Can you just explain to them why you have to use the K_{sp} , cos I tried, but I didn't think I did a good job.

Kellie We didn't understand, yeah, why. You have to square, we understand that bit, but then like, why do we put that in place of the S_1 when you use the equation? ^(PC1.433-434)

As a consequence of the specificity of the question, the tutor was able to tailor her explanation more finely to the students' difficulties, and to focus on the conceptual underpinnings rather than the mechanics of carrying out the calculation:

Tutor Okay. The reason you put it in place of the S_1 is the S_1 is only a substitute for the equilibrium constant. So the real, um, values that go in the van't Hoff isochore have to be equilibrium constants. But what we've done on this page here and over the page is say let's look at some specific equations, oh sorry, specific reactions, and say well, for that particular reaction, can we simplify the equilibrium constant to something else. So we looked at, um, evaporation, and it turns out the equilibrium constant is actually equal to the vapour pressure. Because everything else is 1. When we look at the dissolution of drugs that don't form ions, everything else has an activity of 1, and so the equilibrium constant is numerically equal to the solubility. And only because that's true, can we put it into there. OK. So that's really an equilibrium constant, because the van't Hoff isochore requires an equilibrium constant. But because in this specific case, equilibrium constant is also equal to solubility, then you can use it.

Denise And is that only for when they don't dissociate?

Tutor Yep. When they do dissociate, over the page, you have to work out what the equilibrium constant is in this new situation. And the new equilibrium constant is not the solubility, but the K_{sp} , because you've got the two ions now, that's the product of their activities. And so that's K_{sp} , rather than solubility. And so you have to use K_{sp} because it's the equilibrium constant ^(PC1.435-437)

Modeling appropriate discursive practice

As was the case with the TC group, the tutors frequently engaged in responses which were intended to provide a model of discourse appropriate to the pharmacy community. In contrast to the TC group, however, members of the PC group often followed the model discourse with articulation in their own words. A clear example of a cycle of tutor modeling, followed by student articulation is found in episode PC2.2 ^(PC2.2:1094-1119). The tutor initially modeled the pharmacy perspective on the significance of pH and pKa, namely that pKa was a characteristic of the drug molecule and the pH of the environment, rather than the Chemistry perspective that drugs were characterised by pH ^(PC2.2:1094). This was followed by an explanation of the method of determining the state of ionisation of the molecule at specific pH values ^(PC2.2:1100-1103), which was then articulated by Denise ^(PC2.2:1106-1108). A reiteration of the concept by the tutor ^(PC2.2:1109-1111) was subsequently followed by Isabelle's articulation of her understanding ^(PC2.2:1113-1116, accompanied by pointing to the worksheet).

A long explanation of the relationship between equilibrium constants, solubility and K_{sp} during workshop 1 was followed by a reprise of the concept, initially by Kellie and secondly by Denise, both of which were affirmed by the tutor:

Kellie So we're not actually looking at the solubility. We're looking for equilibrium constant?

Tutor Yep.

Kellie And it's just for in this equation, in this situation, it's the solubility.

Tutor In that situation, equilibrium constant is the same as the solubility, yes.

Kellie OK ^(PC1.445-449)

Denise And that is, they're the only two places, isn't it? When they do dissociate, then it's the K_{sp}

Tutor Yep

Denise and when they don't, it's solubility

Tutor That's right, yep.

Denise OK, that's pretty simplified ^(PC1.462-466)

Tutor modeling was not always accompanied by student reiteration, however, and additional examples of modeling of appropriate discursive practices can be found in the tutor's explanation of the rationale for assigning molecules as neither acidic nor basic ^(PC1.5:1221, 1237, 1239).

Suggesting a starting point

Since the students in the PC group had generally been able to make a start on the exercises they attempted, in general the tutors asked questions rather than suggesting starting points. A starting point was suggested to Isabelle as a result of diagnosing her calculation error (page 234), but this was a rarity.

Student behaviours in interaction with tutor

As was the case with the TC group, members of the PC group valued the assistance of the tutors, but in contrast all PC participants generally remained engaged in the interaction for the duration of the tutor's explanations. Engagement took the form of eye contact, listening while looking at worksheets or lecture notes, and writing in response to the tutor's words. Entering into the interaction was sometimes staggered, as individuals finished the immediate task at hand before attending to the tutor, and occasionally an individual disengaged to return to individual work, but the pattern was clearly joint attention. Isabelle and Alicia were more likely to participate tacitly rather than actively, but their engagement was apparent in the direction of their gaze.

Isabelle was the only student who engaged in an extended one-on-one interaction with a tutor, which took place in the context of the tutor's general direction about the method of carrying out a calculation. Isabelle indicated to the tutor that she had already attempted the suggested approach but could not find where she had made the error ^(PC2.678-782). At the time of this interaction, the remaining five group members were engaged in an animated follow-up discussion of the tutor's explanation and individual attempts at the same calculation, which were ultimately successful.

Consistent with their approach to the workshops as learning opportunities, members of the PC group commonly asked questions of the tutor which extended the discussion to concepts and approaches which were only indirectly addressed in the workshop activity, or which linked concepts from different exercises. For example, following the discussion about the difference between the equilibrium constants for sodium cromoglycate and morphine (page 233 ^(PC1:664-679)), Jasmine addressed an issue which had arisen in a previous exercise: '*Yeah, like the question before. We were thinking oh yeah, silver chloride, that's a precipitate, you can't break it up and stuff. But how could that dissociate?*' ^(PC1.691). This was an important question because it identified a conceptual difficulty for the group which was not directly related to the specific exercise, but which the tutor was nevertheless able to address. During a later discussion about discriminating between amines and amides, the students spent some time speculating about the reasons for the different characteristics of the nitrogens and finally summoned the tutor to ask '*Is the reason why the N*

attached to the amide group is not basic because its lone pairs are engaged in the bond, or something?' (PC1.1268). The chemistry underlying this question was not relevant to the activity of identifying acidic and basic functional groups, as it was part of the second rather than first year curriculum, but the students' wish to learn and understand at a more meaningful level manifested itself in a deeper exploration of the topic.

In summary, the PC group behaviours were consistent with a strong focus on developing conceptual understanding, and as a consequence, the PC group appeared to gain greater advantage from their interactions with the tutors. Certainly the tutors were regarded as problem solvers, but they were also perceived as useful in explaining underlying phenomena and principles. Members of the PC group were prepared to continue discussing activities after the departure of the tutor, and these discussions provided critical opportunities for appropriation of conventional concepts, and thus for conceptual change.

7.4 Participants' perspectives on the relational space

During the second and third interviews, each study participant was asked for comments about the functioning of their group during the teaching semester. The questions were very open-ended, and sought to allow the expression of frank and honest opinion. References in this section are to interviews, and unless specifically noted, the interview is of the student under current discussion. The participants' responses can be found in Appendix G.

Transient change group

General

All students found their experience of working as a group somewhat frustrating and less than ideal, and it was apparent that significant tensions developed between them throughout the semester. Important determinants of these tensions included the closeness of college life, the competitiveness of the higher achievers, and the different ways of approaching learning and studying. All students identified that Janine had been the major contributor to the group tensions in an academic sense, but that more general interpersonal tension was also significant. As tension mounted close to the exams, they requested that the final workshop session not be videotaped, although interviews with all group members suggested that it was only Larry who was particularly agitated by the presence of recording equipment.

Janine's perspective

Janine was very forthright in expressing her opinions, and she clearly felt that the group experience had been less satisfying than some groupwork situations which she had experienced previously^(2.98). Janine suggested that it was essentially differences in personality, study habits and goals

which lay at the heart of their group difficulties, and she clearly saw herself as different in terms of her role within the group, dedication to study, and personal goals.

Janine saw her role in the group as the authority who was expected to know the answers and provide assistance and explanations to the others^(2.106, 2.216); there was little evidence that she expected to learn anything from other members of the group, and her expectations defined her attitude and behaviour. She was to some extent aware of her own shortcomings as a group member^(2.128), and expressed the opinion that her study behaviour had exacerbated the group tensions^(2.142-2.144), however some contradictions were apparent in her comments. At some points she claimed to be willing to make explanations, but at others she adopted a more self-focused approach in which her personal goals were pursued to the exclusion of her friends' perceived needs^(2.212-2.216).

Janine was critical of the other group members' dedication to work^(2.116), suggesting that they could be uncooperative and lazy, and did not meet her expectations for focusing on the task at hand^(2.216-2.218). Larry's behaviour was seen as particularly counter-productive^(2.106), while she was both sympathetic and frustrated by Emma^(2.102-2.106). By her own admission, she did a lot of work, perhaps more than was necessary^(2.154-2.158), and believed that others, particularly Lucy^(2.108), were not prepared to do as much as her. The only group member who was not criticised was Geoffrey, whom she described as '*fine*'^(2.110). There was little if any suggestion that Janine believed herself to be more able than the others, rather she generally attributed her success to working harder. A hint of condescension was however evident in her comments about other group members whom she described as less advanced than herself^(2.154).

According to her own comments, Janine had '*different aims towards study*'^(2.138) than the others in her group, and was generally happier working by herself^(2.142, 2.210-2.212). This was also evident in the workshop sessions, although Janine was by no means the only person who worked alone. She would have been happy to work with someone else who was, as she put it, '*on the same level in terms of dedication*'^(2.140-2.142), but she believed that no other student in her group met that criterion^(2.116). She did not necessarily blame them, but conceded that perhaps she had contributed to their feelings of frustration^(2.154-2.158). In general, Janine believed that group work was better with smaller numbers of very like-minded students^(2.100-2.102, 2.112).

Janine's behaviours in workshop sessions reflected her aims. She was highly task oriented and regarded the sessions as a vehicle for getting the work done^(2.112), rather than an opportunity for learning together. Her interactions with other students revolved around the exchange of information rather than a collaborative attempt at joint problem solving, and she appeared to be unwilling to be dragged behind^(2.112) by those who were slower than her at completing the assigned activities.

In spite of her dissatisfaction with many of the aspects of the group academic dynamics, Janine felt at the end of the year that these students were still her best friends^(2.132). She remained ambivalent

about the wisdom of combining academic and social relationships, insisting that it could work in theory, but that in the current situation it had not ^(2.139-2.146).

Geoffrey's perspective

Geoffrey was positive about working with others as well as working by himself, and perceived advantages to both modes since they complemented each other: by himself he '*got more done*' ^(2.62) because he faced fewer distractions ^(1.594-1.600), but in a group he found he could learn more ^(2.130). The advantages of group work were the opportunities for all group members to benefit from collective knowledge ^(2.144-2.156); not only could peers pose and answer questions from each other, but also assist them to '*pick up a lot of what you don't know*' ^(2.148), which would be less likely to happen when the individual worked alone. He also demonstrated an awareness that learning occurred more effectively when members supported each other's learning rather than focusing on their own needs. Geoffrey did recognise that there were potential disadvantages to group work ^(2.162), however on balance he appeared to find the group interaction more beneficial than constraining.

Geoffrey found the format and atmosphere within the workshops to be conducive to learning ^(2.120-2.128), however, he expressed the strong opinion that informal group work outside class time was more beneficial than time spent in the classroom. This was clearly and unequivocally attributed to a single factor, the absence of Janine in the informal sessions ^(2.68-2.80). He identified a number of reasons why Janine's presence was problematic for the rest of the group, in many respects pinpointing the same issues as Janine herself, but from a different perspective. Firstly, he corroborated Janine's self-perception that she had different aims in relation to the workshops compared to the others in her group ^(2.100-2.104). Geoffrey believed that Janine had studied the lecture material before attending the workshops, and that she used the workshops as an opportunity to confirm what she already knew rather than to learn anything new ^(2.106-2.108); as a result she simply completed the work assigned ^(2.106). He attributed this to conscientiousness rather than superior understanding ^(2.110-2.112), although he did acknowledge that she was '*a bright girl*' ^(2.82). In contrast, Geoffrey and the rest of the group treated workshops as learning opportunities ^(2.104). Janine's differential aims constrained the learning of the others in the group, even when they were not interacting directly with her, and thus the most effective group learning occurred when she was absent.

Secondly, he did not necessarily perceive a dedication to study such as that demonstrated by Janine in a negative fashion, but he regarded it in Janine's case as affecting, and perhaps reflecting, attitudes which were counterproductive to the group dynamics: '*Like some people do work hard, some people work very hard right, but then when it comes to, like they, they don't, (pause) it doesn't affect their character though. Whereas it will get, affects her char, her character*' ^(2.236-2.238). His opinions about Janine's attitudes were expressed in strong terms, including '*arrogant*', ^(2.202),

'cocky' ^(2.240) and 'narky' ^(2.90), and he regarded her as displaying her knowledge in an insensitive, superior and discouraging manner.

The combination of conscientiousness and unhelpful attitudes was clearly seen by Geoffrey as manifesting in unproductive interpersonal interactions between Janine and other group members. He perceived Janine as focussed on herself, rather than sensitive to the collaborative purpose of the workshop, and as unwilling to engage in activities which were not to her liking ^(2.88-2.98). In the single-minded pursuit of her own aims, Janine was seen as 'pushy' ^(2.86) and 'bossy' ^(2.86), and a source of tension and stress within the group ^(2.84). Geoffrey expressed the opinion that Janine did not like group work because she saw it as a hindrance ^(2.162-2.164), and he believed that others shared his opinion. He himself was unwilling to interrupt her during class sessions ^(2.165-2.166), and believed that this unwillingness was shared by Lucy ^(2.170-2.172). He was particularly incensed by an incident which occurred between Janine and Emma during the examination period. As indicated earlier, Emma suffered from glandular fever for most of the semester, missing many of the scheduled classes, and therefore needing to learn largely by herself in a much abbreviated period. Geoffrey related an incident occurring a few days before the IPS exam in which Janine was purported to have told Emma, '*Oh it took me a long time to get a grasp of all this sort of stuff, and I don't think you'll be able to do it in two days so I think you're pretty much screwed*' ^(2.224). This incident was reported second-hand and therefore may not be entirely accurate, and Emma did not refer to it at all, but it appeared to be of significance in shaping Geoffrey's opinions about Janine.

As a result of their experiences during the semester, Geoffrey felt that friendships with Janine had deteriorated ^(2.196-2.228). He did not see this effect as originating from the workshops or participation in the study, but felt that it was a result of getting to know more about what Janine was like ^(2.228-2.234). The friendship which had originated from the shared circumstances of living in residential colleges during the first year in a new learning environment was seen as untenable because of the magnitude of the incompatibilities between the individuals involved, where one member was perceived as lacking the interpersonal qualities necessary for the maintenance of a collaborative relationship.

Although his opinions were strong, Geoffrey always appeared to be uncomfortable in criticising Janine, and was careful to be as fair as he could while remaining honest about his feelings. He demonstrated considerable insight into his peers and their motivations, and came across as generous, caring and encouraging towards other people. He offered few opinions about the rest of his group, and the opinions he shared were generally positive. He perceived Larry as studious and hard working ^(3.112), and competitive in terms of study, although Geoffrey felt that competition was beneficial to both of them ^(3.118). He displayed considerable empathy in relation to Emma and the difficulties she faced as a result of her protracted illness ^(2.226), and was perceived by others in the group as helpful and pleasant to work with. Emma described him as '*wonderful*' ^(Emma 2.210); he '*helped whenever he was requested, and never yelled and [would] be very patient all the time*' ^(Emma 2.186).

Larry's perspective

As previously indicated, Larry was returning to study after a break, and was struggling to re-establish effective study patterns. Consequently, group work was an important key to Larry's success in learning ^(2.22).

Like Geoffrey, Larry perceived that group work outside formal class times was more beneficial than group work during workshops, and was in agreement that the fundamental reason was the absence of Janine ^(2.36). His three primary concerns with Janine closely mirrored those expressed by Geoffrey: her approach to learning which he saw as poorly compatible with the approach of the others in the group, her attitudes towards the others, and her behaviours when interacting with the others.

Larry perceived that Janine attended the workshops in order to complete work that she already knew, rather than learning it during the workshops ^(2.36-2.40) which contrasted with that of the other members of the group ^(2.40). Like Geoffrey, Larry acknowledged that Janine was a particularly hard working and conscientious student ^(2.40), and that as a result she was able to work at a much more rapid pace on the problems during the workshops. This in turn was perceived by Larry as putting additional pressure on the remaining members of the group to work in such a manner as to match Janine, rather than in their preferred way ^(2.36-2.42).

Larry shared Geoffrey's opinions about Janine's attitudes, and believed that she was not '*conducive*' to his learning ^(2.96). According to Larry, Janine saw herself as more advanced than the others who were '*not up to her level*' ^(2.38), displayed no sense of responsibility or loyalty to the group ^(2.44), and did not '*appreciate the fact that, you know, you're trying to learn*' ^(2.38).

Larry related a number of ways in which he saw Janine's attitudes reflected in unhelpful interpersonal interactions. Shortly before the IPS exam, while the rest of the group was studying, Janine indicated that she had already learned all there was to know, much to the exasperation of the others ^(2.116). He was also critical of her interactions during workshops, where she was perceived as '*reluctant to give assistance*' ^(2.92), and liable to behave in an insensitive and superior manner because of her greater knowledge. She would help by providing the answer or the approach to use in solving a problem, but she would do so in a manner which indicated her irritation at being asked ^(2.36).

The sessions without Janine were seen as considerably more beneficial because the other four students were more relaxed and cooperative with each other, and were closer in level of understanding and approach to study ^(2.44, 2.64). Larry corroborated Geoffrey's description of, and enthusiasm for, the pre-examination study sessions ^(2.12-2.16) which were characterised by mutual respect and willingness to help, with individuals seeing benefit both in explaining to others and in listening to others' explanations ^(2.22-2.24). Larry clearly drew a contrast between this type of

collaborative interaction, and the ways in which Janine responded to requests for assistance from other members of the group. Even though there was some form of implied imposition within the group study sessions where valuable study time was diverted into explanation to another student, this time was not given grudgingly because of the mutual benefit gained.

Beneficial collaboration was not, however, limited to extra-classroom activities, as Larry believed that working within the workshops could also be productive, provided that Janine was not present. He indicated that when Janine had left early from the final workshop, the remaining four students worked productively since they found themselves '*a little bit more relaxed, just trying to do it at our own pace*'^(2.64). This is particularly significant because two factors might have been expected to increase the pressure in the final workshop. Firstly the final workshop involved Emma, who had not been well enough to attend the earlier sessions, and was struggling to understand and solve problems relating to material she had not previously seen. As a consequence she was highly reliant on assistance from the others. Secondly, the workshop was held in the final week of semester, and Larry had made it abundantly clear that the proximity of the exams was a significant source of stress for him, and possibly the others^(2.54). Despite both of these potential stressors^(2.48), Emma was helped considerably by the other members of the group, and was able to understand how to solve the problems by the end of the workshop^(Emma 2.178-2.182), and Larry still found the session more relaxing. It is also likely that the absence of the video recording equipment facilitated this perception, however the absence of Janine was clearly a significant factor. Larry did admit that his reaction to the proximity of exams may have exacerbated underlying tensions within the group^(2.48), and significantly, that much of the pressure was of his own making^(2.78-2.80).

In terms of the impact on friendships amongst group members, Larry was initially the most equivocal about how things had changed during the semester, but five months later he was the most vocal. During the second interview, he was clear that working together with Emma, Lucy and Geoffrey had strengthened their friendship, but was less certain about whether his relationship with Janine had changed irrevocably. He felt that perhaps it had^(2.106), but that it was more likely that the problem would be temporary and reversible^(2.117-2.118). During the third interview, however, his perceptions had changed dramatically, and he suggested that many relationships within the group had deteriorated significantly^(3.466-3.478). The catalyst was not perceived to be what had happened specifically in IPS, but rather underlying interpersonal issues and the amount of time they had all spent together^(3.470-3.486). Larry was optimistic, however that these difficulties were not irrevocable, and that their relationships could be saved in time^(3.488).

Lucy's perspective

Lucy had not previously found group study to be effective^(2.20), but this time started informal group work with Larry and Emma, asking Geoffrey for assistance when they needed it^(2.8), and she found the approach beneficial. Her stated reason for engaging in group work on this occasion was fear of the exams^(2.22), however, the group work was perceived as useful in itself because of the benefits of

collective knowledge^(2.12). Lucy's comments were consistent with those of the other group members about the effectiveness of the group study sessions before the examinations.

As with the others (apart from Janine), Lucy found that the group work outside the workshops was more effective than the work in formal sessions. She agreed that Janine was one of the reasons, but also attributed the greater effectiveness to her own preparation and contributions^(2.28). Attempting the workshops during the semester as they were scheduled did not allow Lucy time to revise and attempt to understand the material beforehand, and thus her time in the workshops was not used to best effect²¹. She was generally unenthusiastic about the workshops, and found it difficult to pinpoint anything particularly useful about them^(2.32). Within the workshops, she did find Geoffrey and Larry helpful, primarily because she felt more comfortable asking them questions than she did Janine^(2.34-2.36). On the other hand, when exams were close, she was willing to work more diligently outside class time, as were the others^(2.12).

Lucy felt that her friendships had not been significantly affected by working together as a group during the semester, and on reflection at the end of the year, believed that working in that group had been beneficial, although it was not clear from the interview whether she was including Janine in the group when she discussed it^(2.40). She indicated that she had never really been close friends with Janine^(2.42-2.44), and so the experience of working together in IPS had not really changed that situation, although she did admit that '*I probably talk to her less now I think*'^(2.44).

Lucy's interviews portrayed her as someone who was happy to meet her own, fairly modest goals, and to 'go with the flow'. It was not clear if she was particularly aware of the depth of the group tensions: if she was, she chose not to discuss them, perhaps because she herself did not experience them as personally detrimental. Certainly it appeared from the comments of all group members that Lucy was the least affected by the issues which frustrated the others, and she appeared to be able to get on with everyone else in a reasonably friendly manner.

Emma's perspective

Emma engaged in the informal group study sessions with Larry and Lucy, and found them particularly useful for Chemistry^(2.144), with the benefit mediated primarily by a relatively equal sharing of knowledge and expertise^(2.146-2.148). However, because Emma was a long way behind in IPS, the group study simply made her feel more inadequate, and she believed her knowledge was so poor that she could not even begin to study with them^(2.150). As a result, Emma tended to study by herself, using the printed course notes, and her interactions with other group members were restricted to requests for help with specific difficulties^(2.152-2.154).

Although she attended few of the workshops, Emma was aware of the tensions and experienced them for herself in the final workshop. When asked by the interviewer how the group functioned

²¹ This was consistent with her workshop behaviours as described earlier in this chapter.

during the workshops, Emma's immediate response was to talk about Janine's propensity to work by and for herself^(2.170-2.172, 2.182). In relation to the final workshop, which included a smaller set of problems than the earlier sessions, Emma's description of Janine's behaviour was graphic: '*She finished early and then I got rather pissed off actually, (laughs) coz she um, she finished and we'd all, you know, we all knew what we were, I didn't know what I was doing, but I picked it up from them ... she had to make a show of the fact that she'd finished, and she slammed down her books, and organised, and talked, and then went "I'm leaving", really loudly, and then left.*'^(2.178-2.182). From the responses of the others who remained, Emma clearly identified the friction that this incident highlighted^(2.182).

Despite Emma's perception of Janine as highly competitive and somewhat ostentatious, she nevertheless recognised in Janine some enviable characteristics, specifically her self-discipline, and Emma was honest enough to recognise her own shortcomings in this area^(2.66-2.74). Emma was a self-confessed crammer for exams, and clearly wished to be able to use a different approach, but was realistic enough to be aware that her level of self-discipline was unlikely to allow her to mimic Janine's work ethic. A further area in which Emma recognised Janine's good qualities was in group work, where Emma acknowledged that the outcomes from working with Janine in a group project were likely to be good, because '*she tends to (pause) tell you what to do*'^(2.224), and '*she does know her stuff, and she does her work well, and in terms of, you know, when you're doing group work, you want the marks and she's good for that*'^(2.230).

Interestingly, Emma did not find Janine as aloof and uncaring towards her as the others expressed, discovering that Janine would answer questions, provided Emma did not ask too many^(2.192-2.194). In particular, Emma valued Janine's ability to explain, especially when she had been unable to understand the explanations of others^(2.188). She did recognise that Janine did not act the same way towards everyone, and observed that Janine left Larry feeling stupid, even when his questions appeared to be reasonable^(2.190-2.192).

A number of explanations for Janine's more accommodating behaviour towards Emma are possible. Emma was closer to Janine in temperament and goals, since both were competitive and forthright in expressing opinions. Further, both perceived group work as a means of completing a specific task, and Emma was appreciative of the fact that Janine would pull her weight in a group assignment so that the end product would result in good marks^(2.230). Emma specifically indicated that she and Lucy did not have a great deal in common^(2.222), whereas she indicated that she did generally get on well with Janine, apart from times when Janine was under stress^(2.208). Further, Emma's preference for Janine's explanations may have indicated that the two of them thought and talked using similar language, and that intersubjectivity was more easily established between them. Janine appeared to be more sympathetic towards Emma because her need for assistance was a consequence of her poor health^(Janine 2.102-2.106); certainly Emma did not draw the criticisms Janine leveled at both Larry and Lucy of laziness^(Janine 2.106-2.108). It is also likely that Janine perceived Emma's manner in approaching her for help as less irritating than Larry's^(2.190). Finally it is

possible Janine was aware that Emma looked up to her to some extent, both academically and intellectually, was and somewhat flattered as a result.

Nevertheless, Emma was cautious in her overall opinion of Janine, describing her as '*lacking in other things and personality-wise*'^(2.66), and sometimes '*very difficult to work with*'^(2.230). Emma appeared to appreciate the different sides to Janine and to make the most of her 'good' qualities while being careful to avoid annoying her. It is particularly interesting that Emma made no reference at all to the incident described by Geoffrey in which Janine was purported to have acted insensitively towards Emma^(Geoffrey 2.224), since this incident was clearly significant in shaping Geoffrey's attitudes towards Janine.

Emma offered positive and affirming opinions about the others in the group. Lucy was perceived as a diligent worker^(2.186) who was good to have in a group^(2.218-2.222). Larry was seen as helpful and generous with his time^(2.200-2.202). Although Emma was clearly aware of Larry's reaction to the proximity of exams, she was not critical when he was under stress^(2.202). Geoffrey was seen as '*wonderful*'^(2.210), patient and always willing to help^(2.186). Further, he was able to offer calm reassurance, both by what he said and how he behaved, when Emma was feeling overwhelmed by the amount of work she needed to complete^(2.210-2.216).

Emma believed that participating in the study had little impact on group friendships apart from the fact that she was now going out with Larry^(2.196). She still described Janine as a friend^(2.206), but did admit that some distance had developed^(2.204-2.208). As with others in the group, she had decided to start '*branching out in terms of friendship*'^(3.22), not because she no longer liked the others in her group, but because there were plenty of other people to meet^(3.26-3.28).

In summary, this group discovered that the circumstantial bonds formed by living together in adjacent on-campus colleges were not in themselves sufficient for the creation of a collaborative unit. Differences in personal characteristics, goals and approaches to study, and poorly compatible interpersonal attitudes and behaviours created tensions which constrained productive interactions when all five students were together. Although the constraints were to some extent ameliorated by the spontaneous formation of a smaller study group, the fact that this study group met outside formal class time meant that the resources for collaborative learning were limited to peers. Interaction with tutors, as members of the pharmacy community, was not possible under these circumstances and the students were thus unable to experience appropriate modeling of discourse and approaches to problem solving. Further, encouragement of conceptual change was minimal, since the study group formed late in the semester for the purpose of achieving examination goals rather than learning the practices of the pharmacy community. Conceptual change was certainly not impossible under these circumstances, but the nature and direction of any change was open to idiosyncrasy rather than developing towards socioculturally accepted norms.

Persistent change group

General

All students found their experience of working as a group to be positive, enjoyable, and beneficial for learning, all commented positively about the helpfulness of all other members of the group, and none was willing to single out any individual as being detrimental to the functioning of the group as a whole. In general, participants did not spend much time discussing other members of the group, largely because there were no perceived issues.

Veronica's perspective

Veronica strongly believed that her group was a good one in which to be involved, both for social and learning outcomes. She indicated that the group had largely organised itself before the first workshop as a consequence of pre-existing relationships^(2.76-2.80), with Kellie known from school^(2.82), and the other girls as acquaintances from the previous semester. Both academic and social ties linked Veronica to other members of the group^(2.92-2.98), and although Alicia was a relative outsider, she was clearly welcome within the group as evidenced by the specific invitation extended to her to join^(2.76-2.80).

The group was seen as beneficial for a number of reasons. Primarily, Veronica was comfortable discussing issues with the rest of her group^(2.106-2.112). This ease of talking had some drawbacks in that *'because we were friends, we used to go off the topic heaps, well, and we didn't really finish all of the worksheets'*^(2.48-2.52), however Veronica did not perceive this as a particular problem because of the thoroughness of the discussions^(2.56-2.64).²² All group members were regarded highly for their contributions and helpfulness, and none was criticised. Veronica was conscious of the quieter members of the group, but believed that they all contributed appropriately and supportively^(2.148-2.150).

Veronica believed that participation in the research study had benefited the group because they were all motivated towards greater diligence^(2.128-2.132, 2.136-2.138).

Denise's perspective

Denise was positively predisposed to group work, since it was important for her learning that she be able to discuss concepts and problems^(2.118-2.126). Involvement in a good group was therefore critical for Denise, and she was very happy with the group in which she worked throughout the semester^(2.52). The academic and social dimensions were equally important: she considered that the

²² Observations of the videotaped workshops and analysis of the transcripts did not suggest that this group was excessively off topic in comparison to others. They spent considerably more time on task than the TC group as described in an earlier section of the chapter.

workshops were the most useful learning environment within the subject ^(2.164-2.170), and by the end of the semester, the other group members were all regarded as good friends ^(2.76).

Denise offered three major reasons for the effective functioning of her group. Firstly, she believed that all members of the group were cooperative ^(2.54-2.56); secondly, because she knew them all, discussion was easier ^(2.64-2.66); and thirdly, they were all willing to contribute to each other's learning ^(2.130-2.134). Denise also felt that she had contributed to the group, although she was modest about the extent ^(2.137-2.142).

From a personal perspective, Denise also found the discipline of group work in a weekly tutorial to be helpful for her learning ^(2.174). She found that the workshop activities requiring discussion were the most beneficial for her, because they required the group to '*discuss, yeah, and come up with different ways of thinking, yeah that was good*' ^(2.148-2.152) since '*it required discussion, like it's not a matter of just working it out, like using a formula*' ^(2.154). She also believed that group work was most effective when she already had a preliminary understanding of the material to be covered ^(2.300-2.316).

Denise perceived that the purpose of the workshops was to spend time on the problems, and she felt that this was a good use of time. She suggested that even more time in workshops would be appropriate, although she felt that two hours was sufficient for any session ^(2.180).

Isabelle's perspective

Isabelle described herself as '*not too much of a group work person*' ^(2.118), but she found the experience of working with this group to be good ^(2.129-2.130, 2.173-2.174). She identified four reasons for her satisfaction with her group. Firstly, they were easy to work with because '*they're easy to talk to*' ^(2.138) and '*good to get along with*' ^(2.142); secondly they were motivated and conscientious, which reduced Isabelle's stress levels particularly with respect to group tasks and assignments ^(2.176-2.186); thirdly they became her friends through the semester, and she was happy to socialise with them to some extent ^(2.134-2.136, 2.166-2.168); and fourthly they accepted her, despite Isabelle's perception that she was not as intelligent as the rest of the group ^(2.140-2.144).

Isabelle tended to work by herself for much of the time, partly because she indicated that she preferred to do so ^(2.118), but also partly because she felt inadequate ^(2.128). She sometimes felt guilty about obtaining assistance from the others ^(2.120-2.128), but none of the others begrudged their assistance, and indeed saw Isabelle as someone who also provided helpful input. Isabelle's only perceived negative about this group was her own self-criticism ^(2.154). No individual was singled out for special mention for the provision of particular assistance, as all were considered equally helpful

(2.233-2.236). She did indicate that '*our group was slow at getting answers*' (2.256), but that this was not a problem because '*the answers*²³ *to the tutorials were good*' (2.254).

Jasmine's perspective

Jasmine was the most likely to take on an unofficial leadership role within the group, and her awareness and encouragement of all members of the group to participate was a critical aspect of the group's cohesiveness. She was keenly aware of not excluding the quieter members of the group, particularly Isabelle and Alicia (2.142-2.144).

Jasmine was positive about the benefits of working in a group (2.146), provided that everybody pulled their weight (2.168). Working in a group also provided much of her motivation to carry out the assigned activities (2.88), and this particular group was perceived as good both socially and academically. Jasmine's initial comment was that '*it's really fun*' (2.82), and she found the experience '*socially good*' (2.104), however this was coupled with her opinion that the group facilitated her learning (2.166). Three major reasons emerged for this opinion: firstly, group members responded sympathetically when someone expressed ignorance or poor understanding, secondly group members were more than willing to help each other, and thirdly, group dynamics were based on friendly relationships which facilitated easy conversation between members. Each of these three dimensions is outlined further below.

Jasmine repeatedly expressed the belief that she was '*not as bright*' (2.122) as some of the others in her group, and that she gave the impression when she spoke that she did not understand (2.124). However, one of the benefits of working in this group was that Jasmine's willingness to verbalise her difficulties often uncovered similar difficulties for the other group members (2.106-2.114). When such a situation arose, the group was likely to seek assistance from a tutor (2.94-2.96), thus providing opportunities for students to benefit from expert modeling.

Apart from the tutors, students were also very willing to offer mutual assistance (2.118-2.120). Jasmine made her own contributions to the learning of others, although she was characteristically modest about the extent (2.122).

A critical characteristic of the group dynamics was that '*we get along, like we can easily talk to each other*' (2.134). This was facilitated by friendships outside class, and also by working together in other classes. Jasmine had not been close friends with any other members of her group in the previous semester, but by the end of first year described herself as '*very close friends with Veronica and Kellie, maybe Denise too*' (2.158), and friendly with Isabelle (2.162). Only Alicia was not classified as a friend, but she was still perceived as someone who would be good to work with in future groups.

²³ This was a reference to the printed answers which were provided to students in the following week's workshop.

Although she did not emphasise it, Jasmine was aware that her group worked more slowly than other groups. She attributed this partly to the timing of the workshops ^{(2.88-2.90, 2.96)²⁴}, and partly to the fact that it took the group time to *'settle down and, and really get your head working again'* ^(2.364-2.366). As a consequence they would often skip activities to make sure they covered the worksheet which was to be submitted for assessment and feedback ^(2.342-2.344), however she offered no opinion about the effect of this pattern of activity.

Kellie's perspective

Kellie was very positive about working with the other members of her group, and expressed the belief that the group work was a critical factor in the learning of group members ^(2.60). Kellie focused more on the learning than the social side of groupwork, although she was clear that she regarded the others in her group as friends, and that she spent a good deal of time with Veronica, Jasmine and Denise ^(2.94-2.100). Kellie identified three aspects of group work that she found beneficial for her learning and the learning of the others in the group.

Firstly, Kellie perceived the group as strongly collaborative, manifested as a willingness to share ideas and explanations ^(2.50-2.60), and she believed that the level of discussion was a key factor in their learning ^(2.148). She expressed the opinion that Denise, Jasmine and Veronica were particularly helpful ^(2.122), but even those individuals who were quieter were valued, as Kellie believed that they were participating by paying attention to what was being discussed ^(2.72-2.78).

Secondly, the group was open and supportive of anyone who expressed a lack of understanding or an inability to solve the problems that were set ^(2.62-64, 2.154). Interestingly Kellie recognised the experience of providing the explanation ^(2.64-2.68) as an additional benefit to the individual.

Thirdly, Kellie found the experience of working together provided both motivation to attempt the work, and an environment in which she could be more efficient and productive ^(2.118-2.120). Kellie was also positive about the workshop format itself ^(2.162-2.168), and particularly appreciated the chance to work through problems which had proven to be difficult in the class quizzes ^(2.126-2.132).

Alicia's perspective

Alicia's initial response was to focus on the fact that *'we were slow'* ^(2.62), and *'so we couldn't move onto other questions'* ^(2.68), but she did not see it as necessarily negative ^(2.121-2.122) because *'it was good that you had other ways like, of doing it'* ^(2.68). She perceived that the group was supportive and helpful, and that members were *'trying to get each other to understand'* ^(2.77) by engaging in extended discussion ^(2.170).

²⁴ The workshops ran from 1pm to 3pm on Thursdays.

Alicia believed that participation in the group had been beneficial for her learning, both at the time of the workshops and subsequently when she was learning by herself. At the time, although they were slow, and tended to finish only the relatively easy questions and '*left the harder questions out*'^(2.126), Alicia believed that they were thorough and that '*I understood the really basic basics*'^(2.130) well. As a result, Alicia was able to use this solid grounding in the basics to learn the more complex material herself^(2.174-2.176). Working with the assistance of others allowed Alicia to solve the workshop problems she would not have been able to solve alone^(2.74-2.76). Often this assistance took the form of alternative ways of approaching a question or concept^(2.62), and whilst this meant that the group was slow and unable to complete everything, Alicia nevertheless perceived significant advantage in sharing ideas^(2.68-2.72).

Alicia confirmed that she had not begun the semester as friends with any other member of her group, but that she was acquainted with all of them from the previous semester^(2.86). By the end of the semester she still did not describe them as close friends, but she was certainly on good terms with all of them^(2.90-2.98).

In summary, this group functioned effectively because of the coherence of the goals (both academic and social), approaches and behaviours of the members, which meshed to create an inclusive learning environment which promoted productive interactions. Key characteristics identified consistently throughout the interviews included cooperation and collaboration, conscientiousness, willingness to contribute, ease of conversation and feeling comfortable in the group. Interpersonal relationships were characterised by acceptance and respect, and friendships were strengthened, in contrast to the experience of the TC group. The focus of the group was to a greater extent on learning than on completing the task, thus discussions were extensive, and although the pace of work was relatively slow, participants believed that the time was well used in reinforcing the fundamental concepts.

7.5 Impact of the recording equipment

Since none of the participants in the study had any prior experience of being recorded in classroom settings, the possibility existed that the presence of the recording equipment might have significantly influenced behaviour, and thus the learning which occurred. All students were asked about their attitudes towards the presence of the recording equipment, and how they perceived that the other students responded. A summary of each group's responses is described below, and individual responses are included in Appendix J.

Transient change group

The majority of comments suggested that individually, each student apart from Larry had little problem with the presence of the recording equipment, but that each believed that the group dynamics were affected to some extent. The consensus was that the presence of the equipment did

not hinder learning, but that the stress levels were somewhat higher than might have been the case in the absence of the equipment. In general, the equipment was not seen as the primary cause of the stress, but as a factor which exacerbated already existing tensions, particularly as experienced by Larry. It provided Larry with an external factor on which he could focus his stress and anxiety, but even Larry was aware that the recording equipment was not the real source of his difficulties.

Persistent change group

Unlike the TC group members, the majority of comments by PC participants suggested that the equipment had little impact on their behaviours. None of them indicated that they had been inconvenienced or upset in any way by the presence of the equipment, and most felt that they had not behaved any differently than they would have done in the absence of the equipment. Most recalled that it was there, at least for part of the time, but none believed that it was detrimental in any way either to individuals or to the group as a whole. Denise even articulated a positive aspect in that the group may have been less inclined to engage in off-task activity.

7.6 Overall summary

Evidence from the workshops, supported by the participants' opinions expressed during interviews, has demonstrated that the interpersonal processes occurring within each group were markedly different. Employing Barron's (2003) notion of content and relational spaces as a framework, analysis of these processes has revealed that the PC group engaged in more productive interactions than the TC group in both spaces. The PC group was primarily focused on learning during the workshops, and their behaviours towards each other and their use of the tutors facilitated this learning. They were cooperative and constructive, supportive of each other, and persistent in problem solving, and they gained benefit from the assistance provided by tutors because they canvassed issues thoroughly in advance. Their discussions suggested that they were developing both discursive practices appropriate to pharmacy and contextual discrimination between pharmacy and chemistry. On the other hand the TC group was primarily focused on completing the tasks assigned in the workshops rather than regarding them as opportunities for learning, and their behaviours towards each other and the tutor were individualistic rather than cooperative. Their use of the tutors provided only limited benefit because they were less interested in explanations than answers to the workshop activities, and their discourse revealed considerably less development of either new discursive patterns or contextual discrimination.

Clear correlations are evident between the findings reported in this chapter relating to process and those reported in chapter 6 relating to outcomes of conceptual change. These correlations are discussed in chapter 8 in relation to the general discourse model described in chapter 3, and an emerging local situated version of the general model is proposed and discussed.

CHAPTER 8 DISCUSSION AND CONCLUSIONS

8.1 Introduction

Chapter 6 has outlined the evidence for the extent of conceptual change learning by the participants in this research study, and chapter 7 has described some of the processes at work within two small groups. Conceptual change outcomes were evaluated by analysing the extent to which participants used appropriate discursive practices, both within workshops and in interviews after classes were complete. Group processes were observed during workshops by means of video recordings, and individual participant perspectives on their group functioning were elucidated during interviews. Clear differences were apparent between the groups in the nature and persistence of the learning achieved by their members, with one group (PC) demonstrating long-term retention of both appropriate discourse and contextual discrimination, and the other (TC) displaying evidence of short-term learning which appeared to be targeted primarily towards examination performance. Group dynamics and behaviours were also significantly different, with the PC group exhibiting consideration of others and collaborative, learning-focused interactions involving extended and progressive discourse, while the TC group engaged in individualistic and task-focused behaviours which were characterised by less extensive and poorly coordinated discussion. In the current chapter, the evidence for outcomes and processes is drawn together and considered in relation to the general discourse model of conceptual change described in chapter 3. The chapter begins with the description of a situated version of the general discourse model which emerged locally as an explanation of the findings, and continues with consideration of the extent to which the findings can be generalised, both to the whole cohort from which the two groups were drawn, and beyond the specific context of the study. Implications for teaching which arise from the findings are discussed, together with issues of methodology and study design, and directions for further research. The chapter concludes with reflections on the relationship of the findings to prior research on collaboration in learning, and on the contribution of the thesis to developments in conceptual change theory and practice.

8.2 Conclusion – a situated process model of conceptual change learning and cognitive socialisation

The general discourse model highlights critical aspects which underpin conceptual change from a sociocultural perspective, however features of the specific setting are critical in shaping the distinctive nature of the learning which occurs. From the findings described in chapters 6 and 7, a local version of the general discourse model emerged as an explanation of the ways in which the processes facilitated and constrained the outcomes in the context of the study. This situated process model of conceptual change learning is illustrated in Figure 8.1 and described in the following sections, firstly in general terms and subsequently in more detail by comparing and contrasting the TC and PC groups, with reference to the personal and interpersonal planes and their interdependence (Rogoff, 1998). In comparing these groups, it should be noted that with only rare

exceptions the differences between them were not related to the presence or absence of particular features, but rather to the observation that some aspects were strongly characteristic and frequently observed in one group, and considerably less so in the other.

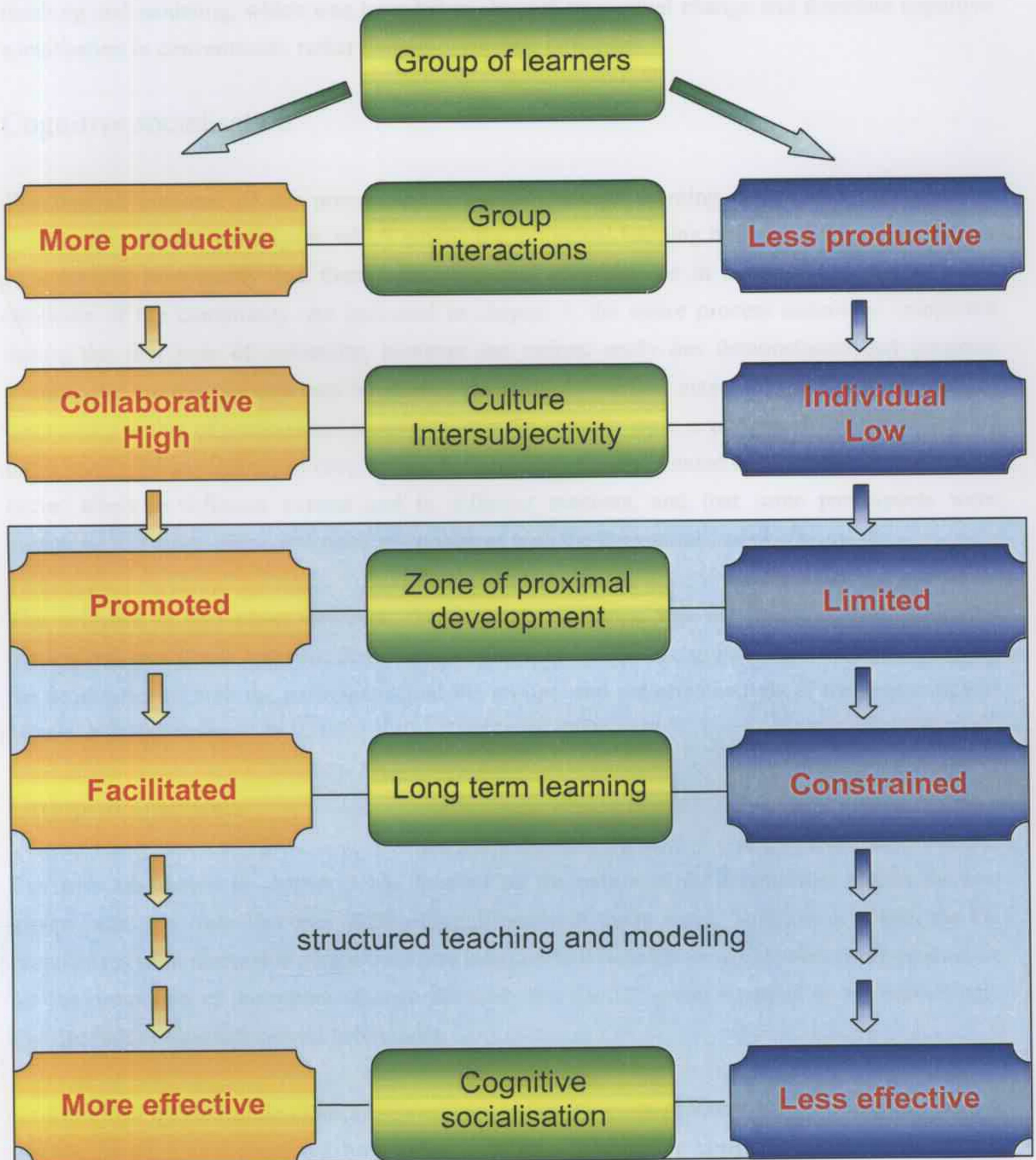


Figure 8.1: Situated process model of conceptual change learning and cognitive socialisation

This situated process model of conceptual change learning and cognitive socialisation posits that eventual cognitive socialisation is grounded in long term conceptual change learning which develops most effectively within zones of proximal development. These zones were differentially apparent within the study, appearing more frequently and with more effect among members of the PC group than among members of the TC group. The creation of these zones was promoted or

constrained by the nature of the group culture and the level and quality of the intersubjectivity attained within group interactions, which were in turn differentially characterised by greater or lower levels of productivity. Underpinning the process was the extent and nature of structured teaching and modeling, which was intended to channel conceptual change and therefore cognitive socialisation in conventional, rather than idiosyncratic directions.

Cognitive socialisation

The desired outcome of the process of conceptual change learning is the eventual cognitive socialisation of each participant, which entails the individual learning both the discursive practices of a specific community and their appropriate and effective use in communication with other members of the community. As indicated in chapter 3, the entire process cannot be completed during the first year of university, however the current study has demonstrated that progress towards the desired outcome can be made even from the earliest stages. In this study, the target community is that of professional pharmacy, and the specific topic is one which comprises part of the scientific underpinnings of drug action. Evidence has been presented that conceptual change did occur, albeit to different extents and in different manners, and that some participants were beginning to display discursive patterns consistent with the conventions of pharmacy.

The evidence is also clear, however, that conceptual change was not homogeneous across all participants, and it was apparent that the interactions within the two groups were critical in shaping the trajectories of both the participants and the groups, and the effectiveness of the beginnings of cognitive socialisation.

Group interactions

Extensive discussion in chapter 7 has focused on the nature of the interactions within the two groups, and it is clear that they differed significantly in many ways. Taken as a whole, the PC group engaged in discursive interactions and interpersonal behaviours which were more productive for the promotion of conceptual change learning, and the TC group engaged in correspondingly less productive interactions and behaviours.

As described by Roschelle (1992), interactions which are more productive for conceptual change include iterative conversational turn-taking involving cooperative construction of ideas, sharing new ideas in common frames of reference, and repairing differences and divergences in discourse and understanding. In the current study, productive interactions were those which promoted discussion and exploration of concepts and approaches to solving problems, and which allowed each participant to contribute and gain benefit. A higher incidence of more productive interactions and behaviours was apparent in the PC group: these included cooperation, equality of status, engagement in extensive and progressive discourse, a focus on learning, and persistence. In

contrast the TC group was characterised by competition, inequality of status, engagement in less and more poorly coordinated discourse, a focus on task completion, and lower persistence.

Cooperation and competition

The cooperative nature of the PC group's interactions was clearly apparent in their propensity for working together on the same problem, pursuing consensus and attempting to ensure that everyone in the group was able to understand as well as to write an answer. On the other hand, members of the TC group worked independently to a greater extent, and consensus was rarely an objective. The PC group would generally wait for everyone to complete an activity, whereas TC group members worked at their own pace and moved ahead as they finished each task. Janine was the most prominent in demonstrating the latter behaviour, and was perceived by most of her group as highly competitive, even to the extent of wanting to be the first in her group to finish the workshop. However the level of unspoken competition between Janine and Larry also contributed to the tension underlying their interactions, as Larry believed that Janine's approach placed additional pressure on the remaining members of the group, himself included.

Cooperation was also evident in a range of behaviours. Within the PC group, consideration of others was prominent, and was manifest in a willingness to share belongings and an awareness of needs (for example offering cough lollies). Within the TC group, Lucy was generally considerate in sharing, but the others were less so.

These cooperative and competitive behaviours, manifest on the interpersonal plane, revealed and resulted from the personal focus of each participant, preferentially either on others or on the self. The group which consisted of participants with a greater outward focus engaged in more cooperative behaviours than the group whose participants were characterised to a greater extent by a focus on their own needs.

Status

Status or interpersonal ranking within a group may be explicit or implicit, but is frequently revealed through the actions of group members (Chiu & Khoo, 2003). Status may be self-conferred or conferred by others but is always a response to perceived relationships between individuals (Cohen & Lotan, 1995), and thus results from an intertwining of the personal and interpersonal planes within a particular context.

It was clear that in the TC group Janine was perceived as possessing the highest academic status, and Lucy the lowest. Janine regarded herself as academically superior, with some justification, and the others also explicitly accorded her the status of 'expert' on the grounds of her greater knowledge. The status of expert can, however, be used in more or less productive manners, and Janine's expertise was perceived differently by Lucy, Larry and Emma. Overall, it was apparent

that Janine's status and behaviours tended not to result in consistent benefit for the other members of her group.

Lucy's status was less explicit, but the behaviours of others towards her made it clear that her academic opinion was poorly valued, despite the fact that on a number of occasions she was closer to articulating an appropriate approach. As a consequence, she resorted to off-task behaviours which confirmed their opinions, and relegated herself to the role of scribe, although even in the latter case her contribution was sometimes rejected.

Within the PC group, in contrast, variations in status were significantly less apparent, and no individual appropriated the role of expert for herself. The group perceived all of the other members to be helpful, and shared the role of temporary expert at different times during the workshops. Similarly, no individual was regarded as possessing lower status than any other, although it was acknowledged that some were quieter and more reticent in contributing. The greater equality of perceived status among group members was associated with greater levels of cooperation.

Extent and nature of discourse

The extent and nature of the discourse of the two groups has been extensively discussed in chapters 6 and 7, and substantial differences were clearly apparent. In terms of productivity, the critical differences lay in the extent to which discourse was coordinated and progressive, and the opportunities that were created for transformative internalisation and externalisation.

The evidence strongly supports the contention that the PC group was more productive in both of these dimensions. Episodes of progressive discourse, involving coordination of speaking turns and co-construction of understanding (Wells, 1998) were both more frequent and longer than was the case in the TC group. Since this discourse was necessarily constituted by consecutive externalisations, it thus represented both resources and evidence for transformative internalisation. Indeed a short series of turns by Denise during an exploration of the structural characteristics of amines (PC1.7:1611-1622) revealed the process of her transformation in thinking in successive externalisations. Coordinated discourse was present on occasion in the TC group's interactions, but it generally lacked the key features of progressive discourse which include a common commitment to construction of shared understanding and critical evaluation of a range of ideas. Poorly coordinated discourse was also frequently apparent in the TC group's interactions.

The PC group therefore created greater opportunities for appropriation of new ideas through transformative internalisation and externalisation, by means of both a greater number of speaking turns and coordination of those turns within discourse intended to reach consensus. Evidence for effective appropriation was apparent, during and immediately after the workshops, but particularly in the third round of interviews, where retention of the new concepts was high. The transformative nature of each participant's internalisation was also apparent as each expressed the concepts in

slightly different ways, both during and after the workshops, thus highlighting the interdependence between the socially communicated concept and the individual's unique conceptual framework.

It would be incorrect to imply that no concept appropriation occurred among members of the TC group, since it is manifestly clear that learning did occur. However it appeared that most of the opportunities for transformative internalisation and externalisation were realised outside the classroom, particularly in the pre-examination study group. It also appeared from student interviews that much of the time in this study group was occupied with completing past examination papers and revising the workshop problems, rather than engaging in conceptual discussion. As a consequence, the ideas which were transformatively internalised and externalised were unlikely to lead to fundamental conceptual change, and the third TC group interviews bore out this belief. Since even high levels of transformative internalisation and externalisation do not of themselves lead to change in conventional directions, and unguided peer groups may develop idiosyncratic understandings (Roschelle, 1992), the guidance provided through structured teaching and modeling is critical in channelling the discourse into conventional patterns, and the TC group had little if any access to this guidance during their study group interactions.

Learning or task focus

Conceptual change leading to cognitive socialisation relies on the learning of new ideas and their incorporation into the conceptual framework of an individual, so that the individual becomes able to communicate effectively within a community of practice. The workshops in IPS were specifically designed to create an environment where the learning of ideas was promoted, and the tasks were planned as a means to this end. However the intention of the workshop designer is not automatically 'imprinted' on the workshop participant, and all facets of the context, including the participants, interact to create environments which are unique to each occasion. Particularly significant in this study were the motivations and attitudes of participants towards the workshop activities, and while both groups were keen to complete the tasks, the TC group tended to perceive them as an end in themselves. As a consequence, they focused primarily on the task, and only peripherally on its significance for their conceptual understanding. In contrast, the PC group displayed attitudes more closely aligned with the workshop designer, in that they focused primarily on learning from the tasks and only secondarily on their completion.

The interdependence of the individual and social was clearly evident in shaping different behaviours within the two groups in relation to the workshop tasks. Although the tasks themselves were identical and equally accessible as social artefacts, the unique combinations of individuals who comprised the groups used them differently to achieve different outcomes. The underlying motivations for attending workshops and completing the activities played a critical role in channelling effort into more (PC) or less (TC) productive endeavours.

Persistence

Either a learning focus or a task focus could in theory lead to high levels of persistence, however a clear difference between the two groups was apparent in the extent to which they persisted both with individual activities and within the workshop itself. The relationship between persistence and productivity is not straightforward. On the one hand, if the students 'give up' before reaching a satisfactory conclusion or consensus, the full benefits of attempting the activity will not be realised, and this was frequently apparent in the TC group when some members were willing to copy the correct answer with little or no understanding of how it was achieved. On the other hand, if the students spend excessive time on a question in an attempt to reach understanding and consensus, they risk leaving insufficient time to complete other equally valuable activities. The latter was characteristic of the PC group, which 'finished' only one workshop during the semester.

Clearly a balanced approach with efficient use of time is ideal, however the unique constitution of each group results in differences in how balance is both perceived and achieved. Members of the PC group were aware of their slowness in workshops, but most believed that the time was generally well spent, and the solid grounding they achieved in the fundamentals allowed them to construct the more complex concepts themselves. The TC group on the other hand, appeared to be more concerned with task completion, particularly the tasks which were to be submitted for assessment. As a consequence, the balance they sought was to allocate sufficient time for the completion of the back page, yet to leave as early as possible, although they did not in fact complete the back page for workshop 2.

Persistence is both an individual and group characteristic, where individual motivations and preferences interweave to create group behaviours. It is more likely that a group composed of individuals with compatible attitudes towards persistence and cooperative behaviours will achieve a mutually satisfactory balance than one where less compatible and less cooperative behaviours are evident.

The example of phenol and alcohol

Although by no means unique, the treatment of the task of identifying and classifying phenol groups serves as a clear example of the differential productivity of the TC and PC groups' interactions. As described in chapter 7, the TC group engaged in a very brief and largely uncoordinated consideration of the characteristics of a phenolic OH group, with asynchronous contributions from Larry and Janine, the latter primarily self-directed. Janine's higher perceived status gave her the 'authority' to make an incorrect identification without challenge, and the achievement of an answer signalled the end of the task without a perceived need to explore alternative options. As a consequence, the task failed to achieve part of its purpose, conceptual change was not promoted, and the group interaction was unproductive. When interviewed at the end of the study, Larry struggled with the concept of OH groups, reverting to his pre-instruction

concept that they were basic, and the remaining members of the group were more hesitant about identifying phenols than they had been at the second interview.

On the other hand the PC group engaged in extensive exploration of the issues, which meant that opportunities to appropriate the concept through transformative internalisation and externalisation were available for each member of the group. When Denise struggled with the possibility that OH could be acidic, rather than basic as she had always understood, the group supported her learning by persisting with explanations until she was able to grasp the concept, and they did not move to the next task until her needs had been addressed. Equality in status resulted in the serious treatment of each member's contributions, and the outcome was the co-construction of a conventional concept of phenols. Evidence from the third round of interviews indicated that all members apart from Kellie were confident and accurate in their identification of phenols, and moreover were able to explain the rationale for their identification in the terms which had been constructed during the workshops. Kellie incorrectly identified the OH in codeine as a phenol, but was confident in explaining that a phenol required the OH to be directly attached to a benzene ring: her difficulties lay primarily in her weak background in organic structures as she failed to recognise the ring as not benzene.

In summary, the discursive interactions and interpersonal behaviours which characterised the two groups channelled them into either more productive or less productive directions. Cooperation and equality of status, combined with extensive progressive discourse and persistence on tasks with a focus on learning from them emerged as productive, while a more self-focused approach, with difference in status, poorly coordinated effort and a focus on task completion emerged as considerably less productive.

Culture and intersubjectivity

Culture – collaborative or individual

The characteristic cultures of the two groups were created through the interdependence of the individuals and all other aspects of the context and were thus uniquely created in each situation. Individuals brought to the group setting a range of motivations, approaches and goals, which interacted with the motivations, approaches and goals of the other members, the artefacts available to them and the physical environment of the classroom. However, without downplaying the significance of the physical environment, the major difference between the groups was the productivity of their interactions, and thus the difference between the two cultures was both shaped by and reflective of the group interactions and behaviours.

The PC group, with its more productive interactions was associated with the creation of a collaborative culture which more effectively promoted learning than the more individualistic culture created within the TC group. As has been described at length in chapter 7, the PC culture

was marked by cooperation, support, a learning-focus and persistence, while the TC was characterised as competitive, poorly supportive, task-focused and less persistent. A further dimension which differentiated the culture of the two groups was the extent to which each group engaged in polite or impolite behaviours (Brown & Levinson, 1987; Chiu & Khoo, 2003; Watts, 2003). Members of the PC group were unfailingly polite in their interpersonal speech and behaviours, and sought to include and encourage their peers. On the other hand, members of the TC often lapsed into speech which was mocking or mildly insulting towards each other, and their behaviours included brusque responses and ignoring the contributions of others (chapter 7). Interestingly the TC group missed a number of learning opportunities as a consequence of disregarding the contributions of others, as on several occasions Lucy introduced approaches which could profitably have been pursued, but which were simply ignored.

Notwithstanding the interdependence of the individual and the social, the cultures created by the TC and PC groups also highlighted the impact of specific individual behaviours. In the TC group, Janine's self-focus acted to create division within the group as the others responded to her actions and her perceived motivations, and the culture that resulted was heavily coloured by this division. In the PC group, Jasmine acted in ways that promoted inclusion, particularly of the quieter members of the group, and this inclusiveness was a key characteristic of the collaborative culture created within the group. Thus culture can be regarded as exemplifying inclusive separation (Valsiner, 1998), where individuals can exhibit distinct behaviours, which are nonetheless seamlessly part of the whole.

Intersubjectivity

Chapter 7 has highlighted the differences in intersubjectivity, or shared thinking, that were apparent between the two groups, with the PC group displaying a greater prevalence of this phenomenon. Characteristics which indicated the presence of intersubjectivity included co-construction of understanding, achievement of consensus and co-regulation of activity and effort, whereas individual construction of understanding and regulation of activity were signs of its absence. As suggested in the general discourse model of conceptual change (chapter 3), the presence of intersubjectivity was closely related to the quality of the progressive discourse and cycles of internalisation and externalisation observed in the two groups. Intersubjectivity was occasionally and fleetingly apparent in on-task TC group interactions and more frequently in their off-task discussion, while intersubjectivity was a characteristic of the critical interactional episodes of the PC group. For the latter therefore, high levels of intersubjectivity both emerged from and reflected the collaborative culture and were constitutive of the group's interactions and behaviours.

Zones of proximal development

Productive interactions, a collaborative culture and high levels of intersubjectivity are valuable attributes of a learning environment, but in themselves do not promote learning which can lead to

cognitive socialisation. According to the general discourse model of conceptual change, the critical aspect for mediating learning and conceptual change is the creation and maintenance of zones of proximal development (ZPDs). This thesis does not focus on detailed characterisation of the ZPD, but utilises the concept as an analytical and explanatory tool (Wells, 1999b) to highlight patterns of interaction and intersubjectivity which are associated with conceptual change and development. ZPDs are potentially created when intersubjectivity arises from contextually situated transformative internalisation and externalisation, but not all instances of intersubjectivity create a ZPD, since a ZPD is an interactive system within which individuals collaborate on activities which they cannot successfully complete alone (Newman et al, 1989). Thus what differentiates a ZPD from other situations involving intersubjectivity and tool-mediated collaboration is the emergence or development of new skills or enhanced understanding which correspond to conventions. Further, affective dimensions including mutual respect and concern for others are critical for the creation of a ZPD (Wells, 1999b, Mahn & John-Steiner, 2002). The mediational tools of significance in the current study were discourse, and artefacts such as the worksheet, lecture notes, writing implements and calculators.

ZPDs were differentially apparent in the interactions of the TC and PC groups as outlined in the following sections.

Transient change group

Joint attention and intersubjectivity were apparent in a number of interactions, however few of these instances resulted in the creation of a ZPD. Chapter 7 details a number of instances, of which two appeared to meet the criteria defining a ZPD. In the first instance Larry and Lucy jointly solved a problem of algebraic rearrangement that neither had been able to solve alone ^(TC1.499-525, page 209). Intersubjectivity was clearly apparent in the coordination of speaking turns, and in the joint attention to the mediating artefact, Lucy's worksheet, and a ZPD emerged in the collaborative solution of the problem through contributions from both participants. Lucy's questioning of Larry forced him to articulate his reasoning and thus to consolidate it, indicating that both learned something from the interaction. A transitory ZPD was also apparent where Larry and Janine explored the nature and identification of phenols ^(TC1.4:899-936, page 210). Coordinated discourse and reference to the mediating tool of their lecture notes combined to create a short period of mutual learning.

Other instances of intersubjectivity were, however, not associated with the formation of a ZPD. A discussion about the method of calculating a required parameter ^(TC1.188-1.196, page 211) appeared to involve shared thinking, but a ZPD was not evident as the participants were unable to resolve their difficulties. A further instance of intersubjectivity was apparent when Geoffrey and Lucy discussed the properties of acids and bases ^(TC1.3:737-750, page 194). Throughout this exchange each appeared to be contributing from memory, and neither actually wrote anything down as they spoke. Their dialogue and maintenance of eye contact were indicative of joint attention and shared thinking, but neither

progressed beyond the understanding which they brought to the discussion. Indeed the discussion did not actually relate to the activity on the worksheet, which dealt with structural features, strength and ionisation. Instead, the focus quickly moved to the physical characteristics of acids and bases with which Lucy and Geoffrey were very familiar from their prior study. In addition to reinforcing Chemistry concepts at the expense of Pharmacy concepts, the reversion to familiar knowledge also precluded the emergence of a ZPD.

Peer tutoring rarely if ever led to the creation of a ZPD. Although intersubjectivity was briefly evident in the final stages of a peer tutoring interaction between Janine and Larry ^(TC1.115-1.129, page 189), a ZPD was not created because the understanding which was shared was not novel. Intersubjectivity was apparent in the tacit understanding which was communicated by the speaking turns, and joint attention to Larry's worksheet. Further, Janine's oblique explanation appeared to supply the missing information that Larry needed to solve the problem, suggesting that they were sharing a common understanding of the problem space. However the missing information was not novel, but rather a reminder of forgotten knowledge, and thus no conceptual development or change ensued.

The interpersonal behaviours exhibited by this group often demonstrated little respect or concern for others, as individuals generally focused on achieving their own goals. Further, their language was often mocking or mildly offensive, again highlighting a lack of respect. Under these conditions, ZPDs were constrained.

These examples highlight the general scarcity of meaningful learning interactions within the TC group. ZPDs did occasionally form, but they were short-lived (50 seconds each in the two examples cited), related to relatively minor aspects of the topic and did not involve the whole group. The low frequency of interactions involving intersubjectivity necessarily limited the emergence of ZPDs, and when intersubjectivity was achieved, it often did not lead to demonstrable learning.

Persistent change group

ZPDs were both more common and more lengthy in the interactions of the PC group, and were created primarily as group members engaged in extended progressive discourse.

A ZPD was created from discussion about the algebraic rearrangement of the equation which the students had answered incorrectly in a previous quiz ^(episode PC1.2:806-871, page 223). During this 2 minute episode the students engaged in progressive exploratory discourse resulting in high levels of intersubjectivity, and co-constructed both the appropriate problem solution and the relationship between the solution, the underlying rationale and relevant problem-solving strategies. The discourse was accompanied by joint attention to a worksheet and set of lecture notes, and by hand gestures which illustrated the concept of inverting equations. Conceptual development of the ideas

of each participant was evident, as each contributed differentially to the total, thus it was clear that their intersubjectivity was associated with a ZPD.

Perhaps the most significant instance of the creation of a ZPD was the episode in which the students discussed the nature of the OH group ^(PC1.5:1080-1225, pages 223-225). This episode has already illustrated the productivity of the participants' interactions (pages 258-259), and was strongly characterised by high intersubjectivity. Importantly however, it was also clear that significant learning and conceptual development emerged as the students challenged each others' ideas, and offered a range of explanations for consideration. Tool mediation was apparent in the joint attention to worksheets and lecture notes at various stages during the 5½ minute interaction, and as participants engaged in cycles of writing, erasing and rewriting on these artefacts as their ideas flowed and developed. The ZPD thus created was somewhat asymmetric in that Veronica took on a temporary role as expert, but her participation clearly facilitated the conceptual change learning of others in relation to the OH group and the recognition of benzene rings. As has been described above, the learning which was apparent in this ZPD persisted strongly until the end of the research study.

Intersubjectivity without the creation of a ZPD was also apparent on occasion within the PC group. The most significant instance occurred towards the end of the second workshop when the students spent 3 minutes attempting to classify the two forms of phenobarbitone as ionised or unionised ^(PC2.3:1917-1959, page 222). Intersubjectivity was apparent in the coordination of their speaking turns, and tool mediation was evident though joint attention to worksheets and calculators, and the use of gestures and pointing when describing the concept of swapping. Consensus was apparently reached, but the interaction cannot legitimately be classified as a ZPD because the conclusion was incorrect and based on idiosyncratic reasoning.

ZPDs were also created on other occasions during the workshops and resulted in significant learning in relation to the dissociation behaviour of molecules containing multiple functional groups ^(PC1.7:1766-1848), and aspects of IPS not relevant to the current study. PC group ZPDs were characterised as greater in length and complexity than those of the TC group, and involved more participants. Moreover, the learning which emerged from the ZPDs tended to persist to a greater extent among PC members than it did among TC members.

In contrast to the interpersonal behaviours exhibited by the TC group, PC group members were generally respectful towards each other in their language and actions, and showed concern for the others' needs. The atmosphere within the group was encouraging and supportive, thus when their interactions led them into situations where ZPDs could form, the positive affect was a strong affordance.

In summary, as a consequence of the more productive interactions and the high levels of intersubjectivity evident in the collaborative culture thus created, ZPDs were promoted to a greater

extent within the PC group than in the TC group where the emergence of ZPDs was limited by the less productive interactions, individual culture and lower levels of intersubjectivity.

Structured teaching and modeling

As suggested above, underlying the concept of ZPDs is the notion that the learning and conceptual development which occur within them are aligned with the conventions appropriate to the context. In many cases peer collaboration is able to achieve the appropriate understanding, however structured teaching, guidance and modeling are also important in scaffolding and channelling learning into productive directions. Structure and guidance in this study were provided in a range of forms, including explicit teaching and modeling of discourse by the lecturer and tutors, the provision of lecture notes, the design of the workshop sessions, the nature and structure of the activities included on the worksheets, the provision of model answers to each workshop in the following week and the provision of opportunities for formative feedback through submission of selected problem solutions. The examples of ZPDs described in the previous section were all underpinned by most of these aspects, and the failure of an interaction to create a ZPD was always attributable to a failure to utilise critical supports. For example, Lucy and Geoffrey achieved high levels of intersubjectivity when discussing the properties of acids and bases (TC1.3:737-750), but their failure to refer to worksheet, lecture notes, other students or the tutor effectively prevented them from progressing in their learning.

ZPDs could be created with the primary support of written tools such as lecture notes (eg. PC1.5:1080-1225), but were more commonly apparent when modeling of conventional discourse by the tutors supported exploratory discourse by students. Tutor modeling created the potential for asymmetric ZPDs, where the tutor was able to act as expert in scaffolding the learning of less able participants, however the potential was realised differentially between the two groups.

Transient change group

The roles adopted by the tutor in interaction with the TC group have been outlined in chapter 7, and included modeling of appropriate discourse, however in many cases this modeling was not clearly associated with the emergence of a ZPD. Two reasons in particular were apparent. Firstly, on several occasions the student to whom the modeling was offered chose to disengage from the interaction before the explanation was complete, and secondly little or no subsequent externalisations of new understanding were made. Examples of the former have been detailed in chapter 7 (page 217).

Subsequent externalisation of new ideas is necessary for recognition of the creation of a ZPD, because externalisations provide the only evidence of transformative internalisation. When Geoffrey asked the tutor to explain the rationale for classifying molecules with both acidic and basic groups as neither acidic nor basic, she modelled the conventional reasoning (TC1.4:842-846), but

the only responses from Geoffrey and Lucy were brief and non-conceptual (TC1.4:347-348). The tutor later provided a similar explanation, initially to Janine but subsequently to the whole group (TC2.3:1060-1102), but only Janine articulated her new understanding, and that only in relation to the definition of ionisation (TC2.3:1123). A ZPD could perhaps be postulated for Janine in this interaction, but her interviews suggested that she had not appropriated the concept effectively (Janine 2:450-2.452, 3.176-3.186), and the formation of a ZPD could not therefore be supported.

Persistent change group

Modeling of discourse by the tutor in interactions with the PC group was more frequently associated with the creation of ZPDs, primarily because members of the group remained engaged with explanations to their conclusion, and subsequently externalised their new understanding. The latter was apparent in relation to the tutor's discourse regarding the identification of the state of ionisation of acids and bases as a function of pH and pKa (PC2.2:1094-1119, page 235), and also in an interchange about the relationship between equilibrium constants, solubility and K_{sp} (PC1.445-449, 462-466, page 235).

Importantly, however, the utility of tutor modeling was enhanced for the PC group because they sought assistance from the tutor after spending significant time discussing concepts among themselves, and had achieved high levels of intersubjectivity in advance of the tutor's arrival. As a consequence, the tutor was often able to channel the existing shared thinking into conventional directions. For example, the students engaged in many discussions about the characteristic and distinguishing features of amines and amides (pages 181-183), which revealed intersubjectivity but also a degree of conceptual confusion. When the tutor was called for assistance, the students were able to offer for consideration the suggestions that had emerged in their own discussion (PC1.6:1627-1628, 1630, 1639), allowing the tutor to clarify their ideas and provide structure for their conceptual frameworks (PC1.6:1636-1666), rather than needing to model the discourse in its entirety. Similarly, lengthy consideration of the concept of ionisation state (PC2.2) included three interactions with the tutor, and on each occasion the preceding student discussions provided the tutor with an opportunity to channel ideas in conventional directions.

In summary, structure in the form of both artefacts and discourse modeling was available to both groups, but different conceptual change outcomes were apparent. The available resources were utilised more effectively, and intersubjectivity more frequently resulted in the creation of ZPDs within the PC group than the TC group, thus conceptual change and development was channelled more effectively in conventional directions for the former, which in turn contributed more fruitfully to the process of cognitive socialisation.

Learning trajectories and the emergence of nascent cognitive socialisation

The evidence presented in chapter 6 from student interviews, particularly the final round, indicates that both long term learning of new concepts and development of contextual discrimination between chemistry and pharmacy were more apparent among PC group members than TC group members. The preceding sections have highlighted how significant differences between individual and interpersonal aspects intertwined to create qualitatively different learning environments within the two groups, and have established an unambiguous correlation between learning context, quality and persistence. This section focuses on the individual and group trajectories which were manifest in the learning environments, particularly as they tended towards or away from cognitive socialisation.

The interdependence of individual and group created an inclusively separated whole (Valsiner, 1998), in which group trajectories were both constituted by and reflective of participant trajectories, which were in turn unique to the individual while emerging through group participation. The two group trajectories were quite divergent, with the PC group moving generally in the direction of pharmacy conventions and contextual discrimination, and the TC group continuing generally with an undifferentiated perspective of acids and bases. The differences between groups were apparent in both the personal characteristics, behaviours, goals and approaches to study of the constituent individuals, and in the interpersonal interactions which emerged as the particular groupings of unique individuals worked together.

In general, the group and individual trajectories of the PC group favoured progress towards cognitive socialisation, whereas those of the TC group made little progress in that direction and perhaps moved along other paths. These findings are illustrated in Figure 8.2, which suggests that the learning environment, as constituted by the individuals and their interactions either facilitated (PC group) or constrained (TC group) the process of cognitive socialisation.

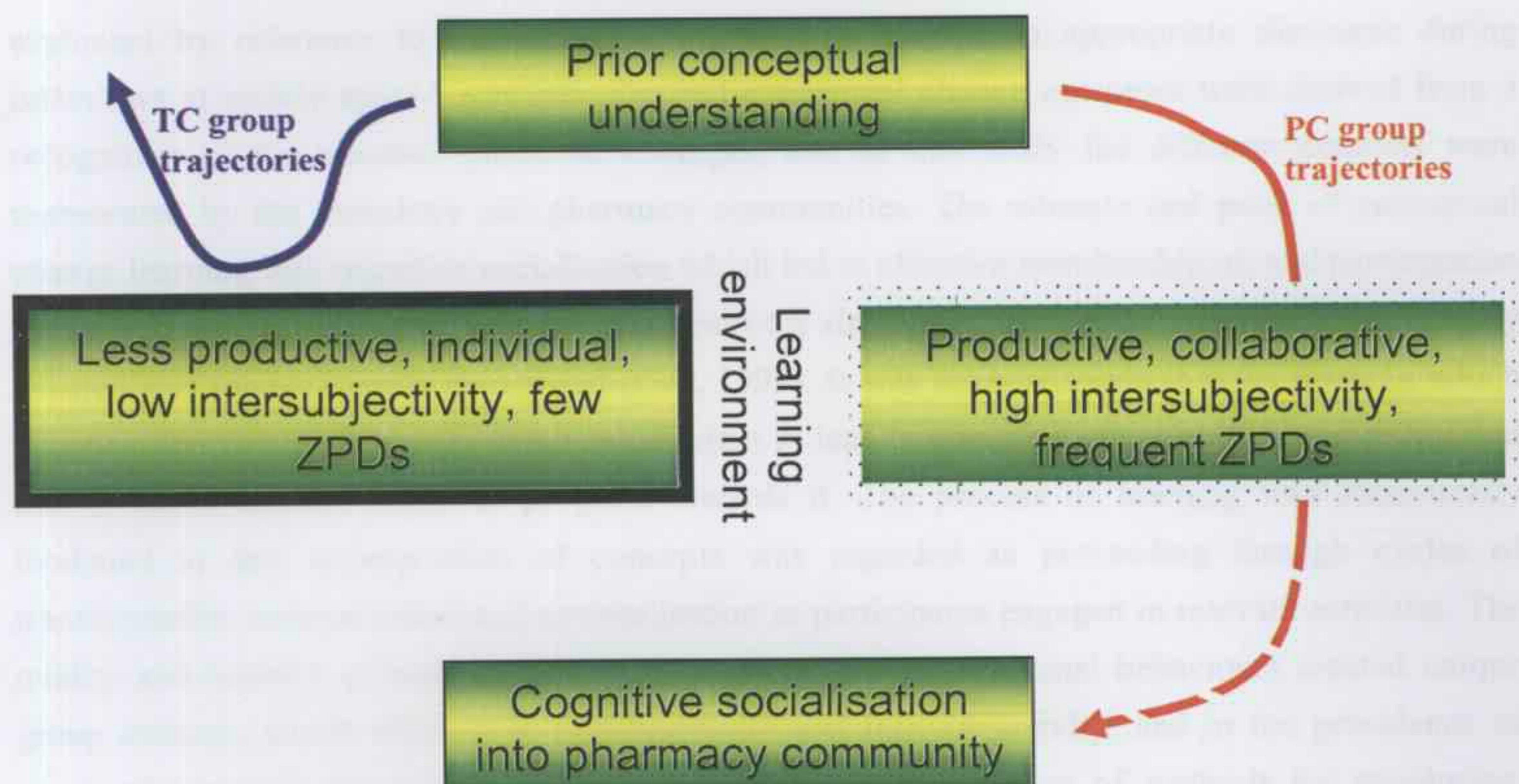


Figure 8.2: Trajectories towards and away from cognitive socialisation

This diagram represents the learning environment created within the TC group as a barrier which deflected the group and individual trajectories away from cognitive socialisation, whereas that of the PC is represented as providing little hindrance to the developing trajectories. As suggested previously however, cognitive socialisation into a professional community is not achieved in the first year of a university degree, and thus any learning that occurs leads to only nascent socialisation. Moreover trajectories by their nature are flexible and can change direction many times, therefore failure to approach the desired end point in early stages is not irredeemable. Nonetheless, it is clearly preferable that as many opportunities as possible are exploited to guide individuals towards participation in community practices and discourse.

8.3 Relationship of the situated process model to the general discourse model

The preceding sections have described the situated process model (Figure 8.1) which emerged in the specific setting of the research study, however it is critical to verify that this local instance is indeed representative of the general model outlined in chapter 3. The general model comprises ten interrelated aspects: the discursive nature of concepts, cognitive socialisation, context and situated understanding, community membership, semiotic mediation, collaborative learning and intersubjectivity, zones of proximal development, structured teaching and modeling, conceptual change outcomes and the interdependence of individual and social. Many of these aspects have been explicitly addressed in the description of the local model, but others have not, and this section provides an overall summary.

The discursive nature of concepts underpinned the methodology of the study in that classroom discourse was the primary mediator of conceptual change, and conceptual change outcomes were

evaluated by reference to the individual's ability to engage in appropriate discourse during interviews at widely spaced intervals. Desired conceptual change outcomes were derived from a recognition of the situated nature of concepts, and in this study the different contexts were represented by the chemistry and pharmacy communities. The ultimate end point of conceptual change learning was cognitive socialisation which led to effective membership of, and participation in the pharmacy community, and development of a situated identity which was both individually enacted and socioculturally recognised (Gee, 1999). It was acknowledged that the learning which was possible during this study was not sufficient to lead to complete community membership, but that it could and did result in progress towards it. The process of learning was semiotically mediated in that appropriation of concepts was regarded as proceeding through cycles of transformative internalisation and externalisation as participants engaged in relevant activities. The quality and quantity of both discursive interactions and interpersonal behaviours created unique group cultures, which differed in collaborativity and intersubjectivity, and in the prevalence of zones of proximal development, which were enriched by a range of methods for structuring, guiding and modeling appropriate discourse. Finally, the interdependence of the individual and social was emphasised in the creation and emergence of context, learning environment and trajectories. Therefore the process model which emerged during the current research was clearly a local instance of the general model, with strong correspondence to the key aspects but situated in its own context. The correspondence of the two models suggests that some generalisation beyond the immediate context is possible, and the extent to which this is valid is explored in a later section.

8.4 Sample and population studies

In addition to consideration of the generalisability of the finding beyond the immediate context, it is also critical to evaluate the extent to which the findings of a small sample can be applied more generally to the population from which the sample was drawn. This is particularly important when, as in this study, the results tend towards the extremes. That the results of the two groups were substantially different is not a disadvantage, as Barron (2000) has commented that "the strategy of comparing extreme groups helped to make usually more subtle differences salient" (p. 412). The two groups chosen for this study provided high levels of contrast in a number of dimensions including the extent and persistence of conceptual change, and the nature of the processes occurring within the groups, and it is likely that other groups within the cohort would have displayed a variety of different patterns of working together and different conceptual change outcomes, many of which would have been less extreme. However, the findings from the two groups which were studied highlight the breadth of possibilities and allow identification of important affordances and constraints for conceptual change which may have been less apparent with less divergent groups. Importantly, the findings of the population study in relation to conceptual change were broadly consistent with those of the selected groups, although they were clearly derived from completely different sources, thus suggesting that the groups were not outliers but valid expressions of the diversity of the cohort. Results from the final survey, described in chapter 4, indicated that student perceptions of acids and bases moved in general from a focus on

physical properties and pH to a more structural and functional group definition which emphasised proton donation and acceptance (Table 4.5a). Some confusion between pH and pKa decreased, and the association of pKa with strength increased (Table 4.5b), although there was still a clear persistence of the chemistry notion that strength was dichotomously defined by complete and partial dissociation, alongside the relativist pharmacy definition (Table 4.5c). Therefore the population results demonstrated similar qualitative changes in understanding to those articulated by the students in the intensive phase of the study, thus suggesting that the two small groups did capture some of the essential characteristics of the cohort.

The broad agreement in trends between the results of a survey of the population and intensive discursive interactions among members of the two small groups supports the demographic and attitudinal data (Table 4.6) which suggest that the sample was broadly representative of the cohort. That similar trends were seen in data collected in significantly different methods and based on widely different assumptions is evidence of the validity of the discursive approach, and also lends support to the legitimacy of generalising the findings beyond the two specific student groups to the rest of the cohort. Application of the findings beyond the cohort is discussed in a separate section and is less general, but within the cohort, considerable similarities were present in many aspects of the learning environments within all of the small groups. Clearly each group comprised a unique collection of individuals, but the classroom context and mediating tools which were designed to promote learning were to a large extent common. The two-hour sessions, arrangement of students in small groups around tables and self-selection of groups were used in all classrooms, and all students were able to access artefacts such as worksheets, lecture notes, calculators, writing implements, model answers and written formative feedback. Thus it is valid to extend the findings of the sample to the cohort and to suggest that the creation of ZPDs within a collaborative culture characterised by high levels of intersubjectivity and productive interactions, and underpinned by appropriate use of the available structures, guides and modeling is likely to be effective in promoting cognitive socialisation within IPS.

8.5 Generalisation of the findings to other settings

While extrapolation from the sample to the population has been justified on the basis of commonalities in the physical learning environment, generalisation to other learning settings is more complex. The learning which occurred during this study was embedded in its own context, and the same is true of all other learning which occurs, thus a direct extrapolation of the local model is clearly not possible. However, the local model which emerged has been shown to correspond with the dimensions of the general discourse model as outlined in chapter 3, and it is therefore proposed that the general model will be useful in at least two interrelated ways in other settings.

Firstly, the model highlights dimensions of importance for the design of learning environments which are applicable to a wide range of domains. Whilst this study was carried out in the context of

learning scientific concepts, the dimensions of the model are not specific to science and can be validly applied to other subjects or topics because of the universal mediation of learning through language that is posited by sociocultural theory. Classroom environments can be designed to foster maximum opportunities for cycles of transformative internalisation and externalisation, supported by appropriate structures and modeling by experts, in ways that are tailored to the specific setting. Curricula and activities can be designed to promote the creation of ZPDs by engaging participants in endeavours which are sufficiently beyond their current individual capacity so as to be challenging, but not so far beyond that capacity that the students are unable to attempt them. The problems to be solved or issues to be discussed can be either authentic in themselves, or framed in ways which highlight their relevance to authentic practice, thus emphasising the desired outcome of cognitive socialisation.

Secondly, the general model provides a useful framework for interpretation of the interactions which occur in these learning environments, and particularly the ways in which the characteristics and behaviours of individual participants both shape and are shaped by the observable interpersonal plane of activity to create the unique circumstances of each setting. As was the case in the current research, local situated models of learning will emerge to characterise and explain patterns and processes in these unique settings, and to suggest potential means of further enrichment of the environments.

The general model and its local instances therefore provide a rational basis for cycles of design and interpretation, and potentially powerful means of enhancing learning and conceptual development in a range of educational settings.

8.6 Implications for teaching

The findings and conclusions of this study have a number of implications for teaching, some general and others more specific to teaching for cognitive socialisation into a community.

Most generally, as outlined in the previous section, the findings suggest that design of learning environments should be carried out carefully and with close attention to promotion of collaborative discussion and co-construction, creation of ZPDs and provision of appropriate supports and models. Further, the findings suggest that the students may need some form of guidance in setting the ground rules for their behaviours in order to promote productive interactions and limit those which are less productive. In the current study no guidance was provided, but in subsequent teaching by the researcher, negotiated group contracts have been generally successful in maintaining more collaborative cultures within small groups.

When the outcomes of conceptual change include contextual discrimination, teaching must be structured so as to acknowledge and affirm prior learning as relevant within its context, and to highlight explicitly why and how the novel conceptual understanding relates to its own context.

This may involve provision of direct contrasts between meanings in the two situations, or other means of illuminating the need for making distinctions, depending on the nature of the conceptual frameworks involved.

In the specific instance of conceptual change teaching with the aim of promoting cognitive socialisation into a particular community of practice, the curriculum must additionally be designed in such a way as to emphasise clearly those concepts which are relevant to that community. Where possible the activities should address authentic issues of importance and involve the development of discursive patterns which are characteristic of members of the community. Further, teaching should support students in appreciating the relevance of their activities, particularly in early years or when the topic appears to be of little intrinsic significance.

The disparity between the discursive conceptual outcomes and results of examination performance observed in this study also has implications for the assessment of learning, particularly in formal education institutions where examination results are often regarded as a means of determining readiness to proceed to the next stage. The findings challenge educators to create methods of assessment which are both valid and feasible – valid in the sense of evaluating outcomes which are authentic and of relevance to the community of practice, and feasible as a means of assessing large student cohorts efficiently to provide a useful and equitable gauge of learning. As has been described in chapter 2, this dilemma is far from novel, as students continue to complete examinations successfully while retaining a poor conceptual understanding.

8.7 Methodological issues

Study design and methodology

As previously suggested by Mayer (2002), the design and methodology of an empirical research study must be consistent with its theoretical basis, and further must generate data which are capable of providing valid evidence in support or contradiction of proposed explanations or theories. The intensive phase of this research focused closely only on a small sample of the available number of student groups because this type of research

provides detailed portraits of collaborative interactions that are missing in studies that look for patterns across many groups... [and] can describe interactions that capture the dynamic interplay in meaning making over time in discourse between participants, what they understand, the material resources they use, the types of contributions that they make, and how they are taken up or not in a given discourse. This kind of research highlights the complexity of learning together and can identify key processes (Barron, 2003, p.312).

The design was congruent with sociocultural theory in that the study was situated in the authentic learning environment of the classroom, and involved investigation of the processes which occurred naturally within this setting with its resources, affordances and constraints. The methodology was also congruent with sociocultural theory in that it was designed to capture dynamic discursive

interactions as evidence of both the outcomes and processes of conceptual change as participants engaged in relevant activities. Thus the requirements as outlined by Mayer (2002) were met in this empirical research.

Barron (2000) has pointed out that video recordings of interactions within classrooms allow the analysis not only of talk, but also of non-verbal aspects such as eye gaze, gesture, body positions and facial expressions which provide a deeper understanding of the nature of the interactions by identifying such aspects as tacit participation, joint attention and level of engagement between participants. This study utilised audio and video recordings in order to capture as much as possible of the verbal and non-verbal interactions: audio recordings were necessary because the high levels of background noise within the classroom prevented the capture of all discussion on the videotapes, and the videotapes additionally provided confirmation of the identity of speakers as well as highlighting patterns of interaction which were not manifest in talk. The complementary contributions of verbal and non-verbal interactions have been described, and were important in elucidating the group processes which were manifest both within and outside workshops.

The teacher as researcher

Locating the research in this study within authentic classrooms necessitated the involvement of the researcher in the parallel role of teacher, and raised the possibility of potential conflicts between the two roles. The conflicts fell into two main categories, namely relationships with the student participants, and the ethical dilemmas associated with holding interviews immediately before examinations.

Interactions between students and their teacher involve expectations about the relationships which are involved. Particularly during the first year of university when large classes are common, students often have little contact with their teachers outside formal classes, and the expectation is that neither students nor teacher have the opportunity to develop ongoing relationships. Relationships with tutors may emerge for some individuals, but the large workshop classes which characterised IPS tended to constrain such opportunities. Within the study, however, the teacher spent considerably more time with the eleven participants than with other students in the cohort, engaging in three one-on-one interviews with each individual lasting from twenty minutes to more than an hour. As a consequence, stronger personal relationships emerged which set the selected students apart from their peers to some extent. It was therefore possible that the students could have exploited their relationship with the teacher, or that the teacher could have either consciously or subconsciously favoured the students over their peers.

Neither of the possibilities appeared to be realised. To their credit, none of the students attempted to gain any advantage because of their participation in the study, nor did they behave in inappropriate ways as a result of their greater contact with the teacher. The teacher-researcher was highly conscious of avoiding showing preference, and conversations with the other tutor and with

the research assistant who carried out the recordings during the classes indicated that neither perceived any difference in behaviour by the teacher-researcher towards the selected groups within the workshops.

The second potential conflict between the roles of teacher and researcher arose because some of the participants were interviewed immediately prior to their examination in IPS, while others were interviewed afterwards. For those who were interviewed before the examination, *the teacher* felt an obligation to challenge confused conceptual understanding, with the result that interviews could potentially have become 'coaching' sessions. For the *researcher*, however, this intervention could result in contamination of the data, since student responses would now be influenced by input from the *teacher*, and the data potentially less 'authentic'. Additionally, the students who were interviewed after their examination may have perceived a potential disadvantage because they had no opportunity for such last-minute assistance.

Again, there is evidence that neither of these potential conflicts was realised. The former issue was ameliorated by the conduct of the third interview five months later, where no timing issues were relevant, and where long-term learning was evaluated. In relation to the latter issue, the students were all given opportunities to select the time of their interviews, and discussion during the workshops among both groups indicated that issues other than the possibility of last-minute coaching were more important in shaping their choices. No student indicated in any interview a perception of unfairness, and no written feedback to that effect was received (page 98).

8.8 Directions for future research

The findings of this study suggest a number of directions for future research. Most obviously it would be important to validate the general discourse model in other settings, and to analyse the emergence of different local variants in those settings. This study was situated in the earliest stages of cognitive socialisation, therefore even within the domain of pharmacy, considerable scope exists to expand the context beyond preliminary and scientific learning into the more clinical arena. However the model is applicable to other communities and learning contexts, and could profitably be utilised to evaluate and enhance learning in other environments.

As described above, teaching for conceptual change which involves learning to discriminate between contexts needs to focus explicitly on the different discourses of relevance to each context. When one of the contexts is profession- or career-oriented, many students will be motivated by the prospect of becoming a member of that profession or entering that career, and it should therefore be possible to harness their motivation to promote conceptual change by focusing on the distinctive discourses that they will need to learn in order to become a member of the professional community. Student motivations were not specifically investigated in the current study, although the significance of motivation in learning is well known and acknowledged (Pintrich et al, 1993; Pintrich, 1999; Sinatra, 2005), and it became apparent that the groups differed in their motivations

for completing the workshops, therefore research which explicitly investigated the emergence and channelling of motivation would be beneficial. Further, learning to become a member of a professional community also involves the development of a professional identity, and it would be interesting to study the relationship between learning, motivation and the developing identity.

Thirdly, future research could explore in more detail the relationship between friendship and learning (Barron, 2003). This thesis highlights the complexities of this relationship, and in particular the interdependence between the two. Friendship was shown to be a dynamic dimension of the learning environment, and a critical aspect of the culture which arose through group interactions. Rather than acting simply as a static pre-existing influence on individual and interpersonal behaviours, friendships both shaped and were shaped by the emerging group culture and were clearly significant in either promoting or constraining long term conceptual change, thus studies designed to investigate friendship trajectories at the same time as learning trajectories should provide critical insight.

Finally, only passing mention has been made in this study to the significance of written representations in contributing to the shape of conceptual change trajectories (Nunes, 1999), and the role of gestures in underpinning the communication of meaning through discourse (Givry & Roth, 2006). A more fine-grained analysis which included these elements would be likely to provide additional illumination of the processes underlying conceptual change, and may suggest ways of integrating the discursive approach outlined in this study with other proposed mechanisms and processes (eg. Miyake, 2008; Nersessian, 2008; Schwartz, Varma & Martin, 2008; Vosniadou et al, 2008).

8.9 Conclusions

Findings of the empirical study

A sociocultural perspective posits that all human activity, including learning, is situated in its social, cultural and historical context, which both shapes and is shaped by that activity. In this thesis, a general approach to conceptual change learning from a discursive perspective was proposed, and empirical evidence sought for its validity within a specific context. What emerged was a local, situated instance of the general model, with its own unique characteristics, but which is nevertheless entirely congruent with the general model. Since it is a local version, it is not possible to generalise completely, however some conclusions about a milieu which is more likely to promote conceptual change can be drawn. In summary, the classroom as a context for conceptual change learning can be effective provided all elements work together. The current design was intended to promote cognitive socialisation into a professional community of practice by means of co-construction of conceptual understanding through discourse characterised by cycles of transformative internalisation and externalisation within a collaborative small group environment. Appropriate support to guide learning in directions which are consistent with the conventions of the

community was provided in the form of structured teaching and modeling which explicitly promoted the development of contextual discrimination. Within one small group these aspects combined to create an environment where cognitive socialisation was facilitated, while within the other, cognitive socialisation was constrained by the creation of a far less fruitful environment.

Relationship to previous research on collaboration

Striking similarities are apparent between the findings of the current study and those of Barron (2000, 2003) in relation to the characteristics of collaboration which differentiated groups which were more successful in solving problems from groups which were less so. These similarities in patterns of activities which facilitated or constrained learning are all the more remarkable considering the differences between the ages of the participants (sixth grade compared with first year university) and the domains (primary school mathematics compared with university chemistry). Tables 2.1 and 2.2 summarise the patterns of activity uncovered by Barron (2000) as associated with more and less productive groups, and many of the same characteristics were apparent in the current study. Key features include the propensity of the more successful group (Barron, 2000) and the PC group to

- accord value to the contributions of all members by paying attention and taking them seriously
- respond positively and encouragingly to the suggestions of others
- use an artefact (workbook or worksheet) as a centre of coordination, and agree about documentation of the answer
- be characterised by equality of participation
- display coordinated talk
- attend jointly to the activity at hand
- focus on solving the problem together
- work synchronously on the same aspect of a problem
- adopt and fluidly interchange complementary roles in the process

Further, the “evidence of struggles of control, failure to understand one another, repeated attempts at explanation, rejections of that explanation (even when invited), self-focused talk, admissions of confusion” (Barron, 2000, p. 425) which were characteristic of her less productive group were all in evidence in the TC group, as were the preference for working alone and a competitive rather than cooperative culture. Indeed, her focus on both the content space and relational space in constituting collaboration emerged as an apposite framework for analysis of workshop interactions as outlined in chapter 7.

The role of friendship in establishing and maintaining group culture

Barron (2003, p. 350) further comments that “a relational factor that is infrequently found in the literature on situative learning but is certainly important is that of personal relationship or

friendship". Her review of the literature indicated that interactions between friends were more productive than interactions between individuals who were not friends. However the results from the current study suggest a considerably more complex relationship between friendship and culture.

At the start of the project the TC claimed to be friends from college, having built relationships based on their shared experiences of college life and course of study from the beginning of the year (approximately 7 months before the videoed workshops), although none had known any of the others before beginning at university. Analysis of their off-task talk supported their identification as friends since the topics were consistent with their shared social experiences and displayed a higher level of intersubjectivity than most of their on-task discussion. However, the friendship dimension did not in this case promote productive collaboration, and an element of 'familiarity breeding contempt' was apparent in some of their language and actions towards each other. Further, their interactions outside the formally scheduled class sessions may have undermined their perception of the need to work hard in class. In addition, the second and third rounds of interviews provided evidence that the friendship had become tenuous towards the end of the year, and that the group culture had perhaps contributed to this development. Geoffrey went further in suggesting that friendship between Janine and the rest of group was ultimately untenable because Janine had *'been like that all along, it's just taken us this long to (pause) sort of realise it and then think, like, I mean there's no use in trying that hard anymore, you know what I mean, like trying that hard and trying to you know (pause) stay friends because it's really hard'* (Geoffrey 2.228-2.234).

The PC group on the other hand appeared to benefit from friendship, and indeed to strengthen in friendship through the semester of the study. However, while members of the PC group socialised with each other outside class, they did not live in such close proximity to each other as the TC group members, and were perhaps less vulnerable to 'familiarity breeding contempt'. The relationship between friendship, culture and learning is one in which further research would be illuminating.

Contribution of the study to conceptual change theory and practice

This thesis offers a unique approach to the development of conceptual change theory from a sociocultural perspective. By drawing together ideas from a range of sociocultural theoreticians including Säljö, Wells and Valsiner, together with notions from the traditional conceptual change literature, it creates a rich means of understanding and interpreting conceptual learning and development. Moreover, it describes the application of empirical research methods which are both socioculturally valid and capable of providing an analytical and interpretive framework for the simultaneous investigation of the processes and outcomes of change. The empirical research described in this thesis appears to be the first report exploring the interdependence of these two dimensions, and identifies a number of key issues which have the potential either to promote or constrain conceptual change learning. It thus provides a theoretically rigorous foundation for the

development of curriculum and the design of learning environments which are capable of enhancing student learning and development.

Further, this thesis addresses a number of published concerns currently facing conceptual change research. In a recent review of the state of conceptual change research in learning and instruction, Vosniadou (2008b) suggested that the major issues facing contemporary researchers include the nature of concepts and types of conceptual change, the processes and mechanisms of conceptual change, and the role of sociocultural factors. This thesis has addressed Vosniadou's issues from a sociocultural perspective and offers the following insights.

Implicit in the sociocultural discourse model and in agreement with Säljö (1999) is the proposition that concepts are essentially discursive tools whose primary functions are to mediate communication of meaning and facilitate individual and collaborative activity. They are regarded as having evolved from ongoing social practices and experiences within communities of practice, and as therefore socially, spatially and chronologically distributed, rather than existing as mental constructs or models in individual minds. From this perspective therefore, conceptual change from a sociocultural perspective has been presented as a process of developing discursive proficiency and contextual discrimination.

With respect to processes of change, this thesis posits a mechanism based on transformation of conceptual understanding through discourse (specifically, repeated cycles of internalisation and externalisation) which results in "the construction on the intra-mental plane of the discourse practices that are first encountered on the inter-mental plane of activity-related social interaction" (Wells, 1999a, p. 319). Reflecting Sfard's (1998) caution about selecting only one possible metaphor for learning, the general discourse model does not seek to replace all other sociocultural approaches, but rather extends them by suggesting plausible mechanisms by which transactions occur between the individual and the social.

Discussion of the model which emerged in the current study has clearly demonstrated how a sociocultural perspective can illuminate the mutual interdependence of the individual and social. This interdependence thus challenges the perspective of researchers who reduce the sociocultural approach to one of social influence in which the environment is regarded as a source of social and cultural factors which play a role in influencing conceptual change (chapter 2). The notion of inclusive separation, and the technique of alternate foregrounding and backgrounding the personal and interpersonal planes against each other have been used for the first time in conceptual change theory to illustrate how the individual and social can be considered as distinct yet still constituting a seamless whole, rather than as separate factors which influence each other. In terms of reconciling individual and sociocultural perspectives on conceptual change, this approach is in alignment with that of Leach and Scott (2003, 2008) in that neither the individual nor the social is denied or privileged; however this thesis offers a more comprehensive approach, firstly by emphasising the inclusive separation of the individual and social, and secondly by focusing on transformative

internalisation and externalisation as the processes by which discursive activity mediates conceptual change and development.

In addition to addressing critical contemporary issues identified by Vosniadou (2008b), this thesis has also addressed the criticisms articulated by both Roth (2008) and Vosniadou et al (2008) of the sociocultural approach to conceptual change as they perceive it. Firstly, Vosniadou's claim that sociocultural theory downplays the role of the active individual is countered by portraying each participant as a unique individual, coming to the study with prior knowledge, goals, motivations, histories, beliefs and behaviours, and moving throughout the period of the study along a unique trajectory which is shaped by the interdependence of the individual with the other individuals within the group and the broader social setting. Secondly, Roth's criticism that sociocultural approaches are socially reductionist is countered by clear evidence of the activity and agency of the individuals involved. The participants' preferences and choices in relation to behaviour and talk are important in shaping the nature of their own participation, while simultaneously shaping and being shaped by all other aspects of the field of participation, thus contesting any suggestion of social determinism or reductionism. Thirdly, the recognition of externalisation as a transformative process endorses Roth's (2008) contention that new understandings cannot be described as direct copies of an internal mental representation but as emergent phenomena.

As this thesis concludes, it is illuminating to return to the original model of conceptual change proposed more than twenty-five years ago by Posner, Strike, Hewson and Gertzog (1982). In initiating the field of enquiry, they identified two critical questions to be answered by conceptual change research: how and why change occurs. Answers to these questions have been offered in many different ways by many different researchers in the intervening years but the fundamental issues still remain. The research described in this thesis is a critical contribution to the development of conceptual change theory through the introduction of a discourse model grounded in sociocultural principles, and to conceptual change practice through the model's powerful potential for interpreting and explaining the results of empirical investigation. The findings provide new and significant insights into the original questions regarding both the processes and outcomes of conceptual change learning, and suggest fruitful directions for further research and effective means of improving learning and instruction in formal education settings.

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Of making many books there is no end, and much study wearies the body. Now all has been heard; here is the conclusion of the matter.

Ecclesiastes 12:12-13