Students’ perceptions of context, approaches to learning and metacognitive development in a second year chemical engineering course

by

Jennifer Margaret Case
MEd (Leeds), HDE (Cape Town), BSc (Hons) (Stellenbosch)

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# Table of contents

<table>
<thead>
<tr>
<th>List of tables</th>
<th>page</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of figures</td>
<td>(vi)</td>
</tr>
<tr>
<td>Abstract</td>
<td>(vii)</td>
</tr>
<tr>
<td>Declaration</td>
<td>(viii)</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>(x)</td>
</tr>
<tr>
<td></td>
<td>(xi)</td>
</tr>
</tbody>
</table>

## Chapter 1 Introduction
1. The focus of the study 1
2. The essential motivation for the study 4
3. An outline of the thesis 5

## Chapter 2 Literature review
2.1. Introduction 7
2.2. Perspectives on learning 7
   2.2.1. Students’ conceptions of learning 8
   2.2.2. A constructivist view on learning 9
   2.2.3. A phenomenographic view on learning 10
   2.2.4. A relational view on learning 11
   2.2.5. Conclusion 13
2.3. Approaches to learning 13
   2.3.1. Deep and surface approaches 14
   2.3.2. The influence of context 17
   2.3.3. Relationships between approach to learning, outcomes and conceptions 18
   2.3.4. Use of the deep/surface model in research 20
   2.3.5. Approaches to learning in different subject contexts 21
   2.3.6. Conclusion 22
2.4. Students’ perceptions of the learning context 23
   2.4.1. Early research into students’ perceptions of the learning context 24
   2.4.2. Students’ perceptions of learning science and engineering 27
   2.4.3. Theoretical approaches to perception of context 29
   2.4.4. Conclusion 41
2.5. Metacognition and metacognitive development 41
   2.5.1. Research into metacognition 42
   2.5.2. Metacognition and conceptual change 44
   2.5.3. Metacognition as knowledge, awareness and control 44
   2.5.4. Teaching for metacognitive development 46
   2.5.5. Metacognitive development and approach to learning 48
   2.5.6. Conclusion 49
2.6. Summary of theoretical framework 49

## Chapter 3 Research methodology
3.1. Introduction 52
3.2. Epistemological issues 53
3.3. Research paradigms 54
  3.3.1. Naturalistic inquiry 55
  3.3.2. Grounded theory 58
  3.3.3. Phenomenography 60

3.4. Theoretical issues relating to research methods 62
  3.4.1. The interpretation of interview data 63
  3.4.2. Ethical issues around anonymity and use of pseudonyms 65

3.5. Conclusion 66

Chapter 4 The context for the study 67
  4.1. Introduction 67
  4.2. Locating the CHE231F course 67
    4.2.1. The University of Cape Town (UCT) 68
    4.2.2. The undergraduate chemical engineering programme at UCT 68
    4.2.3. A global perspective on context 71
  4.3. The evolution of the CHE231F course 72
  4.4. A closer look at CHE231F in 1999 73
    4.4.1. The course content 73
    4.4.2. The lecturers 75
    4.4.3. Structure of the course 77
    4.4.4. How the course ran in 1999 82
  4.5. Conclusion 89

Chapter 5 Methods of data collection and analysis 91
  5.1. Introduction 91
  5.2. The pilot study 91
    5.2.1. Research methods 92
    5.2.2. Findings of the pilot study 92
  5.3. An examination of my positioning in the course 94
  5.4. Research logbook 96
  5.5. Course data 97
    5.5.1. Lecture and tutorial observations 97
    5.5.2. Class materials and assessment items 97
    5.5.3. Class records 98
    5.5.4. Lecturer informal discussions and interviews 98
  5.6. Interviewee data 99
    5.6.1. Selection of interviewees and practical arrangements 99
    5.6.2. Interview protocols 103
    5.6.3. Other interviewee data 108
    5.6.4. Distinction between self-reflective and conceptual data 108
  5.7. Data analysis 108
    5.7.1. Stage 1: Analysis during data collection 109
    5.7.2. Stage 2: Preliminary analysis 109
    5.7.3. Stage 3: Verification and modification of preliminary analysis 109
    5.7.4. Stage 4: Independent analysis of data 110
  5.8. Conclusion 110
7.5.3. The influence of context 200
7.5.4. Further comments on metacognitive development 201

Chapter 8 Perceptions of time 203
8.1. Introduction 203
8.2. Common perceptions of time 205
8.2.1. ‘Time is money’ metaphor 205
8.2.2. Criteria for decisions on time allocation 206
8.2.3. Decisions about whether to invest time in understanding 207
8.3. Problems with time 208
8.3.1. Not coping with time in lectures 210
8.3.2. Not coping with time outside class 211
8.3.3. Not coping with time in tests 213
8.3.4. Conclusion 214
8.4. Relationship between perceptions of time and metacognitive development 215
8.4.1. Development of new perceptions of time congruent with conceptual focus 215
8.4.2. Unlimited time test and possibilities for metacognitive development 216
8.5. Conclusion 218

Chapter 9 Conclusion 220
9.1. Summary of findings 220
9.2. Assessment of the theoretical framework 222
9.2.1. Approach to learning 223
9.2.2. Perception of context 223
9.2.3. Metacognitive development 224
9.2.4. Relational perspective on learning 225
9.3. Implications for practice 225
9.3.1. General implications 225
9.3.2. Specific implications for CHE231F 227
9.3.3. An aside regarding comparisons of 1998 and 1999 230
9.4. Conclusion 230

Appendix A. CHE231F course handout 232
Appendix B. Journal tasks 238
Appendix C. Sample interview transcript 249
Appendix D. Interview protocols 261
Appendix E. Interview scheduling 278
Appendix F. Concept maps from journal task 9 280
Appendix G. Using the textbook – the concept of bypass 292
Appendix H. Hand-in and test schedule 297

References 299
### List of tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 4.1</td>
<td>Number of students who submitted each journal hand-in</td>
<td>85</td>
</tr>
<tr>
<td>Table 5.1</td>
<td>Selection of interviewees according to purposive sampling technique</td>
<td>101</td>
</tr>
<tr>
<td>Table 6.1</td>
<td>Marks obtained by interviewees in CHE231F assessments</td>
<td>130</td>
</tr>
<tr>
<td>Table 6.2</td>
<td>Analysis of activities which were regularly performed by interviewees</td>
<td>134</td>
</tr>
<tr>
<td>Table 6.3</td>
<td>Record of journal submissions and marks obtained by interviewees</td>
<td>135</td>
</tr>
<tr>
<td>Table 6.4</td>
<td>Initial analysis of interview conceptual data</td>
<td>148</td>
</tr>
<tr>
<td>Table 6.5</td>
<td>Comparison of conceptual scores with CHE231F final marks</td>
<td>149</td>
</tr>
<tr>
<td>Table 7.1</td>
<td>Summary of individual approaches to learning as seen in self-reflective data</td>
<td>168</td>
</tr>
<tr>
<td>Table 7.2</td>
<td>Summary of individual approaches to learning used in response to mass balance conceptual questions</td>
<td>181</td>
</tr>
<tr>
<td>Table 7.3</td>
<td>Comparison of students' perceptions of the purpose of the examples before and after engaging with the conceptual discussion questions</td>
<td>184</td>
</tr>
<tr>
<td>Table 7.4</td>
<td>Summary of individual approaches to learning used in response to energy balance conceptual questions</td>
<td>192</td>
</tr>
<tr>
<td>Table 7.5</td>
<td>Summary of individual approaches to learning</td>
<td>200</td>
</tr>
</tbody>
</table>
# List of figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 2.1</td>
<td>A model of student learning in context (Ramsden, 1992, p. 83)</td>
<td>31</td>
</tr>
<tr>
<td>Figure 2.2</td>
<td>A stylised view of Gurwitsch's field of consciousness (Booth, 1992, p. 266)</td>
<td>38</td>
</tr>
<tr>
<td>Figure 4.1</td>
<td>Chemical engineering undergraduate programme structure</td>
<td>70</td>
</tr>
<tr>
<td>Figure 4.2</td>
<td>Pass rate for second year mass and energy balance course</td>
<td>73</td>
</tr>
<tr>
<td>Figure 4.3</td>
<td>Schematic diagram of a simple chemical process</td>
<td>74</td>
</tr>
<tr>
<td>Figure 4.4</td>
<td>Sample input-output table for simple single pass system</td>
<td>74</td>
</tr>
<tr>
<td>Figure 4.5</td>
<td>CHE231F class test results in 1999</td>
<td>86</td>
</tr>
<tr>
<td>Figure 4.6</td>
<td>Final CHE231F marks in 1999</td>
<td>88</td>
</tr>
<tr>
<td>Figure 6.1</td>
<td>Worked example 2: Recycle system with no separation, product stream acts as purge (CHE231F workbook, Lecture 21, page 1)</td>
<td>141</td>
</tr>
<tr>
<td>Figure 6.2</td>
<td>Worked example 1: Recycle system with ideal separation (CHE231F workbook, Lecture 20, page 2)</td>
<td>142</td>
</tr>
<tr>
<td>Figure 6.3</td>
<td>Graph of enthalpy versus temperature (CHE231F workbook, Lecture 30, page 3)</td>
<td>144</td>
</tr>
</tbody>
</table>
Abstract

The notion of approach to learning has proven a powerful construct for describing differences in students’ experiences of higher education contexts, and for explaining the variation in learning outcomes. What has been more difficult to establish is how teaching and learning environments can be designed to promote deep approaches to learning. The present study focused on a second year chemical engineering course where the lecturers had adopted innovative teaching practices specifically with the intention of encouraging the development of conceptual understanding. Recognising that for many students this would involve a change in approach to learning, they also sought to facilitate metacognitive development during the course, for example by a series of journal tasks that required students to reflect on their learning.

This study sought to explore students’ experiences of this course. Specifically, it aimed to uncover what approaches to learning were prevalent, and the extent to which these changed over the duration of the course, that is, the extent to which metacognitive development took place. Rich contextual data were gathered by observation of nearly all classes and tutorials. The major data came from a series of semistructured interviews with eleven students, held periodically over the duration of the course. Other data such as journal entries and course assessments were also gathered for these students.

Three approaches to learning were identified in this context: a conceptual approach, in which the intention is to understand concepts; an algorithmic approach, in which the focus is on calculation methods; and an information-based approach, in which the intention is to gather and remember information. These different approaches were manifested both in students’ reflections on their learning, and in their engagement with a series of conceptual questions in the interviews. While students were shown to use a variety of approaches, in general a dominant approach was identified for each individual. Significant use of a conceptual approach which was demonstrated by some interviewees, was shown to be necessary for success in the overall assessment of the course. Other students showed metacognitive development from algorithmic approaches towards a conceptual approach, but this
development tended to be fairly limited. The next stage of the analysis used the construct of perception of the learning context to establish what lay behind this limited metacognitive development. It was shown that issues of time were foremost in students’ perceptions of the course context. These perceptions inhibited students’ full adoption of a conceptual approach to learning as they perceived this to be too costly in terms of time.

This study has implications both for research and practice. From a research perspective it endorses the need to establish approaches to learning that are particular to specific disciplinary and cultural contexts. It supports the conceptualisation of metacognition in terms of shifts in approach to learning. It has also provided a detailed elaboration of the complex interaction between students’ perceptions of a teaching and learning context and their approaches to learning. In practical terms it shows how important it is to understand from a student’s perspective how the course context is perceived. If one hopes to promote deep approaches to learning it is crucial to ensure that all aspects of the environment support the necessary metacognitive development.
Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university, and, to the best of my knowledge and belief, neither does it contain material previously published or written by another person, except where due acknowledgement is made in the text.

Signed: ...........................................

Jennifer Margaret Case

Date: ...........................................

This research project was granted approval by the Standing Committee on Ethics in Research on Humans of Monash University on 22 December 1998 (project 98/502).
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While working towards this thesis I have had a truly wonderful ‘support team’, and although it is difficult to do proper justice to what they have meant to me, this is an attempt to acknowledge the various contributions.

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My colleagues at the Faculty of Engineering and the Built Environment of the University of Cape Town have supported this work in many crucial ways, amongst which allowing me time to work on the project, giving me access to their classrooms, and most importantly, valuing the significance of educational research. Duncan Fraser has read my work and offered useful suggestions at various stages of the study. Others whose support I specifically wish to acknowledge are Alison Lewis, Dave Deglon, Jill Stevenson, Nelli Dili, Jeff Jawitz, Sue Harrison and Cyril O’Connor.

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The work environment at Monash University has been most conducive to my studies, and that was largely due to the open and friendly community of research students. Those who have made a particular impression on me are too many to name, but in various different ways they have extended my horizons and taught me so much. My friends in Cape Town have also sustained me, not only with their
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Chapter 1
Introduction

1.1. The focus of the study

Concerns about the quality of teaching and learning in tertiary institutions are not a new phenomenon, even though in the current climate of ‘excellence’ and ‘accountability’ it may sometimes seem so. Writing in the mid-nineteenth century, Cardinal Newman lamented

those earnest but ill-used persons, who are forced to load their minds with a score of subjects against an examination, who have too much on their hands to indulge themselves in thinking or investigation, who devour premiss and conclusion together with indiscriminate greediness, who hold whole sciences on faith, and commit demonstrations to memory, and who too often, as might be expected, when their period of education is passed, throw up all they have learned in disgust, having gained nothing really by their anxious labours, except perhaps the habit of application. (Newman, 1852/1964, pp. 112-113)

It is worrying to realise that this quote could easily be a description of the experience of many contemporary undergraduate students. Whatever advances we might have seen in the twentieth century it seems that little has changed in the quality of student learning in higher education. In recent times there have, however, been significant efforts by researchers and educators to address this issue, and the growing field of research on student learning has produced many suggestions as to what tertiary teachers should be doing to promote quality learning amongst their students. In 1997 I was interested to discover that a colleague of mine in the Department of Chemical Engineering at the University of Cape Town, Dr Barnes\(^1\), was planning to implement some of these ideas in a second year course. I expressed interest in exploring from an educational research perspective how students were experiencing this restructured educational environment. Thus began a journey which is the subject of the present thesis.

\(^1\) Pseudonyms are used for all individuals in this study.
Science and engineering contexts pose particular challenges for students owing to the complexity of the subject matter, the volume of work that is typically covered in an undergraduate curriculum, and the wide range of competencies expected of students. These competencies include a facility with mathematical techniques, problem-solving abilities, practical skills, and, in the case of engineering students, design capabilities and other professional qualities. In the South African context, extra challenges have been posed for students who enter these programmes from disadvantaged school backgrounds. Dr Barnes had reflected on this situation in conjunction with reviewing the literature on student learning. She concluded that the central issue in the second year Mass and Energy Balance course (CHE231F) was the development of conceptual understanding, and that this would involve development in the way students went about their learning. The changes she implemented in this course included a significant reduction in the course content, more active involvement of students in lectures, journal tasks to support development in learning, and assessment that matched this new focus.

In a pilot study in 1998 I followed the implementation of these initiatives, and began to explore the ways in which students were developing in their learning and conceptual understanding in this course. The higher education literature suggested that ‘approaches to learning’ might be a useful way of conceptualising different ways in which students experienced a learning context (Entwistle & Ramsden, 1983; Marton & Säljö, 1976a). Furthermore, it was proposed that the way students perceived this context significantly influenced their use of approach (Ramsden, 1984). From the science education literature I drew on the notion of ‘metacognitive development’ (Baird, 1986; Flavell, 1976) for describing changes in the way students approached their learning. Using this emerging theoretical framework, and combined with reflection on the course context in the pilot study, the following preliminary research questions were formulated for the major study to take place during the running of the course in 1999.

How do students perceive the learning context in this course, and how does this influence their approach to learning?

Does their perception of the context change over the duration of the course?
What metacognitive development takes place in the course and what aspects of the course influence this development?

What is the impact of assessment on the above aspects?

During the period of data collection these questions underwent a process of subtle refinement. Firstly, my understanding of the theoretical constructs deepened as I started applying these to the emerging data. In particular, it became clear to me that I first needed to establish the approaches that students were using before unpacking the underlying perceptions. The links between metacognitive development and approach to learning also became apparent, and I no longer saw these as embodying two separate questions. Secondly, and more significantly, the learning outcomes of students in the course caused a substantial change in emphasis for the research. During 1998, when the pilot study had taken place, the vast majority of students had shown notable metacognitive development and a deep conceptual understanding, and the substantially increased pass rate had reflected these largely positive outcomes. In 1999, the situation was completely different. Less than half the class passed the course, and this seemed to be a reflection of limited metacognitive development and inadequate conceptual understanding. This outcome caused the focus of the research to shift from a description of largely successful metacognitive development, to a focus, at least partly, on instances where this development had not taken place, and thus some changes were made in protocols for later interviews (see sections 4.5 and 5.6.2). To ignore this reality would be to ignore the data.

The final set of research questions was therefore as follows:

1. What approaches to learning are students using in the course, and how does the use of these change during the course? (Changes in approach to learning are conceptualised as metacognitive development.)

2. How do students’ perceptions of the context influence their use of approaches to learning and what changes occur in the use of these approaches (metacognitive development)?

3. What aspects of context (including assessment) have, through students’ perceptions, influenced their approach to learning? In particular, what aspects of the context might be related to limited metacognitive development?
1.2. The essential motivation for the study

Having briefly outlined the features of the present research project, I wish to stop and consider the purposes of conducting such educational research, as these have a profound effect on every aspect of the study, even if not explicitly stated. In this regard, the following simple and succinct statement by Ramsden (1987, p. 275) is appropriate: 'We ought to study learning because we want to describe what students do; we should apply what we find out to making learning better'. Ramsden emphasises that research should be closely linked to real teaching and learning contexts, in order that research findings can be used by teachers 'to encourage the changes [they] want to see in students' (p. 281).

The goal of improving education through research can be conceptualised in different ways. Research which aims to 'find out what's wrong and fix it' operates under what has been termed a 'deficit model' (Biggs, 1994, p. 16). Biggs argues that deficit models are attractively simple, but quite inappropriate in educational contexts. This is because education is more like a 'a soft slimy swamp of real-life problems' (Schön, 1987, p. 3) than a faulty machine, and changes are therefore not just like replacing a spare part, but more like a disturbance to an eco-system. An appropriate goal of research is therefore to understand better the elements and complex inter-relationships in this educational eco-system.

Entwistle (1997a) describes how the purpose of educational research has shifted from studies 'which have sought to predict subsequent academic performance', to 'those which have attempted to describe students' experiences of higher education' (p. 11). This is accompanied by a shift in research paradigm, from an 'agricultural-botanical experimental paradigm' (p. 14) in which students are assumed to respond to educational initiatives like plants to fertilisers, towards a paradigm traditionally used by social anthropologists who engage in empathically trying to understand the culture of a group of people. This paradigm shift has also entailed the utilisation of a wider range of research methods than the strictly statistical analyses of quantities of numerical data that were previously advocated.

In the context of engineering education, Sheahan and White (1990) critique the pervasive 'weeding-out mentality' among lecturers, and argue that this should be
‘replaced with a stronger concern for cultivating the human talent that comes to engineering’ (p. 1018). This relates closely to the shift in educational research agendas described above by Entwistle (1997a), from a focus on selection to a focus on development.

At the outset of this thesis I would like to affirm a strong emphasis on understanding the complexities of the teaching and learning contexts described above, and a deep concern with working towards environments which allow the students who participate in these courses to develop to their full potential.

### 1.3. An outline of the thesis

This chapter has provided a brief orientation to the key features of the present study. The study has been located within broader and ongoing concerns about the quality of teaching and learning in higher education. The context within which the study took place has been introduced. Most importantly, the evolution of the research questions has been described, and a stance adopted with respect to the general purposes of such research. This thesis provides detailed reporting on all aspects of this study. The structure is briefly outlined in what follows.

Chapter 2 provides a review of relevant literature, and describes the building of a theoretical framework that was used to guide this study. The key elements of the framework are the constructs of approach to learning, perception of context, and metacognitive development; and research in each of these areas is critically discussed.

Chapter 3 deals with methodological issues, and describes the epistemological position and choice of research paradigms that are used in this study. These theoretical research perspectives provide a justification for the way in which the research was conducted.

Chapter 4 describes the context in which the study took place. Firstly this is in terms of broad background pertaining to the university, the department and the evolution of the CHE231F course. This is followed by a detailed description of all aspects of the course, and how it ran in 1999.
Chapter 5 details the actual methods of data collection and analysis that were used in the present study. The most important data centred on a group of eleven students who were interviewed over the duration of the course. This was supported by a wide range of contextual course data.

The analysis of the data is presented in the next three chapters. Chapter 6 provides an introduction to the data, and covers a number of preliminary issues which set the background for the major analyses of Chapters 7 and 8. This background starts with a summary of the experience of each of the interviewees, after which the data are tested against some commonsense views on student learning. The chapter ends with an initial assessment of each interviewees’ conceptual understanding.

Chapter 7 brings the construct of approach to learning to bear upon the data, and describes the three different approaches that have been established in the context of this course. This analysis is presented by first dealing with data in which students reflect on their learning, followed by data resulting from their engagement with conceptual questions in the interviews, and a brief assessment of the conceptual journal data.

Chapter 8 presents an analysis of students’ perceptions of the CHE231F context, which provides an explanation for the approaches to learning and metacognitive development that was identified in Chapter 7. This analysis shows the dominance of time issues in students’ perceptions, and how these are linked to particular approaches and metacognitive outcomes.

Chapter 9 draws together the findings of the present study, and gives a reflection on both the theoretical and practical implications. This reflection involves an assessment of the utility of the theoretical framework, and an identification of the general and specific implications of the study for practice.
Chapter 2
Literature review

2.1. Introduction

The broad aim of the present study was to research students’ experiences of a particular course. In the previous chapter it was shown that certain theoretical constructs from the higher education and science education literature were used in the formulation of the particular research questions around which the study is based. These constructs were approach to learning, perception of context, and metacognitive development, and were chosen following an initial exploration of the research context and a critical reading of the literature.

This chapter gives detail on the origin and formulation of these constructs, describes the ways in which these have been used in educational research, and provides a critical assessment of these constructs in relation to the present study. This discussion is used to construct a theoretical framework appropriate to this study. The first section of this chapter provides some background on the different perspectives on learning that have been used in this research and subsequent sections deal with the three key constructs in turn.

2.2. Perspectives on learning

In the history of educational research a broad range of perspectives on learning have been used, from behaviourist theory to critical pedagogy. This section does not aim to provide a review of all these possible perspectives, but merely covers those that have been used in the literature which is reviewed in subsequent sections of this chapter. At this stage a brief outline of these different perspectives will be provided, which forms a background for the rest of the chapter. At the conclusion of the chapter these perspectives will be revisited in order to locate the present study within a particular perspective.
2.2.1. Students’ conceptions of learning

Given the interest in students’ viewpoints in the present study, an appropriate starting point in considering perspectives on teaching and learning is to consider what students think learning to be. Marton, Dall’Alba and Beaty (1993) asked this question of a group of university students over the period of their studies in social science, and from the answers they identified six qualitatively different ‘conceptions of learning’, namely:

1. increasing one’s knowledge;
2. memorising and reproducing;
3. applying;
4. understanding;
5. seeing something in a different way; and
6. changing as a person.

The first five conceptions correspond to those established earlier by Säljö (1979), and arrived at independently by Van Rossum and Schenk (1984). Numerous other studies have also come up with similar results (for example, Boulton-Lewis, Marton, Lewis, & Wilss, 2000; Marshall, Summers, & Woolnough, 1999) and this set of conceptions can therefore now be seen to be fairly firmly established in the literature. Marshall’s (1999) study with engineering students is of particular interest given the context of the present study: she found similar conceptions to all except the first one in the above list.

Van Rossum and Schenk (1984) group the first three conceptions of learning together, labelling them ‘reproductive’, while the rest are referred to as ‘constructive’. Traditional notions of teaching and learning are quantitative and reproductive, as illustrated by the content of popular quiz programmes and most school examinations (Dahlgren, 1984), and by the prevalence of the learning-as-eating metaphor as shown in words such as ‘assimilate’, ‘absorb’, ‘digest’ and ‘regurgitate’. (Biggs, 1994). Other metaphors traditionally used to describe learning are associated with passive and receptive minds: empty vessel, sponge, tabula rasa (Baird & White, 1996). However, recent research in student learning has challenged many of these traditional notions, and the constructivist view of learning to be
discussed below is more related to the three higher order conceptions. These conceptions are reflected in what Marton and Booth (1997) have termed the ‘visualisation metaphor’ in which people talk of seeing things in a new light or having new insights.

2.2.2. A constructivist view on learning

Constructivism is a broad philosophical position which holds the view, in brief, that humans construct rather than discover knowledge. Phillips (2000) has made the helpful distinction between constructivism as an epistemological position and constructivism as a set of views about how individuals learn. In the next chapter I will consider the implications of this epistemological position for my research methodology, but for the moment will be focusing on what is meant by a constructivist view on learning. Over the last decade there has been an abundance of educational research that claims to use this view of learning, particularly in science and mathematics education contexts (Gunstone, 2000).

In the constructivist view of learning, learning is seen as an activity in which ‘the learner constructs his/her own understanding from the totality of the experiences which he/she sees as relevant to the concept, belief, skill etc. being considered’ (Gunstone, 1994, p. 132). In this view on learning there is no possibility of passive learning: understanding is not something which can be passively transmitted from the mind of an expert into that of a novice. Learning is ‘not about adding more and more facts and procedures to one’s store of knowledge in much the same way as water might be poured from one vessel to another’ (Ramsden, 1988b, p. 26). On the contrary, learners need to actively make sense of ideas and concepts in their own minds.

Posner, Strike, Hewson and Gertzog (1982) suggest that the fundamental activity in the learning process is conceptual change, which involves the learner capturing new conceptions, restructuring existing conceptions, or exchanging one conception for another. They propose three conditions for successful change: that the learner must know what the idea means (the condition of intelligibility), that he or she must believe it to be true (plausibility) and finally that it must help the learner solve
problems that were previously insoluble (fruitfulness). The conceptual change model has since had several refinements and additions but continues to provide a helpful focus for researchers with a constructivist focus. Hewson (1996) has emphasised the way in which competing conceptions might change in status. In another refinement to the model, it has come to be seen that instead of exchanging one conception for another, learners rather learn to differentiate which concepts are appropriate in particular contexts (see, for example, Linder, 1993).

Effective conceptual change results in ‘a movement towards being able to solve unfamiliar problems, towards recognising the power and elegance of concepts in a subject area, and towards being able to apply what one has learned in class to problems outside class’ (Ramsden, 1988b, p. 15). These are the learning outcomes that are desirable in tertiary science and engineering contexts, and that they appear to be rare in actual educational settings is the concern of the present study.

A constructivist view on learning has two foci: ‘how learners construe (or interpret) events and ideas, and how they construct (build or assemble) structures of meaning’ (Candy, 1991, p. 272). There is a dialectical relationship between these two actions: learning is an active process of constructing a system of meanings which can then be used to interpret situations; and interpretation has a feedback effect on the system of meanings.

Two broad strands of constructivism have emerged: individual constructivism, which emphasises the learner’s active role, and social constructivism, which focuses on the importance of cultural practices, language, and people. These two movements have often been seen to be in conflict; from the perspective of this study they can be seen as two useful sides of the same coin (Driver, Asoko, Leach, Mortimer, & Scott, 1994).

2.2.3. **A phenomenographic view on learning**

The research specialisation of phenomenography developed from research on student learning conducted at the University of Gothenburg in Sweden in the 1970s (Marton & Säljö, 1976a, 1976b). The details of this and related work will be outlined later in this chapter, and phenomenography as a research approach will be
discussed in the next chapter. However, for the moment I wish to consider the phenomenographic perspective on learning.

The key aspect in which this perspective differs from a constructivist view on learning centres on the philosophical debate around dualism, epitomised by the classic Cartesian mind-body split. Phenomenographers argue that both individual and social constructivism set up a dualism between the person and the world, with conceptions inside the learner's head which are separate to the world outside. Instead of this formulation they propose a constitutive view of learning, in which learners are seen to participate in 'an ever ongoing constitution of the world' (Marton, 1995, p. 173). In this view learning is seen as a nondualistic internal relationship between the person and the world.

Phenomenographic research seeks to uncover the different ways in which people experience phenomena. In a recent theorisation Marton and Booth (1997) show that different 'ways of experiencing' can be related to how people's awareness is structured. In this framework learning comprises being able to discern aspects of the phenomenon which were previously not discerned, and being capable of being simultaneously and focally aware of other or more aspects of the phenomenon. In phenomenographic terms, learning is 'a change in someone's capability for experiencing something in certain ways' (Marton & Booth, 1997, p. 208).

Marton (1981) terms the focus on the student's perspective of the learning experience a 'second-order perspective'. This contrasts with the first order perspective traditionally used in research, which is from the perspective of the researcher (although this is often not explicitly stated).

2.2.4. A relational view on learning
In the late 1980s Paul Ramsden (1988b) considered the common views on educational research and development that were being used in phenomenographic and other related work on student learning, and formulated what he termed a relational perspective on learning. This view shares much common ground with the phenomenographic perspective but also draws in elements of the constructivist perspective. Fundamentally it is characterised by the strong emphasis that is placed
on the relation between educational research and practice. This practical focus is
given higher priority than theoretical concerns. Ramsden (1987) argues that a
relational perspective has the potential to reduce the gap that is traditionally found
between educational research and teaching practice.

The relational perspective is largely defined in terms of how it differs from
traditional modes of conducting educational research. Much of this research on
learning has isolated separate dimensions such as learning skills, teaching
characteristics, subject content, and so on. Ramsden (1987) concedes that it might be
appropriate for cognitive psychologists to use such approaches, but argues that
educationalists, especially those working in higher education, need to use a more
holistic approach in order to produce research that will be useful in practice.
Learning is therefore viewed as a relationship between the person and the context,
similar to the nondualistic perspective posited in phenomenography. In practical
terms this means that ‘[t]he major concern is with changes between students and
their world, rather than within students’ (Ramsden, 1987, p. 283).

Ramsden (1988b) also draws a conceptual change view on learning into his
relational perspective in order to emphasise the problems with the ‘empty vessel’
views on learning that are often prevalent in educational contexts. Strictly speaking,
the use of terminology such as ‘changes in people’s conceptions of aspects of reality’
(p. 26) is theoretically inconsistent with the nondualistic view on learning given in
the above paragraph, as ‘conceptions’ refer to mental structures. However, putting
aside these theoretical concerns, the utility of constructivist ideas as outlined in
section 2.2.2 cannot be denied. As stated above, the relational perspective is more
focused on practical than theoretical issues.

A relational perspective emphasises the importance of considering content as well
as process, in that ‘good learning’ cannot be defined separately from the subject
matter that is involved. This approach is dealt with from a constructivist
perspective by Fensham, Gunstone and White in The Content of Science (1994), and is
also central to phenomenographic research.
Biggs (1999) deals slightly differently with the conflict between constructivist and phenomenographic perspectives on learning. Like Ramsden, he is guided by practical concerns, but he chooses to use a constructivist approach, while he recognises the many common points between these two positions.

2.2.5. Conclusion

These different perspectives on learning have been productive theoretical frameworks for the diversity of research that has been conducted on student learning over the last few decades. In the remaining sections of this chapter, three constructs from that literature that are central to the present study are reviewed: approach to learning, perception of context and metacognitive development.

2.3. Approaches to learning

The construct now known as approach to learning arose from a groundbreaking series of studies conducted in the late 1970s by Marton and Säljö (1976a, 1976b), and later broadly disseminated through the publication of the highly influential book The Experience of Learning (Marton & Säljö, 1984, now in its second edition, 1997). In the first study (Marton & Säljö, 1976a), they investigated the processing of information by university students, focusing on what was learnt, rather than previous studies in cognitive psychology which had emphasised how much was learnt. Students were required to read an article, and were told that they would be asked questions on it afterwards. These questions dealt with the content of the article, and students were also asked to describe how they had gone about the task. Analysis of these responses revealed two qualitatively different ‘levels of processing’. Students who employed surface-level processing focused on the text itself, trying to memorise as much as possible, while those using deep-level processing aimed to grasp the underlying meaning of the text. The term ‘approach to learning’, which includes an intentional component, was subsequently adopted instead of the more narrow ‘level of processing’ which had been derived from information processing theory (Marton & Säljö, 1984).
This section discusses research that has been conducted around approaches to learning from a number of different perspectives. Firstly, other early research projects which supported the deep/surface model are described, and this is followed by a synthesis of research around two key aspects of this construct: the influence of context, and the relation to conceptions of learning and learning outcomes. The section ends with a critical examination of research using this construct, and a discussion of approaches to learning as they manifest in different contexts.

2.3.1. Deep and surface approaches

Other studies using different methodologies lent weight to the model of deep and surface approaches to learning. Svensson (1977) did an independent analysis of the same data and came up with the categories of ‘holistic’ and ‘atomistic’ approaches, which described the ways in which students organised the information in the article. In the former approach students directed their attention towards understanding the text as a whole, while in the latter approach there was a focus on memorising separate details of the text. In a review of this research, Marton and Säljö (1984) argued that Svensson’s categories represented an aspect of the deep/surface distinction. In a later phenomenographical framework, the aspect identified by Svensson was termed the structural (how) aspect, while the original deep/surface distinction was termed the referential (what) aspect (Marton & Booth, 1997).

Other researchers asked students to reflect back on what they usually did in their studies in general, rather than focusing on students’ approaches while tackling a particular task. This research approach was used by Entwistle and Ramsden (1983), who designed the Approaches to Studying Inventory (ASI) which was administered to a large number of students in higher education contexts. Based on quantitative analysis of these data, as well as follow-up interviews, they formulated four main ‘study orientations’. The meaning and reproducing orientations correspond to deep and surface approaches to learning, the strategic orientation involves the intention of maximising marks by whatever means are necessary, while the non-academic orientation is a ‘dysfunctional’ response to the requirements of higher education.
Working from a different theoretical perspective, Biggs (1978) produced strikingly similar results with his Study Process Questionnaire (SPQ), in which three dimensions of study process were identified, namely utilising (similar to surface approach), internalising (deep) and achieving (strategic) dimensions. Biggs (1986, p. 133) has provided a useful description of approaches to learning as ‘congruent motive-strategy packages’ in that they comprise both intention and a related strategy. In phenomenographic terms, an approach comprises both a referential (what) aspect which refers to the student’s intention, and a structural (how) aspect which refers to the processes used (Marton & Booth, 1997).

The deep/surface model has subsequently been widely used in research, particularly in higher education contexts. However, it has been frequently misinterpreted, for example, Biggs (1993) has pointed out that some researchers have assumed that the presence of rote learning always implies a surface approach. In their analysis of the ‘paradox of the Chinese learner’, Marton, Dall’Alba and Tse (1996) show that in certain cultural contexts ‘rote’ learning can be an important aspect of deep learning. Biggs (1993) has provided a useful clarification of the core meanings of the different approaches. The surface approach is fundamentally based on an intention that is ‘extrinsic to the real purpose of the task’ (p. 6), involving what Biggs terms ‘satisficing’ (but not satisfying) task demands with a minimal investment of time and effort. The deep approach involves an intention to ‘engage the task properly on its own terms’ (p. 6), associated with interest in the subject matter and a desire to maximise understanding. What each of these terms means in practice depends on the context, the task, and the individual interpretation; they do not have uniform manifestations in all contexts. The achieving approach, which was introduced in the Biggs and Entwistle studies, involves using either deep or surface approaches, depending on what the student thinks will produce the best marks, combined with a generally well organised and systematic attitude. In this approach, the focus is on the recognition obtained from top performance, not primarily on the task. It can be seen that both the surface and the achieving approaches result from the institutional context; they are not ‘natural’ ways of approaching learning (as the deep approach is) (Biggs, 1993).
In another study on student learning in the late 1970s, Pask (1976) identified two learning styles: comprehension learning, which involves the search for broad meaning, and operation learning, where the focus is on using rules and strategies. At first appearance, Pask’s work seems also to mirror and support Marton and Säljö’s (1976a) deep/surface dichotomy (a view advanced by Thomas & Bain, 1984), particularly if one considers Svensson’s (1977) holistic/atomistic categorisation of approaches. Ramsden (1988a) advises that these constructs (learning style and approach to learning) are best left apart, as they describe different processes. Other researchers (Entwistle, 1998a; Newble & Clarke, 1986) have suggested that Pask’s two learning styles both describe aspects of the deep approach. In his original study Pask did find students who relied on rote learning, and he distinguished this from operation learning. Entwistle (1998a, p. 76) writes that: ‘The contrast in Pask’s work is not between understanding and reproducing, but between preferences and habits in the use of different kinds of interpretative frameworks in seeking understanding’.

Pask did warn against over-reliance on either of these strategies which, in his terms, would lead to ‘pathologies’. In the case of comprehension learning, the associated pathology is termed ‘globetrotting’ in which broad claims are accepted without supporting evidence; in operation learning it is ‘improvidence’, where links between ideas are not well developed. Pask felt that the most successful learners would use a combination of both strategies, which he termed versatility. Entwistle suggests that this construct is similar to the ‘Reasonable Adventurer’, identified by Heath (1964) as an ideal position towards which most of the Princeton students whom he followed throughout their studies tended to develop. The Reasonable Adventurer manages a highly effective combination of being at times critical and at other times curious. This is in contrast to students’ undeveloped characterisations as either ‘Non-committers’ (too critical, avoiding personal involvement, analogous to Pask’s improvidence), ‘Plungers’ (too curious, jumping from one point to another, analogous to Pask’s globetrotting) and ‘Hustlers’ (neither critical nor curious but overly concerned with external achievement) (Heath, 1964).
2.3.2. The influence of context

In their original formulation, Marton and Säljö stressed that approach to learning was to be seen as a response to a particular task and not as an unchanging student characteristic. In Marton and Säljö’s second study (1976b), they attempted to induce deep and surface approaches by means of interspersing particular questions in the text. As was expected, the superficial questions did elicit surface approaches to the task. However, two different responses were identified in the group exposed to ‘deep level’ questions. Some of them did in fact use a deep approach, but others made the answering of the questions an end in itself and failed to engage with the task in a deep manner. Marton and Säljö (1976b) use the term ‘technification’ to describe this subversion of the original purpose of the task. The same phenomenon was observed in Australian classrooms where teachers were engaged in the Project to Enhance Effective Learning (PEEL) (White, 1992). In order to encourage reflective thinking and deep learning teachers encouraged students to ask questions that began with ‘What if…?’ With time however, it was observed that some students had developed an algorithm for framing such questions without having to think. White terms this the ‘Principle of Minimum Expenditure of Energy’, a commonsense human adaptation for survival that we all employ in many everyday contexts. The energy input required for deep learning must not be underestimated, especially given that this is almost always a greater input than that demanded by traditional classroom contexts.

Marton and Säljö (1976b) concluded that: ‘Students adopt an approach determined by their expectations of what is required of them’ (p. 125). They argue that most students are apparently capable of using deep or surface strategies, but that the current demands of school assessment are interpreted by them as requiring mainly factual recall at the expense of deep understanding. In an investigation into students’ approaches to tackling different kinds of assessment tasks in a real setting, Thomas and Bain (1984) found that deep approaches (termed ‘transformational’) were associated with open-ended written assignments, while surface (‘reproductive’) approaches were common in multiple-choice and short-answer examinations. Marton and Säljö (1976b) advocate assessment systems that are perceived by students to demand deep-level processing, but do caution that this
process is not all that simple given students’ ability to ‘technify’ the purpose of a

There is an apparent contradiction between Marton and Säljö’s (1976a) context-related, and therefore variable, approaches to study, and Entwistle and Ramsden’s (1983) ‘study orientations’ which describe fairly consistent ways in which students approach their studies. Ramsden (1988a) comments that there is no straightforward solution to this dilemma. There is certainly a multitude of evidence that students in higher education vary their approaches to learning depending on the present task. On the other hand, students are able to give sensible answers to questions about their general approaches to learning as they do develop strong habits in this regard. However, Ramsden (1988a, p. 175) emphasises that ‘stability of orientations does not imply fixity. Orientations to studying are changeable and responsive to the context of teaching, evaluation and curriculum.’ Nonetheless, there may be an element of ‘cognitive style’ in an individual which is inherent and possibly resistant to change (Schmeck, 1988).

A basic psychological assumption that is quite helpful in this regard is that there are two types of influence that affect behaviour: characteristics of the person and characteristics of the situation. On this basis, the choice of which theoretical construct to use depends on the purposes of a research study. If the purpose of the research is prediction of success in order to develop methods of selection then the focus of such research will be on stable individual characteristics. Alternatively, if the aim of the research is to understand better and therefore improve student learning then the focus is on the context and how this influences learning. The present study sits firmly within the latter camp, with the focus on the potential that the learning context has in promoting more desirable approaches to learning. Marton and Säljö’s context-related formulation of the approach to learning construct will therefore be utilised.

### 2.3.3. Relationships between approach to learning, outcomes and conceptions

Marton and Säljö’s (1976a) original research had aimed to provide an explanation for different learning outcomes, and indeed a correlation between process and
outcome was found. In these studies, Marton and Säljö were looking at qualitative rather than quantitative differences in learning outcomes. However, students who used the deep approach not only had a more complete understanding but were also able to recall more facts (Marton & Säljö, 1976b). Svensson (1977) tested this hypothesis in the natural setting of a university course and found that students who used a deep ('holistic') approach were more successful in examinations than those who used a surface ('atomistic') approach. In the context of a first year physics course, Prosser and Millar (1989) showed that students with a deep approach to learning demonstrated a greater degree of conceptual change towards more sophisticated conceptions. Confirming the Posner et al. (1982) model of conceptual change (described in section 2.2.2), Prosser and Millar argue that in order to experience conceptual change, students have to actively seek such a commitment, or in other words, use a deep approach. In discussing the Prosser and Millar study, Marton and Booth (1997) conclude that ‘learning in the sense of changing one’s way of experiencing a phenomenon is contingent on one’s approach to learning’ (p. 158).

Chin and Brown (2000) provide further in-depth detail on the nature of the learning activities associated with these higher level conceptual outcomes. In a study of school students who were engaging in science tasks, they found that those using a deep approach were more spontaneous in voicing their ideas, gave more extensive explanations, asked more sophisticated questions and engaged in more explicit theorising during the task.

Given that approaches to learning comprise both intention and strategy, one would expect to find links between students’ conceptions of learning (as discussed in section 2.2.1), and their approach to learning. In an investigation based on Marton and Säljö’s first study (1976a), Van Rossum and Schenk (1984) explored the relationships between students’ conceptions of learning, their approach to learning, and their learning outcome. As one would expect, they found a strong correlation between conceptions of learning and approaches to learning, with students at the lower (reproductive) end of the conceptions of learning tending towards a surface approach, and those at the upper (transformative) end tending to a deep approach. They also replicated Marton and Säljö’s (1976b) finding regarding the relationship between approach to learning and learning outcome, although they used Biggs and
Collis’ (1982) SOLO taxonomy to classify qualitatively different learning outcomes. Students using a surface approach never obtained more than a ‘multi-structural’ level of learning outcome, in which facts are presented in an unconnected manner. The majority of students using a deep approach reached the ‘relational’ level, in which ideas are presented as a coherent whole.

2.3.4. Use of the deep/surface model in research

Research into student learning over the last two decades has mushroomed, with a large body of work claiming descent from Marton and Säljö’s (1976a, 1976b) original investigations. Many of these studies have used close-ended self-report questionnaires (most widely used is Entwistle’s ASI), and applied statistical analyses to determine correlations and associated predictive value (for example, Meyer, Dunne, & Sass, 1992). Much of this research focuses on approaches to learning as stable individual characteristics by means of which students can be classified. It was argued above that this theoretical position reflects a focus on selection rather than development. As an exemplar of this research tradition, the work of Meyer and his colleagues will be briefly reviewed. One reason for looking at this particular set of studies is that much of this work has been conducted in the same institutional context as that of the present study. Meyer (1991) introduced the term ‘study orchestration’ as a term which covers both approaches to study and perceptions of the learning context, and this has been measured in a number of studies using a modified form of Entwistle and Ramsdens’s ASI (for example, Meyer, 1988; Meyer et al., 1992; Parsons, 1992). It is claimed that study orchestration is context-specific, yet it is difficult to reconcile this claim with the research methodology used and the ‘essentially stable patterns of subject-specific study orchestration’ (Meyer et al., 1992, p. 295) that were obtained. Although it claims to be rooted in the phenomenographic tradition (Parsons, 1992), the approach adopted by Meyer and fellow researchers does not have a research objective of ‘uncovering the qualitatively different ways in which people experience a phenomenon’ (Marton, 1981). The aim of this research seems to be the prediction of success, and indeed a number of studies found that ‘there was a consistent conceptual and
empirical association between the categorisation of students ... and their test and examination performance' (Parsons, 1992, p. 4).

Bock (1986) has provided a strong critique of research such as this which focuses exclusively on correlations between approaches to learning and outcomes, without seriously investigating why study difficulties occur. She cautions that such research with a focus on narrow statistical correlations could lead to a situation where the deep/surface model has ceased to be descriptive, and in fact becomes prescriptive. Bock (1986) also argues that the generalisability of the deep/surface model is in fact a weakness when applied to culturally diverse contexts.

Another critique of the deep/surface model is given by Webb (1997), who works from a post-modern perspective to provide a deconstruction of the deep/surface model. His main concern is with the high status assigned to deep approaches and the denigration of surface approaches. This may be a useful perspective in some studies, but from a practical perspective there is little question that most people would assert that higher education contexts should be aiming for deep approaches to learning. I have therefore put on one side these particular concerns, as did Noel Entwistle in his response to this critique (Entwistle, 1997b). Entwistle ascribes the popularity of the deep/surface model in recent educational thinking to its validity, in that it describes a ‘recognisable reality’. This is a defence that is hard to ignore, especially when one is seeking to produce educational research with utility and relevance, as in the present study.

2.3.5. Approaches to learning in different subject contexts

Ramsden (1988a) points out that deep and surface approaches will have different manifestations in different academic specialisations, in line with the context-dependency of these approaches that has already been outlined. Ramsden suggests that in some science tasks a deep approach will initially demand a narrow focus on details, which taken on its own would appear to be a surface approach. By contrast, in the humanities a deep approach will usually involve establishing a personal meaning right from the start of a task. Entwistle (1998b, p. 88) also argues that approaches to learning need to be ‘re-interpreted, to some extent’ within different
disciplinary contexts. As far as I can establish, there are very few examples of work which have sought to uncover the forms of approaches in particular undergraduate contexts, especially when compared to the great body of statistical work in which these constructs are assumed to be present in their original formulation. One important example of research that has not assumed the existence of deep and surface approaches in a particular context is that of Shirley Booth, who investigated students learning to write computer programmes (Booth, 1992).

Booth identified four distinctly different approaches which can be seen to fall into two pairs analogous to the surface-deep dichotomy. ‘Opportunistic’ approaches were similar to the surface approach. Under this category, students either used an ‘expedient’ approach, in which a previous program is identified which will suit the purposes of the current task, or a ‘constructual’ approach, where elements from their previously written programmes are cobbled together for a solution. In both of these approaches students did not fully interpret the problem itself, but rather focused on the end product. On the other hand, students in this context using ‘interpretative’ approaches, similar to a deep approach, actually interacted with the problem itself. Students using the ‘operational’ approach focused on what the programme was going to have to do, while those using the more advanced ‘structural’ approach focused initially on the problem rather than the programme specifications. Apart from the specific approaches identified, this study also differs from previous work on approaches to learning in that in this context ‘approach’ refers more to the initial response to the problem than to the overall strategy used.

2.3.6. Conclusion

The construct of approach to learning, with the formulation of deep and surface approaches, has been critically reviewed in this section. It has been shown to be a powerful construct in describing the qualitatively different ways in which students go about their learning, and provides an explanation for learning outcomes of differing quality. For the purposes of the present study the validity of the general construct of approach to learning has therefore been assumed, although not the particular approaches that might be applicable in this context (for example, deep and surface). Important aspects of approaches to learning, described as ‘congruent
motive-strategy packages’ by Biggs (1986), are that they are not stable student characteristics but are rather determined by particular contexts, and that they are identified by the intentions that underlie students’ engagement with a learning activity.

2.4. Students' perceptions of the learning context

This section reviews another construct from the student learning literature that is central to the theoretical framework for the present study, namely perception of context. This idea arose in response to the common situation that courses with espoused aims of critical thinking and conceptual understanding so often fail to elicit a deep approach to learning from their students. Ramsden (1984, p. 145) suggests that the following might be happening in these instances.

...university teaching contexts might have unintended consequences for learning - ...they might discourage students from coming to grips with the fundamentals of their subject and encourage them to use tricks and stratagems to pass examinations...

Ramsden emphasises that students respond and react to the situation they perceive, which is frequently quite different to that defined by teachers and researchers. Although the latter might comprise high level objectives the former might be a simple set of rules for what really has to be done in order to pass the course examination.

Ramsden’s work on students’ perceptions of the teaching and learning context forms one of the key elements of the theoretical framework for this study. This section firstly discusses some of the early student learning research in this area upon which Ramsden based his ideas, followed by a focus on students’ perceptions of science and engineering contexts. The final part of this section lays out Ramsden’s theory in detail, and also discusses other theoretical approaches to students’ perceptions which are utilised in the present study.
2.4.1. Early research into students’ perceptions of the learning context

Students’ perceptions have been of interest to researchers since the early days of the student learning research enterprise described in section 2.3 above. A parallel focus can be seen in sociological studies of student learning at the same time. Salient research studies from both these areas are discussed in this section, as they form important background for the later consolidation of this theory (to be discussed in section 2.4.3).

One of the important early student learning studies in this area was by Entwistle and Percy (1974 cited in Entwistle, 1997a, p. 6) who interviewed a range of university lecturers about their teaching. They found a ‘profound contradiction between lecturers’ intentions and what the students achieved’. Although lecturers said they aspired to develop critical thinking in their students, they taught and assessed ‘conformity in ideas and the acquisition of detailed factual knowledge’.

Further evidence for the importance of focusing on students’ perceptions of learning contexts comes from the work of Fransson (1977). He investigated experimentally the relationship between motivation and approach to learning. Initially he analysed his results based on his own assessment as to whether the conditions promoted extrinsic or intrinsic motivation (whether the text related to the students’ course of study or not), and were stressful or not. This initial method of analysis yielded no significant results, but when he analysed his data based on the students’ perceptions of interest and anxiety, strong correlations were found. Students motivated by extrinsic demands to read a text for which they had limited interest tended to adopt a surface learning strategy, while students for whom the text was intrinsically interesting usually utilised a deep strategy. Moreover, perceived anxiety, threat or irrelevance reinforced the use of the surface approach. For students he terms ‘highly trait-anxious’, Fransson points out that expectations built up by previous experiences might be more important in determining their perception of the learning situation, than the characteristics of the actual situation as defined by the researcher.

Laurillard’s (1984) study into how students approach and carry out problem-solving tasks also revealed the central role of students’ perceptions of context. Regardless of
whether they used a ‘surface’ or ‘deep’ approach, students focused primarily on what they perceived the teacher to require, termed by Laurillard ‘the problem as set by a teacher in the context of a particular course’ (p. 131), rather than on the task itself. The consequence of this situation is that a problem-solving task may not actually achieve its stated aim of helping students to understand the subject matter.

Descriptions of students’ perceptions of the learning context appear in sociological studies starting in the climate of student unrest of the late 1960s, during which period it first became popular to consider learning from the students’ perspective (Entwistle, 1997a). In research done at MIT, Snyder (1971) uncovered a contradiction between the messages coming from the formal goals of the curriculum and those messages communicating what actually had to be done in order to attain academic rewards. He uses the terms ‘formal’ and ‘hidden’ curriculum to distinguish between the learning context as defined formally by teachers and that perceived by students. Students sort out these contradictory messages and interpret the mixed signals, ultimately translating what is said by lecturers into a set of ‘discrete, more or less manageable tasks’ (p. 5) which they take to be the basis for the awarding of marks. Snyder argues that the hidden curriculum is central both to students’ and lecturers’ senses of worth, and influences students’ adaptation to higher education far more than the formal curriculum. The hidden curriculum also serves as a powerful tool for maintaining the status quo. However, Snyder found that the hidden curriculum was seldom talked about openly; even amongst students it was only discussed with roommates and certain classmates.

The work of Miller and Parlett (1974), focusing on students’ responses to the examination context, can be seen as an extension of the notion of the hidden curriculum. In this context, the hidden curriculum manifests itself as a series of ‘cues’ given out by staff. They found that not all students responded in the same way to these cues, and identified three different groups of students in this regard. The first group of students, termed ‘cue-conscious’, was receptive to cues sent out by staff. The second group, ‘cue-seekers’, took cue-consciousness one step further and actively interacted with staff to elicit cues. The final group was termed ‘cue-deaf’ because, to all intents and purposes, they were completely unaware of cues.
As stated previously, perception of context has a critical impact on how and what students learn, and these different groups displayed distinctly different methods of engaging with the examination context. Cue-seekers were often highly intelligent, metacognitively aware and hard-working. They were able to analyse the examination situation for what it was: an artificial situation which requires an artificial response. As could be expected, they also generally achieved higher marks than the other two groups, although Miller and Parlett stress that this is merely a correlation and does not necessarily indicate causality. Cue-conscious students achieved moderate marks, and were most likely to credit luck for their success, while cue-deaf students were frequently academically unsuccessful.

In investigating students' perceptions of assessment, Miller and Parlett (1974, p. 110) also uncovered what they termed the 'memory clearance function of examinations', in which the examination is seen as a terminal task, which when completed 'wipes the slate clean'.

Becker, Geer and Hughes (1968) also identified the centrality of assessment concerns in the student's view of the academic environment. In comparison to the work cited above, they were working from the premises of symbolic interaction theory, and as such were looking at collective rather than individual responses to a situation. Defining perspective as 'a coordinated set of ideas and actions a person uses in dealing with some problematic situation', they uncovered a dominant set of ideas amongst students which they termed 'the GPA\(^2\) perspective'. In this perspective, students defined the learning context as an exchange of rewards (marks) for performance, rather than as any sort of learning process. Students regarded their relationship with lecturers as one in which there is a contract by which performance is rewarded in predictable ways. Students put considerable effort into finding out the terms of this contract for a particular lecturer, and trying to uphold their side of it, as they see it, by doing what is required of them academically. Becker et al.

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\(^2\) Grade Point Average: combined average mark for all courses taken; used to determine progress and graduation in certain US universities.
found that the major criterion students used for judging staff was how difficult staff make it for them to achieve their own version of academic success.

2.4.2. Students' perceptions of learning science and engineering

The findings from a number of studies along similar lines to those reviewed above, but specifically investigating tertiary science and engineering, will be used in this section in order to draw a composite picture of students' perceptions of these contexts. Although there are significant differences between the fields of science and engineering, there are also many areas of commonality in student experiences of these fields. In this section, issues specific to a particular context will be highlighted as such.

Before discussing their findings, some of these research projects will be briefly described. Bliss and Ogborn (1977) asked undergraduate physics students to describe 'good' and 'bad' experiences of learning science at university, and analysed their findings according a system derived from linguistics focusing on reported emotions. Tobias, a sociologist, designed a novel project using postgraduate students from disciplines other than science, to take part in and audit introductory science courses (Tobias, 1990). These were able students who had not chosen science careers, and their reflections provided useful insights into why students other than those headed for an academic career might drop out of science. Prosser, Walker and Millar (1996) used open-ended questionnaires to investigate students' broader perceptions of what studying physics is all about, and analysed the data using a phenomenographic methodology.

When science and arts students were asked to describe the major differences between studying in these areas their views were clear and consistent: science is 'hierarchical, logical, ... and rule- and procedure-governed', while humanities and social science are seen to require 'interpretation, comparison, generalisation' and require students to be 'self-governed' (Ramsden, 1984, p. 156). Ramsden points out that these distinctions resemble respectively Pask's (1976) constructs of operation and comprehension learning, and links this to Entwistle and Ramsden's (1983) finding that science and engineering students scored highest on operation learning
measures while arts students scored highest on measures of comprehension learning. Interestingly, science students were also more likely to display what Pask termed versatility: a combination of operation and comprehension learning.

One salient impression from all these studies is of the impersonality of studying science. Tobias's (1990) students were surprised by the absence of community and the impersonal classroom culture that they encountered. Bliss and Ogborn (1977) also reported on the loneliness and individuality of learning science, and noted that involvement with the subject was mentioned more than involvement with people.

Science was seen as 'something out there', 'like a cliff to be scaled' (Bliss & Ogborn, 1977) and the level of competition for marks was obsessive (Tobias, 1990). This had a profound impact on students' senses of self-worth. Self-doubt and insecurity were common, and the extreme reaction when things got difficult was to disengage oneself from the context. Praise was rarely mentioned (Bliss & Ogborn, 1977).

Donald's (1992) sample of engineering students, while generally positive about their experience of studying engineering, talked frequently of survival skills. First years made frequent reference to examinations, while older students shared their coping strategies. One second year student stated that 'Engineering is not a place for those who cannot handle stress' (p. 242). In the context of a course which had recently addressed the issue of overload, Kember et al. (1995) found that students spent an average of 23.6 hours per week in private study, over and above time spent in class. This was 77% of what the lecturers expected them to do, a load considered by them and the author to be quite reasonable. (One staggers to think what it was like before the course content was reduced!)

Learning science was seen as a job, 'an immediate set of demands to be complied with' (Bliss & Ogborn, 1977). Tobias's (1990) mature students were frustrated by the lack of depth and context in the courses, and wished for more opportunities for 'why' questions. They noted an almost exclusive focus on problem-solving, which also appears in Donald’s (1992) study of engineering students. Donald noted that the students’ perceptions in this regard were in line with lecturers’ stated intentions and course objectives: students described the main goal of their studies as 'the learning of ... methods ... which could be applied to solve problems' (p. 240).
Prosser et al. (1996) found that most students used a surface approach to learning and few indicated that they were really seeking understanding or relating physics to the real world, even though most of them acknowledged that physics was the study of the physical world. Prosser et al. speculate that the ‘study of the physical world’ is something of a ‘throwaway line’ that students can repeat without internalising its meaning. Kember et al. (1995) found that a sizeable proportion of the students studied seemed to be adopting a surface approach to their work, and they speculate that this could be related to the fact that engineering subjects have many short well-defined tasks.

Some findings from school science classrooms will now be briefly mentioned, as it seems that they have relevance to similar situations in tertiary contexts. In observing school science practicals, both Tasker (1981) and Baird (1990) found that pupils’ perceptions of the purpose of practical activities frequently differed considerably from what the teacher had intended. On some occasions where the teacher’s purpose was made explicit, pupils established an alternative purpose for the task. On other occasions the actual purpose of the task was not made explicit, and students either developed an activity-related purpose, or else used the fallback purposes of ‘following the instructions’ or ‘getting the right answer’. Tasker also noted that pupils often perceived lessons as isolated events rather than as a related series of experiences.

2.4.3. Theoretical approaches to perception of context

As mentioned at the start of section 2.4, Ramsden’s work on students’ perceptions has been a significant influence on the theoretical framework used in the present study. In what follows this theory will first be described in detail. This is succeeded by a critique of this theory which suggests the utility of a nondualistic view on perception. Finally, I introduce an idea from studies of language that is helpful in identifying perceptions.

Ramsden’s model of student learning in context

In a widely cited chapter in The Experience of Learning, Ramsden (1984) first elaborated his theoretical ideas in this area, formulating a set of ‘interconnected
levels’ at which students’ perceptions of an educational context can be conceptualised, namely:

1. the student’s interest, knowledge base, and previous experience;
2. assessment;
3. teaching and teachers; and
4. course design, department and institution.

It is interesting to note that of Ramsden’s four levels, only the first one, which centres on the student, is usually invoked by teachers to understand less than satisfactory student learning. Student inadequacies such as intellectual inabilities or laziness are the ready explanations to explain any disappointing learning outcomes (Entwistle & Percy 1974 cited in Entwistle, 1997a; Ramsden, Beswick, & Bowden, 1986). It is easy to understand why this argument is so attractive; it serves to protect the status quo, and excuses teachers from having to question their practice. However, as Biggs (1994, p. 7) puts it: ‘...good teaching involves helping students learn; it should not involve finding reasons that conveniently inhere in the student to explain when teaching fails’. There is clearly a whole gamut of issues that extend beyond what an individual student brings to a course and which have a profound effect on how the course is experienced. As seen in the previous section there is ample evidence that the same student can take different approaches in different environments (for example, Laurillard, 1984).

Ramsden has represented the relationship between students’ perceptions, different levels of context, approaches to learning, and learning outcomes in a diagram, a recent version of which is given in Figure 2.1. This model is clearly derived from Biggs’ 3P model of student learning (a recent version of this model can be found in Biggs, 1999, p. 18), although it is Ramsden who has highlighted the central role of perception.
In this diagram the four levels mentioned earlier can be identified on the left hand side of the diagram. The student’s interest and knowledge base have been codified as ‘orientation to studying’, with previous experience shown to be feeding into this. The other three levels are given with slightly different wording in the block headed ‘context of learning’. Ramsden describes perception as the ‘point of contact’ between the educational context and student experience, and also refers to perception as a ‘relation’ between these two domains (Ramsden, 1988a, p. 160). In an earlier version of this diagram (Ramsden, 1988a, p. 161) he had ‘perception’ instead of the more specific ‘perception of task requirements’ in the version herewith.

Ramsden stresses that this diagram should not be taken to suggest a single causal sequence of events, but rather a ‘chain of interactions at different levels of generality’ (Ramsden, 1992, p. 84). Biggs (1993) has also suggested that one should think of the above as open system, where any disturbance or change to a part of the system affects the whole system, until a new ‘steady state’ is achieved. Indeed, a recent version of Biggs’ 3P diagram has two way links between each of the elements (Biggs, 1999, p. 18). This links back to Biggs’ critique of deficit models presented in Chapter 1, where it was suggested that an educational system should be seen as a kind of ecosystem. A predisposition to a particular learning approach is then seen as the ‘individual student’s way of achieving balance in the system as perceived by the student’ (Biggs, 1993, p.10). Biggs posits that ‘students in tertiary institutions
progressively achieve equilibrium with their learning context, with an increasing predisposition for a surface approach’ (1993, p.10). To attempt an intervention when students believe that they have achieved equilibrium is likely to be futile. A sense of disequilibrium is a necessary condition for change; this resonates with the Posner et al. (1982) model of conceptual change. Another way of looking at the situation is to conclude that the learning environment needs to be structured in such a way that adaptive responses are in line with the teacher’s aims (Ramsden, 1988a).

Entwistle (1998b, p. 105) has developed a similar diagram representing the relations between different elements of context, students’ perceptions, learning approaches, and outcomes. This diagram differs to Ramsden’s in that it has no arrows to suggest causality, but rather has different constructs grouped under the dimensions of student, teaching and departmental characteristics. These groups are represented on the outskirts of the diagram, and give the impression of impinging on the centre which contains students’ perceptions, strategies and outcomes. It is therefore conceptually a similar representation.

In unpacking the idea of ‘perception of context’ Ramsden provides an analysis at each of the four levels identified above, which will be discussed in what follows.

Assessment

Ramsden (1988b) argues that assessment is the dimension with ‘the most significant single influence on students’ learning’ (p. 24). He identifies two related aspects for consideration: the amount of assessment work and the quality of the tasks (Ramsden, 1992). A series of interviews that he carried out with university students in the late 1970s illustrate the potent effect of assessment on how and what students learn (Entwistle & Ramsden, 1983). Inappropriate assessment was shown to push students towards learning in less than effective and empowering ways. Moreover many students, especially those that would be described as highly metacognitive, displayed a real awareness of this situation, but felt that they had no choice but to use these methods if they wished to succeed in the course.

It has long been known that students’ learning is affected by the type of test anticipated, with an ‘objective test’ (close-ended) promoting surface learning, and
an essay or oral test (open-ended) encouraging deeper learning (Marton & Säljö, 1976b; Thomas & Bain, 1984). However, owing to the central role of students' perceptions, there is no simple relationship between assessment methods and student responses, as shown in Ramsden's review of Newble and Jaeger's study (1983 cited in Ramsden, 1988a). In a particular medical school, a new ward-based assessment was introduced in order to emphasise the importance of clinical skills. However, from the students' perspective it turned out this assessment was easier to pass, and so they spent more time in the library studying for their feared theoretical examination. The effect of the change was therefore exactly opposite to what was intended. Ramsden suggests that this was due to 'a disjunction between the faculty’s goals and the goals perceived by the students' (p. 166).

Another important study of students' perceptions of an innovation, and how these are linked to perceptions of assessment, comes from Mahmoud (1989). This study was conducted in an engineering context, where the lecturer had introduced a system of audiotapes and tape-slide presentations, in an attempt to improve students' problem solving abilities and reduce the failure rate for the course. These audiovisual resources contained step-by-step explanations of problem solutions, summaries of the course, and practical instructions. The failure rate did indeed decrease, and the lecturer was pleased with the apparent success of the innovation. Mahmoud investigated students' perceptions of this innovation, and found that they had approached the tapes in a surface manner, trying to remember solutions and information, rather than developing good problem solving skills. This situation had been further encouraged by a highly time-pressured assessment with a low conceptual demand. Although the failure rate for this particular course had decreased, Mahmoud speculated that there might be long term detrimental effects owing to the approaches that students had used. This innovation took place some years before the publication of the paper. From a current perspective it is easy to critique the system of audiotapes as representing a transmissive view of teaching, which is inconsistent with the espoused aim of developing problem-solving skills. Nonetheless, the study still illustrates the important role of assessment, as Mahmoud asserts that students focused mainly on the assessment demands of the course.
Although we presumably assess in order to encourage and test the quality of students' work, Ramsden (1987) states that 'all too often what we really test is not changes in how students understand the world, but something that is an invalid proxy for such changes: the ability to apply algorithmic solutions, the accurate reproduction of information, or even just a knowledge of terminology'. Clearly, students are aware of this, and this leads them to use strategies that contradict the formal aims of the course. There is a multitude of evidence from the alternative conceptions literature which shows that students' misconceptions are frequently unaffected by the questions they are asked (and successfully answer) in summative assessments.

Teaching and teachers

Although decades of educational research have generally failed to show direct effects of teaching methods on learning outcomes, Ramsden (1984) shows that there are important indirect effects, between students' perceptions of what lecturers do and their approaches and orientations to learning. Instead of finding a 'best teaching method', Entwistle and Ramsden (1983) found that the most important teacher qualities influencing student approaches to learning were the lecturer's interest in the students and helpfulness with study problems. Secondary factors were enthusiasm for the subject, the ability to teach at the student's level and providing useful feedback on a student's work. Further evidence for these factors can be found in other studies reviewed by Ramsden (1988a) and Hodgson (1984).

Hodgson's (1984) work provides an interesting explanation for the above findings on teacher characteristics which influence learning. In an investigation of students' experience of lectures, she found evidence of what she termed extrinsic and intrinsic 'experiences of relevance', which parallel surface and deep approaches to learning. In addition, she also identified what was termed a 'vicarious experience of relevance' in which students either took on the enthusiasm and interest expressed by the lecturer, or identified with a particular illustration or example. Hodgson showed that the vicarious experience frequently provided a bridge from an extrinsic to an intrinsic experience, and therefore was instrumental in developing student learning. This would explain why teacher characteristics such as interest,
enthusiasm and helpfulness are positively correlated with students’ approaches to learning.

Course Design, Department and Institution

A large scale survey of university departments revealed an interesting relationship between students’ perceptions of a course and their approaches to learning (Entwistle & Ramsden, 1983). Deep approaches to learning were more common in departments perceived to provide good teaching and flexible curricula, while surface approaches were associated with departments perceived to have a heavy workload and lack of choice in content and method. Further evidence of these relationships is provided by Biggs’ (1993) review of similar research in school contexts. Deep approaches were found to be associated with problem-based learning tasks, students’ enjoyment of school, perceptions of school as worthwhile and teachers as reasonable, and a medium (not high) emphasis on examination performance.

Biggs (1986) cites evidence which suggests that a surface approach is more easily induced by situational factors than a deep approach. (He posits that a deep approach is more related to psychological factors such as ability and locus of control.) The most likely factors to induce surface learning relate to assessment and workload, as described in the previous section, but Biggs also identifies negative factors such as authoritarianism, closed decision-making and ‘pointless busywork’ as likely to produce a surface response in students. He suggests that ‘Cynicism is possibly a greater inducement to surface learning than pressure’. (p. 140)

Student interest, knowledge base, and previous experience

This is most probably the area that has received the most attention in traditional studies of student learning. Psychological constructs such as motivation, locus of control (both reviewed in Biggs & Moore, 1993), educational orientation (Taylor, Morgan, & Gibbs, 1981), and mindfulness (Salomon & Globerson, 1987), are only a few of the ideas that have been invoked to explain differences in learning outcomes. Entwistle (1998b) provides a review of a range of traditional psychological constructs that have been used to describe student characteristics, and points out
that because they don’t account for context they have generally been of limited usefulness.

In Figure 2.1, Ramsden has used the construct of ‘orientation to studying’ to encapsulate the elements of student interest, knowledge base, and previous experience. This construct was established in the Entwistle and Ramsden (1983) study (discussed in the previous section), and refers to general preferences that students have for approaches to learning. The use of both orientation to studying and approach to learning in Figure 2.1 illustrates the distinction that Ramsden makes between these two constructs, the first of which is relatively consistent, and the second of which depends on the task at hand.

**Critique of Ramsden’s model and introduction of a nondualistic view on perception**

Ramsden’s work on the significance of student perception has provided an important dimension to the current understanding of student learning, and indeed provided the starting point for the present study. This model is useful in pointing out the links between perceptions, approaches and outcomes, but I will argue that it is limited in its description of perception itself. Perception can be represented by the section on the left of Figure 2.1, but in Ramsden’s work there is not much further clarification on what is meant by perception other than a ‘point of contact’ or a ‘relation’. The only route for analysis suggested by Ramsden is the classification according to the four dimensions of context described above.

Ramsden’s description of perception is also theoretically ambiguous in that he alternates between a dualistic and nondualistic stance. This issue has already been highlighted in the description of Ramsden’s relational perspective outlined earlier. Although he argues for viewing learning as a relationship between learners and subject matter, and in places refers to perception as a ‘relation’ between students and their context (nondualistic), the formulation represented in Figure 2.1 seems to suggest a separation between individuals and the world around them (dualistic).

Marton (1995) presents a complex philosophical argument following the classic problem of Meno’s paradox to argue for a nondualistic stance, in which there is no
separation between individuals, the world around them, and their perceptions of the world. On a more practical level, I would suggest that a dualistic view of perception is associated with notions of ‘blaming the student’, since problems with learning can be located solely with the student. On this note one can identify problems with Ramsden’s use of ‘orientation to study’ in Figure 2.1, which is a relatively stable characteristic which students bring to a context. If one places an understanding of student learning within a nondualistic framework, it is not possible to make such a judgement, since learning is seen to result from the interaction of a student and a particular context, a composite whole from which different components cannot be isolated. Marton (1988) has stated this point as follows:

> If we were to think about approaches and conception as something located within the individual, as it were, it would make a lot of sense to try to change the individual or to try to changing something in him or her, given that our aim is to improve learning. The alternative is to try to change the individual’s experience, perception, or conception of something. (Marton, 1988, p. 75, emphasis in original)

As stated earlier, phenomenography provides a nondualistic view on learning, in which experienced phenomena are seen to comprise an ‘internal relationship between the subject and the world’ (Marton & Booth, 1997, p. 122). Prosser and Trigwell have attempted to reconcile the Ramsden model in Figure 2.1 with a nondualistic perspective, by suggesting that the components in this model are simultaneously present in any act of teaching and learning, with certain components in the foreground of awareness at a given moment in time (Prosser & Trigwell, 1999). I do not see this as a satisfactory resolution of the philosophical problems with the model. Prosser and Trigwell’s formulation deals with students’ awareness of perception, context and orientation to study. Although students’ awareness of their learning is of relevance in considerations of reflection and metacognition, this does not provide a general framework for considering perception (which, following the phenomenographers, I take to be synonymous with awareness, consciousness, and experience). In other words, I am interested in perception more generally, not only in students’ awareness of their perceptions.
A more philosophically grounded model of perception can be found in the work of the phenomenologer Aron Gurwitsch (1964). In his analysis of human consciousness, Gurwitsch divides the totality of perception at a given instant (the ‘perceptual noema’) into a theme, thematic field, and a margin. The theme is that which currently occupies the individual’s focus, and the thematic field is the set of ideas and images simultaneously present with the theme and which are related to the theme. For example, when focusing on a stoichiometric problem based on the formation reaction of ammonia (the theme), items present in a chemical engineering student’s thematic field might include the relations between mass and moles of a gas, the concept of incomplete reactions, strategies for balancing a reaction equation, the physical arrangement of the reactor, and so on. The margin comprises that which is simultaneously present with the theme, but has no relevance to it. For the purposes of this research the concern is primarily with the theme and the thematic field, although of course, as we all know, when students’ weekend plans are present in the margin of the awareness this can have a considerable impact on the ability to stay focused on the theme of stoichiometry. Marton and Booth (1997) suggest that the thematic field be considered in terms of ‘constituent fields’ related to the theme according to relevancy. These constituent thematic fields ‘extend into the very life world of the learner, both back into her learning history and forward into the way she proceeds with her learning’ (p. 99). The relationship between the theme, the thematic field and the margin has been represented by Booth (1992) in the diagram in Figure 2.2.

![Diagram of Gurwitsch's field of consciousness](Booth, 1992, p. 266)
A particular theme could have a variety of different thematic fields associated with it, depending on the individual's background and intentions, and it is the specific thematic field generated by an individual that determines the meaning that they have for that theme. In phenomenographic terms, it can be said that a particular way of experiencing something is related to differences in the organisation or structure of awareness (Marton & Booth, 1997). Structure refers here to the relationships between the aspects that are simultaneously present in the individual's focal awareness (theme and thematic field).

Using this view of perception, Marton and Booth (1997) reconceptualise deep and surface approaches to learning in terms of what is in the learner's focal awareness. In the context of reading a text, a deep approach means that the learner focuses on the words of the text, the meaning of the words, and the broader phenomena associated with the text, while in a surface approach it is only the text that is in focal awareness. They conclude that:

> More advanced ways of experiencing something are, according to this line of reasoning, more complex and more inclusive (or more specific) than less advanced ways of experiencing the same thing, 'more inclusive' and 'more specific' both implying more simultaneously experienced aspects constituting constraints on how the phenomenon is seen. (Marton & Booth, 1997, p. 107.)

What can be seen in the above quote is that approach to learning and perceptions have been combined in the construct of 'way of experiencing'. The link to what the learner does is still clear:

> ...in order to make sense of how people handle problems, situations, the world, we have to understand the way in which they experience the problems, the situations, the world, that they are handling or in relation to which they are acting. (Marton & Booth, 1997, p. 111)

In the discussion above I have suggested that a nondualistic view on perception provides a theoretically fruitful position. The critique of Ramsden's model should not however suggest that I am advocating an abandonment of this earlier theory. In later chapters it will be seen that both of these perspectives have provided useful theory at various stages of the analysis in the present study. Another perspective on
perception of context which I have incorporated comes from the completely different theoretical area of language, and will be discussed below in the last part of this section.

**Language and perception**

There is a large body of theory that deals with the links between conceptual structures and the use of language (for example, Sutton, 1992; Vygotsky, 1962; Wertsch, 1985). Many theorists have argued that most mental constructs have a strong language dimension. For example, Head and Sutton (1985) suggest that understanding often involves finding a way to talk about something, and they write that ‘words can form centers for the crystallization of ideas’ (p. 92). The scope of this thesis does not permit any sort of extensive examination of this area. Nonetheless, one key theory from this field will be briefly discussed, as it has provided a useful additional perspective on perception.

In *Metaphors we live by*, Lakoff and Johnson (1980) propose that our conceptual system is structured largely by the use of metaphor. Metaphors, in which one kind of thing is seen in terms of another (for example, argument is seen as war), can be seen in the way we use language (for example, ‘winning an argument’, ‘indefensible claims’), and have traditionally been regarded as issues of linguistics and style. However, Lakoff and Johnson argue that this is much more than simply an issue of language, and that metaphors are fundamental and pervasive in our conceptual system, and therefore have a profound impact on how we perceive things and act upon them. This is especially true for concepts that are abstract or not clearly delineated by our experience (for example, time, love, ideas), and these we get a grasp on by means of other concepts that are more clearly understood (for example, time is money, love is a physical force, ideas are food). Lakoff and Johnson take the fairly radical position that metaphor is not only a way of conceptualising a pre-existing reality, but that it has the power to create a reality. They reject both the naïve realist position that there is an external absolute objective reality, and the subjectivist position that everything is individually and subjectively defined, and replace these with an ‘experientialist’ philosophy. An analysis of the use of metaphor reveals a surprising coherence within the metaphorical structures of a
particular culture, and hence the remarkable power they hold for shaping the views and actions of individuals within that culture. In the context of the present study, it is argued that there are also underlying metaphors that structure the way students conceptualise the educational context. Uncovering these metaphors will be a significant part of understanding students' perceptions of this context. The consumption and visualisation metaphors relating to how learning is conceptualised (Marton & Booth, 1997) have been mentioned earlier, and it was expected that there would be further metaphors related specifically to the particular course context of the present study.

2.4.4. Conclusion
In this section it has been shown that a consideration of students' perceptions of the educational context is a useful construct for understanding student learning. Ramsden has produced some of the most influential work in this area, and his model of student learning in context forms a significant part of the theoretical framework used in the present study. One aspect of this model that has been critiqued is the separation that it sets up between the student and the context, and it has been argued that a phenomenographic view provides a useful additional theoretical position on the nature of perception. Lakoff and Johnson's work on the use of metaphor has also been incorporated as it offers another productive way of analysing students' perception.

2.5. Metacognition and metacognitive development
The final theoretical construct from the literature to be reviewed in this chapter is that of metacognition. The notion of metacognition arose in the context of information processing studies in the 1970s. One of the first descriptions of metacognition comes from Flavell (1976), who describes it as 'one's knowledge concerning one's own cognitive processes and products or anything related to them'. He also asserted that metacognition includes 'the active monitoring and consequent regulation and orchestration' of information processing activities (Flavell, 1976, p. 232). Baird (1990) used these ideas to provide the following succinct formulation: 'Metacognition refers to the knowledge, awareness and
control of one's own learning' (p. 184). Some writers (for example, Biggs & Moore, 1993) use the term 'metalearning' to relate to metacognition in the context of learning in educational institutions, but for the purposes of the present study the more general term will be retained.

This section begins by providing general background on research into metacognition, after which a number of key issues relevant to the present study are discussed. These are the link between metacognition and conceptual change, a discussion of Baird's formulation of metacognition as 'knowledge, awareness and control', an examination of how metacognition can be promoted in teaching and learning contexts, and the relationship between metacognitive development and approach to learning.

2.5.1. Research into metacognition

Early researchers into metacognition worked in the contexts of children reading stories, with key work conducted by Ann Brown and her colleagues (reviewed in Brown, 1994). This is a still an active strand of research. Much of the research in these contexts has focused on the teaching of specific 'metacognitive strategies', which reflects a focus on the 'control' aspects of metacognition. This focus is also reflected in the conceptualisation of metacognition as the 'planning, monitoring and evaluation' of cognition (Brown, 1978). There have been strong links between metacognitive research and research into self-regulated learning. Self-regulatory strategies are another way of looking at the awareness and control aspects of metacognition (for example, Baird, 1998; Bransford, Brown, & Cocking, 1999; Pintrich & Schrauben, 1992; Vermunt, 1996).

Another strand of metacognitive research has emerged in the context of science education, and the present review draws mainly on this work. In the early 1980s science educators adopted the notion of metacognition and incorporated it into work using a constructivist conceptual change view on learning (this development is summarised in White, 1998). Some of the key research projects in this area will be briefly described, both to give a sense of the approaches and contexts in science
education research on metacognition, and to provide a background for the later
discussion of some of these research findings.

Baird and White conducted an important series of case studies of student learning in
the 1980s which began to illuminate the nature of metacognition in a science context.
In the first case study (Baird & White, 1982a), two contrasting styles of learning
were identified, similar to the deep and surface approaches to learning. The second
case study (Baird & White, 1982b) followed up by describing ‘Poor Learning
Tendencies’, such as Superficial Attention, Impulsive Attention and Premature
Closure. These tendencies were seen to stem from inadequate decision-making, and
this in turn was related to the monitoring and control aspects of metacognition. In
this study the researchers also began to address the issue of how to change these
tendencies. This aspect was the central focus of the third case study (Baird, 1986),
where the researcher spent six months working with a secondary school teacher to
promote enhanced metacognition amongst his students. Although these objectives
were largely achieved, Baird also identified certain factors that limited the extent of
metacognitive development.

Following from the results of these case studies, the Project to Enhance Effective
Learning (PEEL) was established in 1985 (Baird & Northfield, 1992). Where the case
studies took place in a single classroom setting, the PEEL project attempted to
coordinate these initiatives across a broad range of subjects in a school. The success
of this project can be seen in that it spread to a number of different schools and
different countries, and is still running in many of these schools today. Whereas the
case studies had identified poor learning tendencies, the PEEL project researchers
noted ‘Good Learning Behaviours’, and, together with teachers, devised teaching
and learning procedures to foster these behaviours.

The research thrust continued to be directed towards developing teaching and
learning environments that promote metacognitive development. Linder and
Marshall (1997a) developed a set of teaching activities which they termed
‘metacognitive strategies’ for use in their large class introductory physics course in a
South African university. These strategies were aimed at getting students to reflect
on their learning while learning physics. Working with science graduates in a pre-
service teaching programme, Gunstone (1994) researched possible teaching strategies for promoting conceptual change and metacognitive development. The particular focus in his work has been on the important role of science content in this process.

2.5.2. **Metacognition and conceptual change**

The constructivist view of learning, and particularly the conceptual change model outlined earlier in section 2.2.2, imply a central role for learners in actively constructing and managing their learning. These activities are encapsulated in the notion of metacognition. This link between conceptual change and metacognition has been noted by a number of science education researchers. In his preferred conceptualisation of metacognition, Gunstone (1994, pp. 133-134) describes learners as appropriately metacognitive 'if they consciously undertake an informed and self-directed approach to recognising, evaluating and deciding whether to reconstruct their existing ideas and beliefs', and suggests that that metacognition and conceptual change are 'totally intertwined'. Hewson (1996, p. 126) writes that: 'Teaching for conceptual change is explicitly metacognitive'.

Gunstone (1994, p. 136) goes further to argue that metacognitive development should itself be regarded as an instance of conceptual change, in that it concerns the change of ideas and beliefs about learning and teaching.

2.5.3. **Metacognition as knowledge, awareness and control**

As noted earlier, Baird (1990) identified the following aspects of metacognition: knowledge, awareness and control. Under metacognitive knowledge, Baird includes knowledge about the nature of learning, learning strategies and personal learning characteristics. Much of this knowledge is frequently tacit, and improving metacognition includes helping learners be more aware of their implicit beliefs about their own learning. Given the importance of prior knowledge in a constructivist view of learning, it is clear that prior metacognitive knowledge fundamentally influences how learners engage with learning, whether this knowledge is explicit or not.
In Baird’s formulation, metacognitive awareness and control apply to the particular learning activity at hand, and are conceptualised as conscious processes, compared to knowledge which is frequently subconscious. Awareness is taken to refer to the asking of evaluative questions and control refers to learning decisions taken. In the present study, a broader conceptualisation of awareness and control, which refers not to a specific task, but to the learning context in general, would be more appropriate. I would also suggest a broader description of control that includes the ability to modify metacognitive knowledge.

Subsequent authors have added the facet of ‘willingness’ (to exercise control) to Baird’s three dimensions of metacognition (White, 1998). Gunstone and Baird (1988) emphasised the importance of both the cognitive and affective dimensions of learning. In order for learners to improve their metacognitive abilities, it is important that they are not only able (cognitive aspect), but also willing (affective aspect). This move to emphasise affect has also been seen in the other strands of metacognitive research mentioned earlier. Pintrich and De Groot (1990), working with a focus on self-regulation, have made the distinction between ‘the will and the skill’, and Paris and Winograd (1990), writing generally in the context of school-based reading instruction, propose an expanded conceptualisation of metacognition which includes affective and motivational characteristics.

It is one thing to highlight the importance of the students’ willingness, but quite another to suggest teaching methods that might encourage students to be more willing. Baird (1998) argues that the key issue is the degree of ‘Personal Challenge’ that the learning task affords the student. Personal Challenge derives from a combination of a Demand (thinking) component and an Interest/Motivation (feeling) component. Gunstone and Baird (1988) have developed another response to this issue by drawing on the Posner et al. (1982) model of conceptual change. They argue that learners need to see the fruitfulness of putting in the effort required to change their beliefs about and approaches to learning. Thus it can be seen that perceptions and attitudes play key roles in determining whether or not learners understand, value and use metacognitive strategies (Gunstone & Baird, 1988). The reverse side of this issue is that, in the case of effective learning, these cognitive and
affective dimensions also apply to learning outcomes. Baird and White (1996, p. 192) write that 'improvements in learning are as much related to changed feelings as they are to changed thinking'. They argue that the academic benefits of enhanced metacognition are matched by affective benefits, which include increased satisfaction, sense of purpose, control and self-worth.

2.5.4. Teaching for metacognitive development

Gunstone (1994) stresses that all learners are metacognitive and that the associated pedagogical goal should be to enhance metacognition. He suggests that enhanced metacognition is a learning outcome in itself, as well as having a critical impact on the achievement of content-based learning outcomes. Bearing in mind the conceptual change model of learning it is important that learners are appropriately metacognitive, that is that their metacognitive beliefs are applied appropriately and linked to the demands of the task at hand. Gunstone and Baird (1988) argue that enhanced and appropriate metacognitive abilities will only be achieved by means of an integrative perspective on metacognition, in which metacognitive training is recognised to be intimately bound up in issues of content and context.

Some attempts have been made to teach metacognitive skills apart from the context and content within which they are to be used, in so-called ‘study skills’ programmes. This approach rests on an assumption that students will be able to transfer these skills from one context to another. The evidence on the efficacy of these programmes is at best equivocal. Biggs (1993) makes reference to such a programme in which significant changes in approach to learning were noted, but admits that this work was conducted with very highly achievement-motivated university students. More commonly, such programmes in higher education contexts have had limited success. For example, Ramsden, Beswick and Bowden (1986) were surprised to find that students who attended a learning skills programme did not perform any better or worse than their contemporaries who had not attended the programme. Furthermore, those who attended increased their reported use of surface learning strategies, and marginally decreased their use of deep ones. This startling result is explained by the view that students extract from such programmes what is useful to them, with 'what is useful' being fundamentally
determined by their perceptions of the requirements of their courses. In this particular instance, student interview comments showed that their courses were perceived to be requiring the use of surface learning strategies.

Far greater success has been achieved with attempts to teach for metacognitive development in an integrated fashion. The work of Linder and Marshall (1997a) is significant in this regard, in that they have implemented these changes within a university level physics course. They used ‘metacognitive strategies’ such as concept-mapping, peer discussions, and an emphasis on qualitative reasoning during their large class lectures. The changes that they have noted in their students include shifts to more sophisticated conceptions of learning, moves to deep approaches to learning, as well as changes in students views on the nature of physics (Linder & Marshall, 1997b). Gunstone (1994) suggests some requirements of content appropriate for metacognitive development: firstly, the content needs to require real cognitive learning; secondly, the content should be neither already understood or totally unfamiliar. In such contexts it is more likely that learners will see the fruitfulness of investing the greater degrees of intellectual effort that a more metacognitive approach demands, in that prior approaches to learning have not yielded real understanding. This is similar to Baird and White’s (1996) emphasis on having students ‘purposefully inquire’ as a key element of metacognitive development.

Gunstone and Mitchell (1998) point out characteristics of classrooms in which teachers are seeking to promote metacognitive development and conceptual change. Firstly, the rate of ‘coverage’ of the curriculum seems slower than in traditional classrooms. Secondly, the pace of student learning is not linear, but rather takes on a parabolic form with apparently slow early progress followed by much more rapid learning later on. Finally, they stress the importance of an atmosphere of trust between teacher and students if this approach is to have any effect. This bears a strong similarity to much of what has been previously written about constructivist classrooms (for example, see the summary by Yager, 2000).

Many of these authors have emphasised that metacognitive development does not come easy (for example, Gunstone & Mitchell, 1998; White, 1998). Projects to
enhance metacognition need to be long term, and require a considerable energy input from both teachers and students.

2.5.5. Metacognitive development and approach to learning

Biggs (1993) uses Pintrich and De Groot’s idea of ‘the will and the skill’ to formulate metacognition in terms of the following two key questions that students need to ask themselves:
1. What do I want out of this? (What are my motives?)
2. How do I propose going about getting there? (What are my strategies?)

Given that Biggs has suggested that approaches to learning be considered as ‘congruent motive-strategy packages’, in that they comprise both an intention and a related strategy (Biggs, 1986, p. 133), it is clear that the constructs of metacognition and approach to learning are strongly related. Indeed, Biggs (1993) considers them as one and the same thing.

Other researchers who have drawn links between approaches to learning and metacognition include Vermunt (1996) and Chin and Brown (2000). From interviews with a wide range of university students Vermunt (1996) identified four ‘learning styles’ which bear a strong resemblance to Entwistle and Ramsden’s (1983) four ‘study orientations’ (shown earlier in section 2.3.1 to be analogous to approaches to learning). Vermunt’s conceptualisation of metacognition comprises ‘mental models of learning’ and regulation strategies, which encapsulate the elements of metacognitive knowledge, and awareness and control, respectively. For each learning style Vermunt identified a related mental model of learning (similar to the link between approach to learning and conception of learning discussed in section 2.3.3) and the regulatory strategies used. In the latter aspect Vermunt identified a development from external to internal regulation. Using a similar conceptualisation of metacognition to Vermont (incorporating the notion of self-regulation), Chin and Brown (2000) also found a notable relationship between students’ approach to learning and metacognitive activity. Aspects of metacognitive activity that were more prevalent amongst students using a deep approach included the following: self-evaluating their ideas, self-questioning when
they encountered blocks, detecting their errors, attending to anomalous data, considering a range of possible alternatives, and considering limitations in their ideas. Linder and Marshall (1997a) have used a similar conceptualisation to these researchers, in that they evaluated the success of their class-based ‘metacognitive strategies’ by assessing changes in students’ approaches to learning.

The conceptual link between the constructs of approach to learning and metacognition is therefore fairly well established. This link forms a key element of the theoretical framework in the present study. Given that the focus is on metacognitive development rather than metacognitive processes per se, for the purposes of this study metacognitive development has been conceptualised as a shift in a student’s approach to learning.

2.5.6. Conclusion

For the purposes of the theoretical framework to be used in the present study, metacognitive development is primarily conceptualised as a shift in a student’s approach to learning. In this way, a link is provided to the construct of approach to learning, which in turn has been shown to be linked to students’ perceptions of context. Other key theoretical ideas about metacognitive development that are used in the present study are the following: the characterisation of metacognition as comprising knowledge, awareness and control; the link that has been identified between conceptual change learning and metacognitive development; and the assertion that metacognitive development needs to be fostered in an integrated fashion.

2.6. Summary of theoretical framework

In broad terms, the theoretical framework to be used in the present study rests on the three key constructs outlined in this chapter: approaches to learning, perceptions of context, and metacognitive development. In the course of the chapter I have outlined the relationships between these constructs and suggested theoretical stances appropriate to the present study. This last section provides a summary of these positions, which delineates the theoretical framework used in the study.
In terms of a theoretical perspective on learning, the relational perspective outlined in section 2.2.4 was seen to be the most appropriate for the present study. Firstly, it is strongly focused towards research that is useful in real teaching contexts, and this focus is used to determine the choice of theory. Secondly, it incorporates a nondualistic perspective on learning, the utility of which has been repeatedly demonstrated in this chapter. Finally, it draws in elements of constructivism and conceptual change theory where appropriate.

In the present study, approach to learning is taken to indicate ‘congruent motive-strategy packages’ (Biggs, 1986) which are determined by students’ underlying intentions when undertaking learning activities. These approaches are assumed to depend fundamentally on the particular educational context. What they refer to therefore is a variable situation, resulting from the interaction between the student and the learning environment. They do not refer to something stable that students use in all learning contexts. For the purposes of the study I have not assumed the presence of deep and surface approaches in the forms given in the literature, but have rather used the basic construct of approach to learning to uncover the particular approaches in the CHE231F context. This research approach is similar to that taken by Booth in the work discussed in section 2.3.5.

The approaches that students demonstrate in particular contexts are assumed to be fundamentally influenced by students’ perceptions of those contexts. Ramsden has provided the basic theoretical exposition of this idea. However, it is suggested that in order to unpack the notion of perception itself, a nondualistic phenomenographic view is potentially productive. I have also drawn upon the work of Lakoff and Johnson who outline the ways in which language provides clues to the way in which phenomena are perceived.

For the purposes of the study, shifts between approaches to learning are conceptualised as metacognitive development. This construct encompasses students’ knowledge, awareness, control of their learning, as well as willingness to exert that control. Metacognitive development is a fundamental part of conceptual change learning. In the context of the CHE231F course which is the focus of the study, the lecturers were attempting to do what has been suggested by the
literature, that is, to promote metacognitive development as an integrated aspect of
the course. The study sought not only to uncover to what extent they were
successful in their aim, but also to provide a better understanding of students’
experience of the course.
Chapter 3
Research methodology

3.1. Introduction

The purpose of this chapter is to provide a justification for the choice of research methods that have been used in the present study. The starting point for such a decision is the nature of the research questions, as outlined in the first chapter. Given that the aim was to explore issues such as approach to learning, perceptions, and metacognitive development of students in a particular course, and that very little is known about the exact forms of these constructs in that context, a qualitative methodology would be the obvious choice. However, issues of research methodology go far deeper than merely choosing either qualitative or quantitative methods. In fact, many theorists (for example, Crotty, 1998; Lincoln & Guba, 1985) would argue that this dichotomy has been overplayed in importance, and that the more fundamental issue, frequently overlooked, is the question of epistemology. This study is firmly located within a constructivist epistemology, and the implications of this choice will be discussed in the first section of this chapter.

Many different theoretical perspectives and methodologies fall under the constructivist umbrella, and in the second section I discuss those that have been most influential in the formation of a methodology appropriate for the present study. Although in some cases it may be useful to make the fine distinction suggested by Crotty (1998) between theoretical perspective as a broad philosophical stance, and methodology as a more specific research strategy, in this chapter I use the looser term ‘research paradigm’, as suggested by Denzin and Lincoln (1994b). Drawing on an earlier formulation by Egon Guba, they describe a research paradigm as a ‘net that contains the researcher’s epistemological, ontological, and methodological premises’ (p. 13). The issues around research paradigms are not merely to be considered added extras to the real business of doing research, as these beliefs influence every aspect of the research process, even when not made explicit. Indeed, as stated by Guba and Lincoln (1994, p. 105), ‘Questions of method are secondary to questions of paradigm’.
In the final section of this chapter some important theoretical issues at the level of method are dealt with, particularly with regard to the interview process and ethical concerns. The practicalities of how the research was conducted in the present study are dealt with in detail in Chapter 5.

3.2.  **Epistemological issues**

In section 2.2.2 a constructivist perspective on learning was described, a view that is common in much current research on learning and teaching. Taking a constructivist view on learning does not necessarily imply a constructivist epistemology. Epistemology concerns the nature of the knowledge generated in one’s research, that is, how you expect people to view this knowledge, and what store to place on it. In a positivist epistemology, which has been the traditional view in social science research, it is asserted that researchers should use the ‘scientific’ method to produce objective, empirically verifiable knowledge. The positivist position has been roundly critiqued by philosophers in many quarters, particularly with regard to its application in humanities and social science research (see, for example, Crotty, 1998; Lincoln & Guba, 1985). It has been suggested that a constructivist epistemology is more appropriate in these contexts. In this epistemological view we move beyond considering learners as constructing knowledge (a constructivist view on learning) to viewing the products of our research as useful and meaningful constructions (a constructivist epistemology), rather than the objective measurable truth.

Positivist epistemological positions are common in much research on student learning, even those that make use of a constructivist view on learning. Webb (1996) points out that for educational developers, ‘the allure of positivist prescriptions for “good” teaching practice is very tempting’ (p. 29). Especially when attempting to establish credibility with teaching colleagues it is common to support suggestions with statements such as ‘most studies show’ or ‘the evidence suggests’. Positivist epistemologies are especially prevalent in educational research conducted in science and engineering contexts, partly due to researchers usually having an initial undergraduate education in these areas, but also possibly due to the higher pressure to prove to their colleagues that they are doing ‘real research’. This tendency is illustrated in a high profile article by Bunce and Robinson (1997) in the
Journal of Chemical Education, in which they attempt to show how educational research is similar to scientific research.

Leaving aside work in the area of the philosophy of science which questions the appropriateness of a positivist epistemology even in science (for example, Feyerabend, 1987; Kuhn, 1970; Latour & Woolgar, 1986), it can be certainly seen that positivism has been a problematic epistemology in educational research. For a start, it explains the futility of much of the educational research enterprise over the last few decades, in attempting to uncover law-like and context independent generalisations about teaching and learning, which from a constructivist perspective is an unattainable aim. Educational research in this mould makes what I would argue are dishonest claims about the status of the research findings, which has then led to critiques of the usefulness of the whole enterprise when it has been found that these findings are not universally applicable. Adopting a constructivist epistemology will allow us to focus our energies on building constructions that are meaningful and useful in particular contexts. This, I would argue, is not only a more honest position, but also one that is likely to lead to genuinely useful and respected educational research. It is not an easy position for researchers schooled in the scientific tradition to adopt, neither is it easy to communicate to the science and engineering colleagues that we work with, but it is ultimately a far more productive position from which to conduct research on learning and teaching.

3.3. Research paradigms

In the present study, following Crotty (1998) and others, I have used an eclectic mix of elements drawn from various paradigms, chosen and combined for the particular purposes of addressing my research questions. In this section I will discuss the paradigms that were most influential on this study, and highlight those elements which were most useful. I will also discuss briefly aspects of these paradigms that were considered not to be appropriate in my context, although space does not permit an exhaustive critique of each paradigm.
3.3.1. Naturalistic inquiry

With the publication in 1985 of *Naturalistic Inquiry*, Yvonna Lincoln and Egon Guba laid out a coherent argument for human research to be conducted in natural settings, and suggested a logical methodology to be used in such research. This research paradigm has been widely influential, and although later publications have expanded on certain details, the essentials of the paradigm are still encapsulated in the original publication. Lincoln and Guba have subsequently suggested a change in terminology for this paradigm, from ‘naturalistic inquiry’ to ‘constructivism’ (Guba & Lincoln, 1994, p. 105). I would prefer to keep with the original naming, and reserve the term constructivism for the epistemological position described above, and also the view of learning given in section 2.2.2.

In addition to the assertion of a constructivist epistemology and ontology, Lincoln and Guba (1985) take up particular stances on some other related philosophical issues, stances which they term ‘axioms’ of the naturalistic paradigm. Arguing from a constructivist position they question the possibility of generalisability, simple causal linkages and value-free inquiry, all key tenets of positivist research. Instead of aiming for generalisable results, they argue that the onus is on the reader of the research to determine the transferability and fittingness of the results to their particular context. In order to facilitate this decision, researchers need to provide a ‘thick description’ (Geertz, 1973) of their research context, to draw on a technique from ethnography that has since found wider application in qualitative research. Using similar arguments to those I have used in Chapter 1 to make the case for ‘systems thinking’, Lincoln and Guba (1985) point out the problems with searching for simple causal linkages in contexts involving people, and suggest instead that a model of ‘mutual simultaneous shaping’ is adopted. Finally, they suggest that value-free research is not an attainable goal, and that instead one should acknowledge this, and at least seek to make values explicit in the reporting of research. These are not only personal values, but also the values that inhere in paradigms, theory and context.

Following from these axioms, Lincoln and Guba (1985) suggest a number of interlinked characteristics of research conducted in the naturalistic paradigm. These
will be briefly described, as nearly all of them were adopted as key elements in the methodology used in the present study. Because educational research projects typically aim for a better understanding of people and what they think and do, naturalistic inquiry favours natural settings for the conduct of research, and the use of the human as an instrument. Compared to pen-and-paper instruments, humans are able to grasp meaning, pick up on subtleties, adapt to new situations, and generally operate more effectively in any complex situation. For similar reasons, naturalistic inquirers generally, but not always, prefer qualitative methods to quantitative methods. In the naturalistic paradigm, the use of tacit knowledge is also not only permitted, but also actively encouraged, with the usual injunction to make these processes explicit.

Following from the philosophical stance adopted in naturalistic inquiry, the motivation for the traditional representative sampling techniques used in quantitative work falls away. We are no longer seeking to generalise measurements to a broader population, but rather to uncover as much variation, in as much detail as possible, in the area of research focus. The sampling technique which fits this aim is called ‘purposive sampling’, and in broad outline involves choosing such individuals so that one has maximum diversity in the focus areas.

In naturalistic inquiry, inductive data analysis, where analysis proceeds from the research data, is preferred to deductive analysis, where prior hypotheses are tested against the data. In a related vein, Lincoln and Guba (1985) suggested the adoption of the grounded theory methodology, which favours theory that emerges from the data to the use of a priori theory. This methodology will be discussed in more detail in the next section. Another related methodological issue is the preference for emergent or unfolding research designs, rather than attempting to plan the entire course of the data collection beforehand.

With the aim of naturalistic research usually involving the reconstruction of people’s constructions of reality, Lincoln and Guba suggest that research outcomes should be negotiated with the participants themselves. The extent to which this will be possible or desirable will depend on the specific context, but it seems an aim that one should strive towards. In the present study I adopted specific procedures for
communicating and verifying research findings with the lecturers and students involved, although I would not describe this as 'member checking' in the strict sense as defined by Lincoln and Guba.

Possibly one of the most useful aspects of Lincoln and Guba's work is the way in which they address the issues of internal validity, external validity, reliability and objectivity. If one adopts a constructivist epistemological position, it can be shown that these criteria become meaningless. Although it can be possible to fulfil the traditional tests, and indeed one commonly finds, for example, indices of inter-rater reliability in qualitative work, Lincoln and Guba argue that a new set of 'criteria for trustworthiness' are needed in the new paradigm. For each of these traditional constructs they identify the underlying issue, and then suggest an alternative measure for testing whether the results can be trusted.

Internal validity is traditionally defined as the extent to which observed variations can be attributed to controlled variation in an independent variable. Lincoln and Guba suggest that the underlying issue is that of 'truth value', the extent to which the study establishes 'how things really are' (Guba & Lincoln, 1989, p. 234). In place of internal validity, they suggest a new criterion of 'credibility', the extent to which the researcher has represented, not 'the truth', but rather the multiple constructions that are held by the participants. A number of techniques are suggested both for increasing the likelihood of credible results, and also for testing whether these have been obtained. Those that were adopted in the present study include prolonged engagement in the context, persistent observation, and triangulation by use of multiple methods and sources.

External validity concerns the generalisability of results and this issue has already been dealt with above. As regards reliability, Lincoln and Guba show how this depends on an assumption of naïve realism (that there is an unchanging reality 'out there' that one is measuring), and is therefore not logically compatible with a constructivist position. They identify the underlying concern being that of consistency, and propose a new criterion of dependability, which is a measure of the quality of the research process. Likewise they show how objectivity is no longer a useful construct, and suggest that the underlying issue is one of neutrality, and that
a more useful criterion is that of confirmability. Confirmability is the assurance that the research findings are rooted in contexts and persons apart from the researcher, and that they did not merely arise in the researcher's imagination. Both dependability and confirmability can be enhanced and tested by keeping a careful track of the research process, which allows for an independent observer to establish how research findings were arrived at. One of the elements of this record-keeping is a reflexive journal in which the researcher records the daily schedule and logistics of the study, the expression of feelings, reflections and speculations in a form of personal diary, and methodological decisions and rationales.

The naturalistic paradigm was the most influential on the present study, and the elements described above in this section were drawn upon in designing the research process. Other paradigms which were utilised were those of grounded theory and phenomenography, and these will now be discussed in turn.

3.3.2. Grounded theory

Whereas naturalistic inquiry provided, in the main, a broad philosophical framing for the study and some ideas about setting up the study, grounded theory methodology was most useful for establishing specific techniques of data collection and analysis. And, indeed, the emphasis in grounded theory is more on methodology than on broader philosophical issues. It emerged from the field of symbolic interactionism (Crotty, 1998), but has since become detached from any one theoretical position. Strauss and Corbin (1994) describe grounded theory as 'a general methodology for developing theory that is grounded in data systematically gathered and analysed' (p. 273). Where it differs from qualitative research in general is the emphasis on theory generation. Grounded theory methodology is probably most well known for the technique of constant comparative analysis (Glaser & Strauss, 1967), but using this technique alone does not make for grounded theory research (Strauss & Corbin, 1994). What Strauss and Corbin (1994) consider the non-negotiables in grounded theory are the following: the grounding of theory upon data, the making of constant comparisons, theoretical coding, and the development of theory. All of these elements will be used in various forms in the present study, and salient aspects will be discussed in what follows.
The constant comparative method provides a clear step by step outline of a process for analysing qualitative data. In the first stage of this procedure, also termed ‘open coding’, initial categories are developed by grouping similar incidents together. During the coding of each incident it must be carefully compared with other incidents previously coded in the same category. In this process the researcher starts to generate the ‘theoretical properties’ of the category, and the idea is to write these down in memos as they are developed. In the next stage of the analysis, termed ‘axial coding’, a further refinement is done on the categories and their properties by stepping back and testing all incidents coded in a category with the properties of that category. The categories are also compared for overlap, and examined for possible relationships among categories. This coding method with its focus on conceptualising properties of codes and relationships between codes has been termed ‘theoretical coding’. The concluding stages concern the ‘delimiting of theory’ in which the theory is formulated and finalised, and the writing up of the theory.

Strauss and Corbin describe theory as ‘plausible relationships proposed among concepts and sets of concepts’ (Strauss & Corbin, 1994, p. 277), and stress that theory building is very different to mere description. They state a preference for ‘conceptually dense’ theory, that is theory comprising many conceptual relationships. Two foci in developing theory are discovering patterns and identifying processes. They make a distinction between substantive theory, which is grounded in one particular research area, and formal (higher order) theory, which derives from a variety of contexts. From a constructivist position this latter distinction seems somewhat problematic, in that it seems to suggest law-like decontextualised theory. In the present study the focus is on substantive theory, with application to other contexts to be determined following Lincoln and Guba’s transferability criterion discussed above. Strauss and Corbin (1990) also suggest using what they term an ‘action/interaction oriented method of theory building’ (p. 104), which involves a model of linear causality which has been critiqued in the naturalistic paradigm. As stated earlier, in the present study a model of ‘mutual simultaneous shaping’ will be used.
Despite the emphasis on grounded theory, this methodology does not preclude the utilisation of theories from previous studies, as has sometimes mistakenly been thought. Strauss and Corbin (1994) stress that the only condition on the use of a priori theory deemed to be relevant to the study is that it is rigorously tested against the data. Similarly to Lincoln and Guba, they also acknowledge the importance of the researcher’s tacit knowledge.

Another aspect of the grounded theory methodology is that data collection and analysis are tightly interwoven. The initial theories emerging from the data are used to direct further data collection. One possibility in this respect is to use ‘theoretical sampling’, where additional research subjects are selected as the study proceeds in order to explore issues that have arisen. In the present study this option was not practically possible, but in the more general sense this procedure was adopted, where initial theories were used in the formulation of subsequent data collection protocols. Some other aspects of the methodology such as the use of multiple perspectives, and the communicating of research findings to participants have already been discussed under the naturalistic paradigm.

Grounded theory methodology has always been combined with other theoretical perspectives and methodologies, and in fact this process is encouraged (Strauss & Corbin, 1994). In the present study the elements of the methodology outlined above have been incorporated into the research design, and have been particularly helpful in providing guidelines for data analysis.

3.3.3. Phenomenography

Phenomenographic views on learning have already been encountered in the previous chapter, both in terms of an internal relationship between the person and the world, and also in terms of layered focal awareness. In other parts of that chapter phenomenographic research results were presented. Although not termed so at the time, the early work by Marton and Säljö in which approaches to learning were identified and later work on this and related topics have subsequently been labelled as phenomenography (Marton, Hounsell, & Entwistle, 1997; Säljö, 1997). In this section I will consider phenomenography as a research paradigm. In that
phenomenography ‘aims to reveal the qualitatively different ways in which something is experienced’ (Marton, 1995, p. 166), it would seem to be a very useful paradigm for the present study. And indeed many aspects of this paradigm have been incorporated in the research design, although in significant respects I have deviated from the phenomenographic position.

A considerable amount of current research on student learning in higher education describes itself as phenomenographic, and if one looks at these various studies it seems that what they chiefly have in common is using qualitative methods to investigate students’ experiences in these contexts. In this section I will use primarily the writings of Ference Marton, who describes himself as a ‘self-nominated voice’ for phenomenography (Marton, 1995, p. 165), and it will be seen that this paradigm has very specific implications for research projects. These writings should be seen as programmatic statements about what phenomenography is, or should be, rather than a description of what people describing themselves as phenomenographers actually do (Säljö, 1997).

The object of phenomenographic research is ‘a way of experiencing something’ (Marton & Booth, 1997). The nondualistic view on learning outlined in the previous chapter is critical in understanding what is meant by this term: it is an internal relationship between the experiencer and the experienced, not a mental entity. The term ‘conception’ is therefore, strictly speaking, not appropriate in phenomenographic research. As a rule, in phenomenographic research, a limited number of qualitatively different ways of experiencing a phenomenon are uncovered, and these are usually hierarchically arranged. The methods by which these categories are established are general qualitative methods, based on the constant comparative method described above.

Phenomenography has been strongly influenced by phenomenology, and has appropriated some philosophical stances and terminology from this field of philosophy. Nonetheless, Marton (1997) is at pains to stress that phenomenography is very different to phenomenology, and should not even be considered as a subset of that field. Similar to many branches of philosophy, phenomenology has
philosophers investigating their own experience. Phenomenography is more empirically focused, and is concerned with the experience of others.

Where my research deviates from phenomenography concerns the issue of what the ways of experiencing a phenomenon apply to. In phenomenography the description is on a collective level, and cannot be applied to individuals. Individuals are seen as bearers of different ways of experiencing a phenomenon, but also as the bearers of fragments of differing ways of experiencing that phenomenon (Marton & Booth, 1997). In phenomenography it is therefore not valid to assign a way of experiencing to a particular individual, even if you recognise that the individual might have different ways of experiencing at different times. The nature of my research questions and purposes of my research make it important to be able to attach findings to particular individuals, especially given that it was individuals that either passed or failed the course. I am encouraged that Roger Säljö has also recently described the phenomenographic research object as ‘somewhat ephemeral’ (Säljö, 1997, p. 179). In another way of looking at it, the phenomenographic paradigm constrains one’s research to a particular kind of research question. My research questions fall outside this arena. For that reason I have not used that paradigm in its totality, although some elements have been particularly useful, for example the view on learning, and subsets of my analysis have been approached on a collective level as in phenomenography.

3.4. **Theoretical issues relating to research methods**

In the introduction to this chapter it was asserted that key methodological decisions lie at the level of epistemology and research paradigm. And indeed, once these positions are established, the choice of method is relatively straightforward, and tends to hinge on the nature of the research questions and practical concerns related to the research context and constraints such as time and money. In the discussion on research paradigm it has already been established that the following methods would be suited to the present study: naturalistic setting with human instrument (qualitative methods), in-depth small-scale study, and grounded theory methods of analysis.
Interviews have been described by Denzin and Lincoln (1994a) as the ‘favourite methodological tool of the qualitative researcher’, and in the present study these were used as the primary (but not only) method of data collection. This choice was mainly determined by the research questions, which sought to uncover students’ experiences of the course. It was therefore clear that getting students to talk about their experiences, in an interview situation, would provide useful data to address these questions. Given that the research questions also sought to observe students’ progress over the course, it followed that a series of interviews would need to be conducted. In order to reach any sort of depth in the findings it was necessary to choose a small group of students with whom to conduct interviews, and, as suggested earlier, a purposive sampling strategy is appropriate in such studies. The naturalistic paradigm makes it clear that data need to be gathered from more than one perspective or source if at all possible, in order to enhance the trustworthiness of the findings. Apart from the interview data, other sources of data used in the present study included classroom observations, journal submissions, and test and examination scripts.

The methods of data collection and analysis as they were used in the study will be described in detail in Chapter 5. The present section addresses, at a theoretical level, two problematic issues associated with these methods.

### 3.4.1. The interpretation of interview data

Fontana and Frey (1994) touch on the issue of the interpretation of interview data, stating that, ‘Many studies using unstructured interviews are not reflexive enough about the interpreting procedures’. They critique studies that suggest that ‘the data speak for themselves’ or that the researcher is ‘neutral, unbiased, and “invisible”’ (p. 372). Kvale (1996) has pointed out the dangers of losing sight of the original interaction of the interview situation, particularly with the tendency for transcriptions to support a reification of the text (which she stresses is different to the original discourse). Particularly useful for the present study are two critiques that have been written specifically in the context of phenomenographic studies of student learning in higher education: Säljö’s (1996, 1997) recent ‘critical discussion’ and Fleming’s (1986) comments from about a decade earlier.
Both Säljö and Fleming argue that interview data cannot be used without consideration of the social situation of the interview, and the purposes behind what people say in such situations. From some of his earliest work (see, for example, Säljö, 1979), Säljö has been concerned with how the interview context might be influencing the nature of the responses given. Fleming (1986, p. 553) describes the interview as a ‘joint social accomplishment of interviewee and interviewer’. This is similar to Kvale’s (1996) argument that the interviewee’s statements are not ‘collected’, they are ‘co-authored’. Säljö (1997, p. 177) suggests that utterances in an interview indicate ‘the attempt to fulfil one’s communicative obligations when being asked a question or a wish not to lose face when confronted with an abstract and maybe difficult question’. What we have in interview data should be considered more as ‘tourists’ tales’ (Fleming, 1986, p. 549) or ‘accounting practices’ (Säljö, 1997) than as a direct view into how people experience phenomena. In other terms, Säljö describes such data as indicating ‘a way of talking rather than a way of experiencing’ (1997, p. 178).

Säljö argues that socialisation is all about the ‘appropriation of discursive tools’, and suggests that ‘we learn how to experience events in life’ (1997, p. 184). We learn about socially appropriate ways of talking about our experience of a phenomenon, and we frequently borrow accounts from stories that other people have told us. It is therefore problematic to disconnect what is said in an interview from its communicative function in that particular context. Fleming points out that one cannot take what is said in an interview context and assume that it applies directly to the experience of other contexts (for example, studying a text). In summary then, both these writers argue against using ‘literal’ interpretations of interview data.

Each writer has a different suggestion of how one can circumvent this problem. Fleming suggests trying to observe what is happening in the context of interest, although he admits that there is not often much to ‘see’ when students are, for example, revising for an examination. Säljö proposes what seems to me a more practical solution, in that he argues for studying discursive practices when people are trying to achieve something, for example solve a problem, rather than asking
them the sorts of abstract questions that are common in phenomenographic research.

In the present study, the concerns outlined in this section were addressed in a number of different ways. Firstly, I drew on Säljö’s suggestion and incorporated conceptual discussion questions in the interviews which required students to engage with real problems. Secondly, however, I have attempted to conduct the analysis and reporting of interview data within a framework which bears in mind the social situation in which these data were gathered. To this end, in section 6.3 I have presented a summary description of the interviewees’ different responses to the interview situation, and these perspectives have been used in the interpretation of the interview data which is presented later in the thesis.

3.4.2. Ethical issues around anonymity and use of pseudonyms

The present study adopted the usual procedures to ensure ethical practices such as informed consent, openness about research purposes, and assurances of anonymity. These procedures will be described in more detail in Chapter 5, but in this section I wish to address some issues around anonymity.

As is common in qualitative work, pseudonyms have been used in the reporting of this study, and all those involved in the research were informed that this would be done. Two issues emerge in relation to this practice. The first issue is that absolute anonymity is an impossibility. Even were the name of the institution involved to be obscured it would still be possible to someone with a detective bent to identify at least the lecturers involved in the study. Were they to have access to the mark sheets for the course in 1999, it would be easy to identify the students. The approach adopted here has been to ensure the anonymity of the participants as far as possible. In addition to the use of pseudonyms, for the students this has also involved obscuring biographical details where possible.

The second issue is a thornier one. It was decided to give the students ‘real’ pseudonyms rather than using a system like ‘Student A’, ‘Student B’, and so on. The main reason for this choice was to enhance the readability of the study, in that the reader is able to remember characteristics of various students. However, this
gives rise to a dilemma. Some, although not all, of the black students involved in this study themselves used names of an ethnic origin other than English. For at least one of these students switching from their English name was a conscious choice during their first year of university, and an affirmation of their African identity. It was decided to allocate pseudonyms in accordance with the ethnicity of the names that the students themselves used. The danger here is that this might evoke racial stereotypes by the readership, but a number of points need to be considered in response to this issue. Firstly, the racial origins of students are already disclosed in information given apart from their names, given that this was used in the purposive sampling technique, and also because in some instances this was related to different school backgrounds. Secondly, the alternative of giving all students English names might lead to another problem, that of the reader assuming homogeneity in the group. Finally, it is helpful to consider that all names also give clues to gender, and the analogous situation is that readers might draw on gender stereotypes. I doubt whether anyone would seriously suggest giving all students male names in response to this potential problem.

3.5. Conclusion

This chapter has laid out a theoretical justification for the research methodology used in the present study. The starting point in this discussion was the adoption of a constructivist epistemological position, and the implications this has for the knowledge claims to be made in this thesis. This was followed by a critical examination of the research paradigms of naturalistic inquiry, grounded theory, and phenomenography. Although I have drawn most heavily on the paradigm of naturalistic inquiry in creating a methodological framework, I have used grounded theory to provide a rationale for the analysis of qualitative data, and elements of phenomenography in providing a research approach for exploring students’ experience of learning.

The actual methods of data collection and analysis that were used will be discussed in Chapter 5. Before proceeding with that discussion however, Chapter 4 provides a full description of the context of the study, which serves as important background for the rest of the thesis.
Chapter 4
The context for the study

4.1. Introduction
The central focus of the present study is on students' experiences of a particular educational context, the CHE231F course in 1999. This chapter provides a detailed narrative account of that context. The CHE231F course will be located both in the broader geographical context of the University of Cape Town, and the Chemical Engineering programme, and also in the historical context of how this particular course has changed in the years preceding the study. This is followed by a 'thick description' (Geertz, 1973) of the course as it ran in 1999. Drawing on fieldnotes from my classroom observations and interviews with lecturers (these data collection methods will be described in the following chapter), I have attempted to construct an account which will give the reader sufficient understanding of the context to be able to interpret the research findings. This encompasses structural details of the course, including the changes that were made in order to promote conceptual understanding and metacognitive development. The account also deals with how the course actually ran in 1999, both in terms of what the lecturers did, and the student assessment outcomes. Apart from providing background for the interpretation of data, this section explains the context in which the initial research questions were formulated, and how these were modified in the light of the actual course outcomes in 1999, as was previously outlined in Chapter 1.

4.2. Locating the CHE231F course
In this section I will locate the CHE231F in its broader context, starting with the university and the national context, and then moving to the chemical engineering department and its undergraduate programme.
4.2.1. The University of Cape Town (UCT)

UCT is one of 36 higher education institutions in South Africa (21 universities and 15 ‘technikons’), and is one of the ‘historically advantaged’ institutions. This historical advantage derives from its founding during British colonial times to provide English medium education, and its designation for white students by the apartheid government in the 1960s and 1970s (despite sustained opposition from the university community to this policy). UCT today has 16 000 students, of whom about a half are black\(^3\), and envisions itself as a ‘world-class African university’ (Extract from UCT mission statement, available on the official UCT website, 2000).

It occupies a high status position in the South African higher education landscape, both in terms of its undergraduate programmes and research profile. Some evidence to justify this statement can be found in the high entrance requirements for its undergraduate programmes (compared to other South African institutions), and its drawing of more research funds than any other South African university.

All South African university students are required to pay fees for their tuition, and although there is significant state funding of higher education, the fees paid by students are by no means nominal. For example, for an undergraduate engineering student at UCT the annual tuition fee amounts to approximately 20\% of a schoolteacher’s gross annual salary. Although a government funding scheme is apparently in the pipeline (White Paper on Higher Education, Department of Education, 1997), the reality is that most students need to organise their own funding upfront, whether through a bursary, bank loan, or parental support.

4.2.2. The undergraduate chemical engineering programme at UCT

The Bachelor of Science in Chemical Engineering programme at UCT is one of the oldest such programmes in South Africa, and annually produces the largest number of chemical engineering graduates in the country. The Department has strong links with industry, both in terms of its research programme which is largely industrially

\(^3\) The designation ‘black’ includes all three of the groups otherwise classified African, coloured, and Indian.
funded, and in terms of its undergraduate students, more than a third of whom are on industrial bursaries (which are paid back by working for the company after graduating). The undergraduate programme has the highest entrance requirements of all programmes in the Faculty of Engineering and the Built Environment, and across the university, average end of school achievement scores are only higher in the Medicine and Actuarial Science programmes.

The undergraduate student population in chemical engineering in 1999 included 74% black students and 30% female students (statistics from the Annual Report of the Department of Chemical Engineering, 1999). It should not be automatically assumed that these black students are all ‘educationally disadvantaged’, or that the level of advantage or disadvantage is uniform. At least a significant proportion of black students in this particular programme would have spent at least their last years of schooling at a private or formerly white school. Roughly 20% of the chemical engineering undergraduate intake enters through ASPECT (Academic Support Programme for Engineering in Cape Town), an extended degree programme in which the first two years of study are spread over three years. This programme is specifically designed to support students from disadvantaged school backgrounds and to allow entry for students who do not meet the entrance requirements. However, due to the high demand for the limited ASPECT chemical engineering places (15 per year), it usually works out that the ASPECT chemical engineering students are those who would meet the entrance requirements anyway. Furthermore, some of these students have actually attended good schools for at least part of their schooling, but it is their industrial sponsors who wish them to get the added input from the ASPECT programme. This is not meant to deny the reality of the insidious impact of apartheid on so many aspects of these students’ lives and their communities. However it must be recognised that, in the spectrum of black students at South African universities, the UCT chemical engineering group is certainly on average one of the least disadvantaged.

One can therefore justly conclude that the student population in this programme represents part of the ‘cream of the crop’ of South African school leavers, yet their performance in the programme seems in many ways at odds with this profile. Of
those who enrol for the programme just over half eventually graduate, and of these graduates only about a third complete the degree within the specified four years (statistics based on student intakes in the early 1990s given in the Annual Report of the Department of Chemical Engineering, 1999). Concern with this situation has led to a variety of educational research and development initiatives in this programme over a number of years, and in my position as Education Development Officer since 1996 I have been involved with many of these projects, one of which is the present study.

A simplified representation of the programme structure is given in Figure 4.1. Each course carries a certain number of credits, each of which represent a nominal three hours combined contact and non-contact time per week, over one semester. These credits are represented on the vertical axis of the figure, and it will be seen that the total number of credits in each year is between 35 and 38, which equates to about 50-60 hours per week. Undergraduate students typically spend about 30 of these hours in lectures, tutorials and practicals (termed ‘contact time’). The remaining 20-30 hours is the estimated time that students spend studying outside formal classes,
either individually or in informal peer groups (termed ‘non-contact time’). In the junior undergraduate years a large proportion of course time is allocated to the basic sciences, namely mathematics, chemistry, and physics. The chemical engineering theory courses are core courses for progression through the programme, and these start with the first year introductory course, which also incorporates design and laboratory exercises. In second year there are complementary design and laboratory courses that run alongside the theory courses. One of the second year theory courses is CHE231F, indicated on the diagram in black. In third and fourth year students take elective courses from outside Science and Engineering, as well as specialised chemical engineering electives and two professional communication courses.

The nominal contact and non-contact hours indicated in this structure give some idea of the high workload of the programme. The first year contact hour load is similar to the undergraduate science programmes, but after first year, where the science programmes tend to decrease in contact hours, the chemical engineering programme retains a load of about 30 hours scheduled contact time per week. Anecdotal evidence has also long suggested that the estimated 30 hours per week non-contact time is too conservative, and this view was supported in a staff/student workshop held late in 1999.

4.2.3. A global perspective on context

The description provided so far has attempted to locate this study firmly within its South African context, with its idiosyncratic past history and current concerns. Nonetheless, anyone familiar with higher education issues on an international arena will quickly realise the universality of so many of the key issues confronting South African universities. For example, the opening up of access to higher education for ‘non-traditional’ students (from a broader section of society than that which traditionally participated in higher education), common throughout the Western world, is certainly at least partly analogous to the recent demographic shifts in historically advantaged South African institutions. Similarly, it is the same market pressures as exist around the globe that have led to calls in South Africa for more vocationally relevant curricula and greater accountability for state expenditure on
higher education. Many writers commenting on the situation of higher education in South Africa have commented on the similarities with changes taking place elsewhere, while also spelling out the particular South African focus on issues such as redress and transformation (for example, Entwistle, 1998c; Fourie, 1999).

As has been stated in the previous chapter, it is for the reader to judge the applicability of the present study to their own context. Nonetheless, I am hoping to persuade any reader who might be tempted to immediately assume that the South African situation is so unique that this research might have limited applicability elsewhere, rather to suspend judgement until the context and research findings have been fully described.

4.3. The evolution of the CHE231F course

In order to fully understand the nature of the CHE231F course in 1999, it is important to look at the changes in this course over time, as past events have had a significant influence on the current form of this course.

Prior to 1995, the content of CHE231F was located in a large whole year course called Chemical Process Analyses, abbreviated to ‘CPA’. High student failure rates on this course over decades had led to it developing status as a campus legend, to the extent that students in other faculties, and even in other universities, had heard of the dreaded ‘CPA’. In the early 1990s, collaborative learning groups were introduced into the afternoon tutorials in an attempt to improve learning on this course. However, the course remained a cause for concern, and in 1996, as part of a general curriculum revamp, CPA was split into a number of smaller theoretical, design and laboratory courses. One of the larger of these courses was CHE231F, a theoretical course dealing with the topic of material and energy balances. Complementary laboratory and design courses were designed to run alongside CHE231F in the first semester, and the topics of heat transfer and fluid flow were to be dealt with in a set of second semester courses. Associated with the curriculum change were increased efforts to improve teaching and learning in the course, including attempts by lecturers to make their problem solving processes more explicit during the lectures.
In 1998, the course lecturer, Dr Barnes, implemented further changes to the course. Despite the fairly extensive changes that had been implemented in 1996, she had remained concerned with the quality of student learning on the course. These concerns arose not only from the continuing high failure rates, but also from the poor level of understanding displayed in subsequent courses by students who had passed this course. She implemented a considerable shift in focus towards conceptual understanding, and this was seen in changes to curriculum, teaching and assessment, to be described in section 4.4.3. This pass rate in 1998 showed a considerable improvement on previous years (see Figure 4.2) and it seemed that the approach taken and the changes implemented by Dr Barnes were vindicated.

![Figure 4.2](pass_rate.png)

**Figure 4.2** Pass rate for second year mass and energy balance course

### 4.4. A closer look at CHE231F in 1999

Now that the CHE231F course has been located in its broader geographical and historical context, the actual course will be described in more detail in this section.

#### 4.4.1. The course content

The CHE231F course is entitled ‘Material and Energy Balances’. To explain what is meant by these terms, consider the simple chemical process represented schematically in Figure 4.3:
The feed stream consists of various chemical species (compounds), and when these enter the reactor a chemical reaction takes place. The product stream exits the reactor, and has a different composition to the feed stream. A material (or mass) balance is a formulation of the law of conservation of mass specific to this system:

\[
\text{mass in} = \text{mass out} + \text{accumulation}
\]

Under steady state conditions (when compositions at all points in the system are constant) the accumulation term falls away and

\[
\text{mass in} = \text{mass out}
\]

For more complex systems with more streams and more units than that given above, mass balances can be performed over various parts of the system. Mass balances are typically written for whole streams, while mole balances are more useful for individual chemical species, in situations when the reaction stoichiometry and extent of reaction is known. In an input-output table, the various species listed are given in subsequent rows, while each column stands for a particular stream. This is merely a device to organise the information obtained in balance calculations. An example of an input-output table for a simple single pass system (not realistic) such as that in Figure 4.3 is given below in Figure 4.4. In this system ethylene (E) reacts with oxygen (O) in a 2:1 ratio to form ethylene oxide (EO), the reagents are not in stoichiometric proportions and the conversion rate is 75%. The amounts in the table refer to kmol, and a time basis of 1 hour has been used in the problem.

<table>
<thead>
<tr>
<th>Component</th>
<th>Feed stream</th>
<th>Product stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>O</td>
<td>1</td>
<td>0.25</td>
</tr>
<tr>
<td>EO</td>
<td>-</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Figure 4.4  
Sample input-output table for simple single pass system
Similarly to mass balances, the energy balance derives from the law of conservation of energy, and under steady state conditions:

\[ \text{energy in} = \text{energy out} \]

Energy can enter and leave the system in the form of the enthalpy of the streams, or in the form of heat or work, and is given off or taken in during chemical reactions depending on whether they are exothermic or endothermic. All these aspects need to be taken into account when performing an energy balance.

The course outcomes for CHE231F in 1999 were divided into content and skills outcomes, and focused on the ability to perform material and energy balances, both separately and simultaneously (as required in certain problem situations). The full set of course outcomes is given on the first page of the course outline in Appendix A.

4.4.2. The lecturers

Two lecturers were involved in the CHE231F course in 1999, Dr Barnes and Dr Stevens. Dr Barnes had a long history of involvement with the course: first as a graduate student she had coordinated the tutorials in the early 1990s, and then later as a lecturer in the department she had taught part of the course in 1995 and 1996. In 1998 she had sole responsibility for the course, and in that year implemented major changes as mentioned earlier. In 1999 Dr Stevens, a fairly new lecturer, came in to teach part of CHE231F in order to relieve the overall heavy teaching load carried by Dr Barnes. He taught the first three weeks of the twelve-week course, and Dr Barnes taught the remainder of the course, also taking on the role of course coordinator. Dr Stevens had agreed from the outset to fit in with the new approaches to teaching and assessment that Dr Barnes had started using in the previous year. Both lecturers were interviewed as part of this research (see section 5.5.4). The interviews, and other informal discussions, are drawn on here to contribute to this brief picture of how they saw their roles in CHE231F.

Both lecturers were strongly committed to their teaching and displayed an active concern for students. Both were regarded by their colleagues and students as good
teachers. CHE231F is a course viewed by the department as critical to the undergraduate programme and there had been over the years attempts by the Head of Department to have some of the better lecturers teaching on this course. Dr Barnes had been given full responsibility for this course (and another key undergraduate course) in 1998 on the basis of her highly regarded previous work in this course. Dr Stevens was approached to join the teaching of this course in 1999 following good student response to and success in other optional undergraduate courses that he had taught.

Both lecturers subscribed to the notion that the experience of CHE231F should involve serious conceptual engagement and development by students. They differed somewhat though in their view on what the lecturers’ role should be in relation to this development. It seemed that they were both strongly influenced by their own experience of being undergraduates in this course or its equivalent (Dr Barnes did her undergraduate studies at UCT, while Dr Stevens was at another South African university).

Dr Barnes described her undergraduate experience of this course as follows:

As a student, I struggled to come to grips with the concepts in this course. Now, as a teacher, I hope that I have some insight into the difficulties, and that I can help students to overcome them as well as to develop an enthusiasm for the material. (Dr Barnes, Submission for UCT Distinguished Teacher’s Award nomination, page 3)

In her teaching she aimed to create a different environment to that which she had experienced as an undergraduate student, and which she had found alienating and unsupportive. She clearly saw her role as supporting and helping students as they went through a process of conceptual, metacognitive and personal development. She was convinced that a good teaching and learning environment could assist more students to succeed in this course.

Dr Stevens also had vivid memories of his experience as an undergraduate studying material and energy balances. At the time he really disliked both the course and the lecturer, who had used very much a ‘sink or swim’ approach to his students.
However, much later on (after graduating), he came to value what he had learnt on this course and felt that the approach used was justified.

When talking about the way he approached teaching CHE231F Dr Stevens said that:

... I was trying to go from what you call teaching, which I don’t think is the aim of the university, to what you could call educating, in a way. Learning to think for yourself. (Dr Stevens, Interview, page 2)

Dr Stevens described the development that students need to undergo in CHE231F as a cliff that must be climbed. As a lecturer he felt that he could push them a bit of the way, but after that they needed to start climbing on their own. He asserted that this process would be difficult and painful, that some students would be lost along the way (those not destined to become chemical engineers), but Dr Stevens felt that this was an unavoidable harsh reality. He described his role as presenting concepts, and the students’ role as battling with these concepts.

### 4.4.3. Structure of the course

The basic structure of CHE231F that had been established when the course was created in 1995 was not tampered with in subsequent changes: a 5 credit course in the first semester of second year, with parallel and separate laboratory and design courses. In the timetable it was allocated five 45 minute lectures per week, one each morning at 9h05, and a tutorial session on Wednesday afternoons running from 13h40 till about 16h30. In the tutorial session the class was split into three venues, each allocated two postgraduate tutors, and students worked, in groups of three, on a given set of problems. One of the six tutors was appointed as a senior tutor, which involved some organisational duties, as well as marking a section of each class test. In 1999, the CHE231F senior tutor was Ms Fox, who had a number of years’ experience as a tutor, and was well regarded in this role by both staff and students. The tutors met with the lecturer each week on the day preceding the tutorial for a ‘pre-tut’ meeting, during which the tutorial problems were discussed.

---

4 The term ‘problem’ was used in CHE231F to refer to any exercise in class, at home, or in a test, which required students to provide an answer. These included both standard numerical exercises, as well as questions requiring a qualitative explanation.
and worked through. Although ‘post-tut’ meetings were scheduled to take place straight after the tutorial, for the purpose of feedback to the lecturer, these seldom took place as planned. The tutorial system described here had been developed within the department over the past few years, and was in the process of being adopted in most undergraduate courses.

The first semester in 1999 had 12 teaching weeks, and as mentioned above, Dr Stevens taught the course for the first three weeks, with the remainder taught by Dr Barnes. Three class tests were written during the semester, approximately one every four weeks, and the final assessment of the course was in the form of a three hour examination. The final course mark was based on a combination of the class mark (calculated by averaging the three test marks and adding the bonus journal marks) and the final examination mark, in the ratio 30:70. All these details were given to the students in the course outline, which is reproduced in Appendix A.

The changes implemented in 1998 by Dr Barnes, and maintained in 1999 by her and Dr Stevens, fitted within the basic structure described above. The chief objective of these changes was to promote development of students’ conceptual understanding and metacognitive abilities (following similar ideas on student learning to those outlined in Chapter 2), in addition to the existing (and previously almost exclusive) focus on the development of problem-solving skills. It was recognised that aiming for deep approaches to learning and associated metacognitive development had implications for curriculum, teaching and assessment. Complementary changes were implemented in each of these domains, and will be described in what follows.

Curriculum

Overloaded curricula are common in engineering courses worldwide and CHE231F was no exception. In order to ‘cover’ the required material, new concepts had to be presented at an alarming rate. Inspired by the maxim ‘Cover Less, Uncover More’, Dr Barnes decided that in order to achieve her aim of teaching and assessing for ‘deep’ understanding, the amount of material in the curriculum would need to be reduced. She already had an idea of which topics she felt were dispensable (either covered in later courses, or not fundamental to chemical engineering knowledge) but decided to enlist the support of her colleagues in this process. A workshop was
held with all teaching staff in late 1997 (described in more detail in Case, Jawitz, Lewis, & Fraser, 1999, January), in which the key exercise was deciding on critical outcomes for the various second year courses. The existing curriculum was then presented and compared with this list, and on this basis the content in CHE231F was reduced by approximately 25%. Not only did this process ensure the support that was needed for the CHE231F changes, but it also set off a wider process of curriculum change in the department which is still ongoing in 2000.

**Teaching**

The teaching strategies were designed with the aim of getting students to engage actively with concepts, something that is surprisingly uncommon in undergraduate science and engineering lectures (see, for example, Linder & Marshall, 1997a; Tobias, 1990). Primarily this involved replacing the traditional one-way transmission from the front of the classroom with methods such as posing questions to students, getting them to try problems on their own, to discuss issues with their classmates, to report back to the class, and to ask questions. Following this, whole class discussion was used to tie together discussions, deal with alternative conceptions, and provide questions for further consideration. To try and break the passive note-taking habit, Dr Barnes developed a ‘workbook’ that had some information provided, gaps for students to fill in information as concepts were dealt with in class, and problems with space for students to try out their approaches.

She also communicated to students a shift in emphasis away from the lecture providing everything that was needed to succeed in the course, towards an expectation that significant learning would take place in the tutorials and at home, both individually and with classmates.

In a rather radical move in an engineering context, Dr Barnes introduced in 1998 a set of weekly journal tasks into the course. Two of these tasks are reproduced below by way of illustration, and the full set of journal tasks and explanatory handout is reproduced in Appendix B.
Journal Task

WEEK 5

Reflecting on the first class test

1. Give a general analysis of your performance in the test.
   • You may wish to calculate your % mark for each question.
   • Recall how you felt before and after the test.
   • Are you happy with your performance in this test?
   • Do you think your mark reflects your understanding of the material?

2. Identify your weak and strong points as displayed in this test performance

3. What are the most important lessons that you have learnt from this test?
   Is there anything that you need to do differently from now on?

Journal Task

WEEK 8

1. Go back through all your notes and problems so far on Energy Balances. Find two concepts (or definitions or equations) that you don’t understand OR are not too sure of OR would like to find out more about. Write them down.

2. Now go to the recommended texts for this courses (Himmelblau, Thompson & Cecklar, Felder & Rousseau, Reklaitis), and look to see if there is anything there to help you with the two problems you have identified above (make use of the contents page, the index, and general browsing to locate a topic). If you haven’t found anything to clarify these problems, find a classmate or tutor or lecturer to help you.

3. Make some notes on how you have resolved your confusion. You must clearly state what you have discovered your problem to be, and how you have resolved it. Don’t just write out a paragraph from the textbook!!

NOTE: This is not an easy task to do properly. You need to make time to seriously think about what you do understand and what you don’t understand. If you take the time for this task you should be able to progress significantly in your understanding. Merely copying out notes on a topic will not be considered a satisfactory response to this task – the task requires you to think about your own learning of Energy Balances.

Initially the journal hand-ins were compulsory and for no extra marks, but following student feedback, this was changed midway in 1998 to a system of optional hand-ins for bonus class marks. In 1999 there were four hand-ins, one every three weeks; the first was compulsory and the remainder optional. These were assessed primarily by me with some input from the lecturers. Each satisfactory submission earned 1% extra on the class mark, while a hand-in deemed particularly well done earned 2%. The maximum bonus marks that could be

5 ‘Hand-in’ was the term used in CHE231F (and other courses in the programme) to refer to an assignment which students had to submit during the semester for marks.
obtained was therefore 8% added on to the class mark, equivalent to 2.7% of the overall course mark.

Assessment

Dr Barnes was concerned that the pre-1998 assessment question format in CHE231F (traditional numerical problems) did not adequately assess students' conceptual understanding. In previous years there had been an attempt to introduce non-numerical questions, but these tended to require not much more than 'bookwork' recall. She therefore worked on developing items that were non-numerical and assessed conceptual understanding. Initially she focused on separate 'short questions', but then started adding 'Explain why...' and 'What if...' type questions on to standard numerical items. She also altered some multi-step numerical problems so that students had to explain what they would do, rather than performing the actual calculations. These items comprised approximately a fifth of each test and examination. A sample item with conceptual components from the second class test in 1999 is provided by way of illustration below.

<table>
<thead>
<tr>
<th>Question 2</th>
<th>10 marks</th>
</tr>
</thead>
<tbody>
<tr>
<td>In a recycle process for the production of ethylene oxide, the ethylene: air ratio in the fresh feed is 1:10, the separator is ideal, the recycle ratio (recycle: waste) is 2 and the overall conversion of the process is 75%.</td>
<td></td>
</tr>
<tr>
<td>a.</td>
<td>Draw a flow diagram depicting the process. Label all streams.</td>
</tr>
<tr>
<td>b.</td>
<td>Your colleague calculates the concentration of N(_2) in the recycle to be approximately 80 mole %. Explain, without calculation, whether or not this answer could be correct and why.</td>
</tr>
<tr>
<td>c.</td>
<td>Your colleague also calculates the conversion per pass to be approximately 90%. Explain, without calculation, whether or not this answer could be correct and why.</td>
</tr>
<tr>
<td>d.</td>
<td>If the fresh feed rate and the reactor conditions remain unchanged and the recycle ratio is increased to 4, which of the following results are true:</td>
</tr>
<tr>
<td>i.</td>
<td>The conversion per pass increases.</td>
</tr>
<tr>
<td>ii.</td>
<td>The conversion per pass remains the same.</td>
</tr>
<tr>
<td>iii.</td>
<td>The conversion per pass decreases.</td>
</tr>
<tr>
<td>e.</td>
<td>If the fresh feed rate and the reactor conditions remain unchanged and the recycle ratio is increased to 4, which of the following results are true:</td>
</tr>
<tr>
<td>i.</td>
<td>The overall conversion increases.</td>
</tr>
<tr>
<td>ii.</td>
<td>The overall conversion remains the same.</td>
</tr>
<tr>
<td>iii.</td>
<td>The overall conversion decreases.</td>
</tr>
</tbody>
</table>
In order to de-emphasise memorisation, students were allowed to bring in a ‘crib sheet’ to all tests and examinations. This was one A4 sheet on which they could write anything they wished. Owing to the nature of the questions it was unlikely that students would need to use this very much during the actual assessment, but apart from reducing stress, it was also recognised that the act of preparing such a sheet would be an important learning experience.

The assessment in CHE231F has traditionally been tremendously time pressured. Dr Barnes was concerned that students might ascribe their lack of success in the course to this time pressure, and therefore introduced in 1998 one test (the third class test) for which students were given practically ‘unlimited time’ (five or six hours for a two hour test). Time was limited in all the other tests, although the lecturers felt that the time allocated was fair.

4.4.4. How the course ran in 1999

In 1999 there were 61 students enrolled on the CHE231F course, of whom 25% were white, 11% coloured, 8% Indian and 56% African. Over a quarter (28%) of the students were female. Nine students were repeating the course, having failed it in 1998. The class size was considerably smaller than in previous years (in some years the class had had more than 100 students), partly due to a smaller number of students repeating the course following the high pass rate in 1998. Eleven of the students in the class were on the third year of ASPECT, the extended degree programme mentioned earlier in section 4.2.2.

Teaching

The teaching of the course went basically according to plan, following the changed structure sketched above in section 4.4.3, with some minor alterations. The lecturers had met before the start of the semester to plan which parts of the curriculum each of them would be responsible for. They also met with the first year lecturer who had done eight weeks of informal introductory work on material and energy balances. They were in fact surprised to discover what kind of problems had been dealt with in first year, and this led to Dr Stevens covering more complex problems in the first three weeks than had been planned. Dr Barnes was expecting
to introduce recycle problems only in the fourth week and students had already been doing these in Dr Stevens’ classes in the first three weeks. On the other hand Dr Barnes had hoped that Dr Stevens would introduce the technique of the input-output table, but he did not think this was a useful technique and so omitted to teach this. This led to some tension in the changeover period, with students already feeling that they had been taught recycle, while Dr Barnes felt that their understanding of this area was superficial. A large number of students resisted using input-output tables, having not used these in Dr Stevens’ classes. These tensions however appeared to be resolved by halfway through the course⁶.

Both lecturers used a variety of techniques to actively engage students during the class, and students generally responded by involving themselves in these activities. In the previous year there had been some resistance by students to do anything apart from passive note-taking during class, but this did not seem to be the case in 1999. Two extracts from my research logbook will be provided to illustrate what was happening during the lectures. I have deliberately chosen ‘average’ lectures which from my viewpoint often had a combination of good interactive engagement with some traditional transmission. These lectures are by no means perfect, and the reader will no doubt find aspects where they would suggest different approaches. This is the reality of lecturers trying to engage with new methods within the constraints of student and institutional expectations, usually succeeding only in partly achieving their intentions. Nonetheless, it must be borne in mind that the situations described here are still very unusual within the context of undergraduate science and engineering teaching.

Tues 9 March 1999
[Dr Stevens] then pulled out the problem for the day, which was a fairly nasty one involving a coal separator. First he got students to get the objective and the flowsheet sorted out (according to his list of steps). I sat sweating and trying to figure it out, and ultimately made the same

⁶ Evidence for this assertion can be seen in the issues spontaneously raised in the student interviews: in the first interview, which took place shortly after the changeover, most students mentioned that they were struggling with the change. Yet this was not mentioned in subsequent interviews nor even in the final interview when I asked them to reflect back on the course it seemed that they had forgotten all about this concern.
mistake as some students I gather in that I added in a separate input stream of liquid for the draining screen. After I had got a few ideas down I looked around and most students had a fairly good idea of the flowsheet. Everyone was at least tackling it, which is still amazing to me after the apathy I remember from last year’s class... Dr Stevens then put up his flowsheet, which was actually quite simple, and then got everyone to tackle steps 3 to 6. Students worked away at this, and then Dr Stevens put on the board what he had done at this stage. Of course while he was discussing step 3 students were asking to explain what he had written in response to step 6 (he put it all up on the diagram before discussing). I noticed that some students had chosen rather strange bases e.g. the recycle stream. When he asked ‘Did anyone select any other basis other than the mixed feed?’ of course there was silence – I mentioned to Dr Stevens afterwards that I had noticed this and suggested other ways of asking the question. I really enjoyed today’s lecture and decided to add an interview probe getting into students’ experience of this lecture as I thought it was also quite challenging.

(Fieldnotes in research logbook, pages 23-24)

Friday 23 April 1999
In this morning’s lecture Dr Barnes got the various groups to give feedback on the different types of heat capacity data they had used [in a group exercise started in the previous lecture]. She got the groups to focus in their feedback on the method they had used. Jane and Amina gave great feedback on how to use mean molar heat capacity. Then the class joker, James, reported on the polynomials – and engendered much mirth by scribbling on the board something that was actually incorrect. Dr Barnes then corrected him, at which he made a marginally better attempt. It was interesting that sometime at this stage Geoff (from the same group) gave an explanation from the floor of what needed to be done, which was very good. David reported on the graphical method – although he started writing up long equations which was a bit odd seeing as they hadn’t used these. John then gave great feedback on using [mean] molar heat capacities - with a good method to get around the problem. Dr Barnes then asked the class which method they would prefer - and hopefully the case for mean molar heat capacities was made.

Dr Barnes then got them to do exercise 1 to practise using heat capacities in energy balances. At the start she gave students time to puddle around in it - and then got someone to give the energy balance for this problem. Tim asked whether 100 kmol/ s didn’t imply the need for a 0.5v^2 term – and she explained why not. She then went into solving the problem on the board. I was surprised that she used the polynomial method after having lauded mean molar heat capacities earlier on – but maybe just for practice I suppose. Students were asked to try exercise 2 for homework, which she will go through in class on Monday.

(Fieldnotes in research logbook, pages 52-53)
Assessment during the course

The student response to the journal tasks was generally positive, and compared to the previous year (for details see Case, Gunstone, & Lewis, 1999), the journal assessment system seemed to meet with widespread approval. The number of students handing in the tasks at each specified ‘hand-in’ is represented in Table 4.1 below.

Table 4.1
Number of students who submitted each journal hand-in

<table>
<thead>
<tr>
<th>Hand-in</th>
<th>1 (compulsory)</th>
<th>2 (optional)</th>
<th>3 (optional)</th>
<th>4 (optional)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of students</td>
<td>60 (98%)</td>
<td>40 (66%)</td>
<td>36 (59%)</td>
<td>27 (44%)</td>
</tr>
</tbody>
</table>

Note. Percentages are given in brackets

The class test results are represented graphically below in Figure 4.5. There had been an attempt to set a first class test that was not too easy, as this was perceived to have caused a number of students to become complacent in the previous year. The lecturers were consequently satisfied with the results of this test (44% pass rate) as they hoped it would get students working. Before the second test Dr Barnes warned the students that there would be some time pressure in this test, as she felt it was important not only to be able to understand the concepts, but also to be able to work fairly quickly. The second class test results were generally poor; in my logbook I commented on the funereal silence when the tests were handed back in class. In the following lecture Dr Barnes took some time to discuss learning in CHE231F. She used a metaphor which she called ‘Chem Eng City’, in which lights get progressively switched on in different rooms in the buildings. What happens in a lecture she equated to the lighting of a candle in a room, with further lighting in that room happening in tutorials, working in peer groups, and working at home. This discussion was motivated by her judgement that the poor test results were due to students not doing enough work on their own, and expecting to ‘get it all’ in lectures. The results on the third, ‘unlimited time’ test showed a considerable improvement (64% pass rate). Most students made good use of the extended time, and quite a few even had to be ejected at the end of six hours. Two of the three
questions in this test were problems that had been in the workbook, but not tackled in the class or the tutorial (although recommended that students do them on their own). Dr Barnes’ said that she had done this to make the point to the students that they needed to be working at home.

Figure 4.5 CHE231F class test results in 1999

Test 1

Pass rate = 44%

Test 2

Pass rate = 22%

Test 3

Pass rate = 64%
At the end of the semester, both lecturers were generally happy with the way the course had run, although Dr Stevens felt that there were some students ‘who just didn’t get it’, and Dr Barnes was concerned that there were many who had not engaged with the work, especially in what she had been expecting them to do outside class. Five of the 61 students did not achieve the 30% class mark required to be able to write the examination (this is a common requirement in UCT courses). Two of these were repeat students who had not participated much in the course. Despite the generally poor class test results of the remaining 56 students the lecturers were assuming that students would use the time before the examination to remedy problem areas.

**Final assessment outcomes**

The final examination was held in June 1999, and the three hour paper contained four ‘questions’. The fourth question was made up of many short questions, leading the students through a number of calculations and explanations in a problem situation. This question counted for almost half the marks in the paper. Immediately after the examination students complained that they had not had sufficient time to complete the paper, and they were particularly unhappy that one question had counted for so much.

The examination results were not at all good. Only 30% of the students passed the examination, and this ratio remained unchanged when the class mark was factored in to make up the final mark. At the departmental examination meeting, attended by all academic staff, there was a long discussion on what to do in this situation. Dr Barnes had suggested changing the weighting of the questions in order to lessen the impact of students’ poor performance in the last question, but it was felt that this was not a satisfactory solution. The decision was made to offer an optional re-examination in the third week of the second semester.

In setting the re-examination Dr Barnes and Dr Stevens made sure that the problems that students had reported in the original examination were avoided: this time no

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7 This result includes the five students who had not been allowed to write the final examination and who were counted as fails.
question carried more than 20 out of 100 marks, and careful attention was paid to
the time demands of the paper. In order to ensure quick turnaround of the scripts
the paper was marked by a team comprising the two lecturers, the senior tutor (who
had marked part of the class tests during the semester) and myself.

Students were pleased to have the opportunity of a second chance, and although
they had new courses it seemed that most of those who had failed were working
hard on CHE231F during the first two weeks of the new semester. No one seemed
overjoyed at the end of the examination session, but there was not the strong outcry
that had accompanied the first examination.

When the results were compiled it emerged that only some students had managed
to improve their mark in the re-examination. The final course mark was calculated
using the best of the two scores, and the pass rate rose to 43%. The final scores are
represented in a histogram in Figure 4.6 below. This was a sorry come-down from
the triumphant 85% pass rate that had been achieved in CHE231F in 1998, and there
was much soul searching, particularly on the part of Dr Barnes and Dr Stevens, and
myself. The re-examination had not changed students’ success all that much, even
though there had been a more carefully designed paper, a broader team of markers,
and more revision time for students. The lecturers therefore remained convinced
that for some reason students had not engaged with the work in the same way that
they had the previous year. What remained a puzzle to them was why this
engagement had failed to take place to the same extent.

![Figure 4.6](image.png)

**Final CHE231F marks in 1999**

Pass rate = 43%
4.5. Conclusion

In this chapter a description of the CHE231F context has been given, initially locating the course in the broader university and national environment, and then looking from the perspective of the history of this course over the last few years. This was followed by a detailed account of the course itself, in terms of both its planned structure and what actually happened when it ran in 1999.

The material in this chapter serves a number of purposes, all of which derive from the naturalistic research methodology that has been adopted. Firstly, it provides the background for both understanding and interpreting the data collection, analysis and findings to be presented in later chapters. Secondly, the description given here is an important source of information for the reader who wishes to determine the ‘transferability’ (Lincoln & Guba, 1985) of these findings into another context. Finally, the description of the course as planned and as enacted provides an explanation for the research questions as originally formulated and later modified. This latter point will be briefly elaborated in what follows.

The initial research questions were formulated following the planned changes to the CHE231F course (as outlined in section 4.4.3), and the way the course ran in 1998 following the implementation of these changes. Following the pilot study that I conducted in that year it appeared that most students were experiencing significant metacognitive development during this course, and I was interested to explore the nature of this development and how it was related to the restructured course context. The final assessment outcome of CHE231F in 1999, as sketched above, caused me to seriously revisit these research questions. Although it was clear that some students had experienced the course as intended, for many more their marks seemed to suggest that they had not achieved the requisite conceptual understanding. In terms of the theoretical framework of the present study, it seemed possible that this might be associated with less than adequate metacognitive development and inappropriate approaches to learning. These changes did not alter the relevance of the content of the research questions (exploring students’ experience of the course in terms of perceptions, metacognitive development and approaches to learning) but they had a marked impact on the focus of the research.
It became necessary to shift the emphasis, from documenting instances of good metacognitive development and relating this to the restructured context, to explaining instances where this development had patently not taken place. This was not merely an academic concern, but was intimately linked to my sense of commitment to the students, and to the lecturers. These lecturers were not only Dr Barnes and Dr Stevens, but also the broader academic community in the Department of Chemical Engineering, who were looking on with dismay at what had happened in CHE231F in 1999.
Chapter 5  
Methods of data collection and analysis

5.1. Introduction

In Chapter 3 the research methodology used in the present study was outlined. This incorporated a constructivist epistemological stance and a research paradigm based mainly on naturalistic inquiry, but also drew in elements of grounded theory and phenomenography. In the course of this discussion some reference was made to particular methods that were used, and certain problematic issues regarding methods were also considered. However, any in-depth exposition of the research methods used in the study was deferred until the present chapter.

This chapter begins with a brief description of the pilot study that was conducted in 1998, which was used primarily to test out the practicality of data collection methods, and also to develop the focus of the study. The remainder of the chapter deals with the data collection and analysis procedures used in the present study which was conducted in 1999. Starting with a reflexive examination of my positioning in the course context, the chapter moves on to describe data collection procedures. These included the use of a research logbook, which allowed for the coordination and documentation of the entire process, as well being a repository for certain types of data. Data collection procedures are then discussed at the interviewee and class levels. Finally, an outline is provided of the procedure by which the data were analysed.

5.2. The pilot study

As mentioned in Chapter 4, it was in 1998 that Dr Barnes first implemented innovative changes to the CHE231F course. During that year I conducted a form of a pilot study during the course, with the chief objectives being to test out data collection methods and consolidate the research focus for the major study to be conducted in 1999. In this section this pilot study will be briefly discussed from
these two perspectives, namely the trialing of research methods, and preliminary findings which informed the research focus of the present study.

5.2.1. Research methods

During this study I acted as a resource person for Dr Barnes who was developing methods of teaching and assessment appropriate to the course objectives. She frequently came to me to discuss things she was planning to do or had tried in class, and I acted as a sounding board and also gave her productive feedback. Before the semester started she had mentioned introducing a form of student journal to the course and asked for my assistance in developing this aspect of the course. I then took on a coordinating role both in developing the tasks with her input, and in reading and providing written comments for students. With students’ permission I then kept copies of journal entries relevant to the emerging research questions.

I attended virtually all lectures and tutorials during the semester, making field notes regarding anything that seemed relevant to the research project. I had frequent informal interactions with students, and later noted down details from these conversations. Finally, after the course had ended, I individually approached five students from a range of backgrounds and achievements, and conducted one in-depth semistructured interview with each of them.

These methods of engagement and data collection provided a range of rich and useful information. I found that students seemed fairly at ease with having me sit in on the class, and taking on a counsellor role especially in the marking of the journals. Individual students were also surprisingly amenable to my request for an interview. I was therefore fairly confident that these methods, with some elaboration, would prove effective in the major study.

5.2.2. Findings of the pilot study

As discussed in Chapter 1, the pilot study was directed by the first version of research questions later used in the major study. In the pilot study the focus of these questions was on students’ perceptions of the learning context (and how this influenced approach to learning), and their metacognitive development. The
findings will be briefly discussed under these two headings. Further details are available in a series of three papers (Case, Gunstone, & Lewis, 1999, 2000, submitted for publication).

For a number of key aspects of the course, students’ perceptions were compared with the lecturer’s original intentions. This particular analysis focused on the class in general, or, when there were subsets of students with significantly different perceptions, on these subsets. In certain instances there was general congruence between the lecturer’s perceptions and actions and how the students experienced these, for example with the lecturer’s attempts to promote reflection on conceptual understanding through the unlimited time test. In other instances the students’ perceptions conflicted with the lecturer’s intentions, for example with the original system of journals for which no marks were allocated. Following this analysis it was argued that the desired course outcomes were only obtained when the students’ perceptions and the lecturer’s intentions were in agreement.

The second analysis took place at a more individual level, focusing especially on the journal extracts and the interview data, in an attempt to characterise the nature of metacognitive development in the course. At this stage of the study I was working with a fairly general notion of metacognitive development along the lines of Baird’s (1990) formulation, compared to the more specific focus on changes in approach to learning that was adopted for the present study. Within this framework it was notable that a significant majority of students displayed clear evidence of metacognitive development in the course. Aspects of metacognitive development that were described included a development in students’ conceptions of learning, improvements in the organisation of one’s learning, a move towards self-assessment, and personal development with regard to views on the purpose of learning and long-term career goals.

These research findings, although having some value in themselves, served chiefly to inform the research questions and theoretical framework for the present study. In particular, the focus on students’ perceptions was justified, and the need for a clearer theoretical view on metacognitive development to link to the other constructs was suggested. As discussed in some length at the end of the previous
chapter, the significantly different course outcomes in 1999 also served to modify
the focus of the present study.

5.3. An examination of my positioning in the course

In the naturalistic paradigm the positioning of the researcher is made more explicit
than has traditionally been the case in educational research. The human is not
assumed to be a neutral mechanical ‘data gatherer’, instead it is recognised that the
researcher’s motivations, past history, positioning in the research context, and
interactions with the research subjects, all have an influence on the data that is
collected. This is considered inevitable, and instead of trying to ignore this issue,
researchers are urged to make their role explicit, in order to allow the readers to
assess the trustworthiness of the data. It is therefore important at this stage to begin
an analysis of the position that I took up within the context of CHE231F in 1999.

I was not a newcomer to the scene. I had been employed as a lecturer and
Education Development Officer within the Department of Chemical Engineering
since 1996. In the latter role I worked as a student counsellor, staff developer and
educational researcher, with the general brief to improve teaching and learning in
the undergraduate programme. My first encounter with the CHE231F course was
in 1996 when I sat in on the course in order to pick up the basics of Chemical
Engineering. Dr Barnes had lectured half of the course that year, and we had
started talking then around a common interest in student learning. This discussion
had led naturally to her talking at the end of 1997 about her plans to do something
new in CHE231F in the coming year, and my subsequent approach to conduct my
PhD study in the context of her course.

The 1999 CHE231F students and I were also not strangers to each other. I had been
involved in the first year chemical engineering course in 1998, giving a couple of
lectures, helping in the afternoon tutorial sessions, and generally acting as a
counsellor to the first year students, especially regarding study or curriculum
problems. I knew most of the 61 students by face and name at the start of the
CHE231F course.
During the period of data collection in 1999 I took on three different roles within the course: researcher, educational developer and student tutor/counsellor. All three of these roles I laid out explicitly to the students during a five-minute slot that I was given in the first CHE231F lecture for the semester. These roles were very much intertwined and sometimes indistinguishable, but for the purposes of the analysis I have attempted to separate them out in the following descriptions.

My primary role was as a researcher, collecting data for my PhD study. In this role I sat in on the lectures and tutorials and took field notes. To some extent this activity was a form of participant observation, although I would hesitate to classify it as such as I was not really fully taking on the role of a student. In the lectures I sat near the back of the class, often alongside students, and I did whatever the class was required to do, for example drawing a flowsheet. However, in order to find out how the students were experiencing a particular activity, I then took on something of a role of a teacher, moving around and asking students what they had done, and occasionally helping where requested. During the tutorials I took on the role of an extra tutor, moving around the different venues and helping groups as requested, and also asking students to explain what they had done. A quite different form of interaction as a researcher took place during individual interviews, when I met with individual students outside the class, specifically for the purposes of my data collection. In addition to these formal out of class meetings I had frequent informal interchanges with students in the CHE231F class which I noted down in my fieldnotes.

A second role I took was that of educational developer, working alongside the lecturers as a support for the improvements they were trying to bring about in their teaching, and in the structure of the course. This involved giving informal feedback on their lectures, as well as on the content of tutorials and assessments. I played a fairly major role in compiling the journal tasks in conjunction with Dr Barnes, as well as coordinating the hand-ins and doing the primary assessment and feedback to students.

Although I had been explicit to students about my role as researcher, I did not want them to see my interaction with them as only for the purposes of my data collection.
I therefore described my formal (and third) role in the course as ‘learning counsellor’ and this was listed as such in the course outline. From the perspective of the students I hoped that my interactions with them during and outside classes, described above, would also be seen as of value to them in terms of their learning on the course.

All three of these roles required me to be confident with the material presented in the course: as a researcher I needed to be able to probe students’ understanding, as a developer I needed to be able to make sensible suggestions regarding teaching and assessment, and as a tutor/counsellor I needed to be able to respond to students’ questions. This I managed by building on my understanding from doing the course in 1996 and sitting in again during the pilot study in 1998, as well as the current immersion in all aspects of the course during the major data collection in 1999.

5.4. Research logbook

In Chapter 3 the trustworthiness criteria of dependability and confirmability were established as naturalistic equivalents of the traditional notions of external validity and objectivity. Techniques for enhancing these aspects of the study centre on providing a record of how the study was conducted, with a key aspect being the keeping of a reflexive journal. Following on this suggestion I kept what I termed a ‘research logbook’, for the duration of the data collection process, in the format of a Word 97 document. I had aimed to write daily entries, but I actually managed about three entries a week, usually summarising the previous day(s) as well as the current one.

The logbook contained a number of different things. Firstly, I took my handwritten fieldnotes from my lecture and tutorial observations and informal discussions, and wrote these up in a more coherent and elaborated form, often including further reflections. The handwritten notes were kept for later reference if necessary. The logbook also included a record of the process and results of decisions I made regarding data collection, later reflections on these decisions, and any issues emerging from the initial data analysis. Essentially anything that I put into words during the data collection period I wrote in this document. It was then relatively
simple to extract the different forms of data from this document as they were needed in the analysis and writing up process. The huge advantage was having everything in one place, and also being able to develop the discipline to regularly write down reflections on all aspects of the research process, without having to classify into different forms of data at this stage.

5.5. Course data

Although the main data for this study focused on the group of interviewees, a large range of course data was collected as background information to aid in the interpretation and analysis of the main data.

5.5.1. Lecture and tutorial observations

While sitting in lectures I made rough notes of what was happening in class. This included the things the lecturer was saying and doing, and student responses, both in terms of whole class interactions, and actions of the individual students sitting close to me. These rough notes were then used as the basis for entries into my logbook. Examples of such entries can be seen in section 4.4.4. I made similar entries based on what happened in tutorials, although of course it was more difficult to extract a singular impression of what was happening, with students working in groups of three at their own pace on a set of problems. I had asked the lecturers if they would be comfortable having me sitting in on their classes, and when would suit then. Dr Stevens requested that I only come from the second week of his lectures onwards, while Dr Barnes was happy for me to sit in for the full duration of her section of the course. Overall I attended about 90% of the lectures.

During the eighth week of the semester I attended a lecture in each of the Mathematics 2 and Chemistry 2 courses that the students were taking concurrently with CHE231F, and made extensive fieldnotes comparing the class interactions.

5.5.2. Class materials and assessment items

Documents collected in this category included a copy of the prescribed textbook, Basic Principles and Calculations in Chemical Engineering (Himmelblau, 1996), as well
as the course outline, the workbook and additional lecture notes, the set of journal
tasks, and tutorial problem sets. Assessment items which were also collected
included the three test papers, the two examination papers, and sample solutions
for all of these.

5.5.3. Class records

Dr Barnes provided me with a copy of the Excel 97 file which gave the class list with
marks for all three tests, the journal marks, the two sets of examination results, and
also the final course marks for each student.

5.5.4. Lecturer informal discussions and interviews

I had frequent informal discussions with the lecturers, involving both planning of
lectures, tutorials and assessments, and reflections on these. These I noted down in
the research logbook. In the week following the end of the semester I conducted a
more formal interview with each of the lecturers. This followed a semistructured
format, based loosely on the following protocol:

1. What were your main objectives in the teaching of the course?
2. What did you do to try and achieve these objectives?
3. To what extent do you think you achieved these objectives?
4. Are there areas where you struggled with something, or found a clash between
   your intentions and students' intentions, or found a gap between what you
   intended to do and what you actually did? Please describe.
5. What are your overall feelings about the experience of teaching CHE231F in
   1999? Do you feel that you developed at all in your approach to teaching?

Dr Barnes was nominated for a Distinguished Teachers' Award at UCT during 1999,
and for this she had to prepare a statement regarding her teaching philosophy,
values and objectives, and methods of achieving these. At the interview she
provided me with a copy of this statement by way of responding to item 1 above,
and we began the interview at item 2.

Both interviews were audiotaped and transcribed verbatim.
I also had an email interview with the senior tutor, Ms Fox, who was unable to attend personally at that time. I asked her to respond to the following questions.

1. What do you think were the lecturers trying to achieve in CHE231F?
2. To what extent do you think they were successful in achieving these aims?
3. What do you think were the problems causing a limitation in what could be achieved?
4. In what ways, if any, did you notice students developing over the duration of CHE231F?
5. What do you think students struggle most with in this course?
6. In what ways do you think this course could be improved?

5.6. Interviewee data

As discussed in Chapter 3, the primary method for addressing the research questions and uncovering students’ experience of CHE231F was a series of in-depth individual interviews with a small group of students, complemented by other data collected for this group. The collection of these data will be described in this section.

5.6.1. Selection of interviewees and practical arrangements

There were a number of considerations in selecting and recruiting interviewees. Firstly, I decided that approximately 10 to 15 students would be a broad and manageable sample, given the frequency with which I planned to conduct interviews. Secondly, I adopted a purposive sampling strategy, which was briefly mentioned under the naturalistic research paradigm (Lincoln & Guba, 1985) in Chapter 3. This strategy involves seeking maximum diversity in characteristics considered salient to the research question, rather than seeking a sample that is proportionally representative of the whole population, as is common in statistical research designs. The characteristics I considered in this regard were race, gender, and first year marks. It needs to be stressed that these were considered salient only because they would be likely to give the greatest variety of perspectives on CHE231F, and should not in any way be seen as a form of causal variables against
which hypotheses were to be tested. This position is consistent with the stance on research methodology which has been established in Chapter 3. The characteristics of race, gender and first year results were not used in the research questions or theoretical framework upon which the present study are based, and are therefore hardly referred to in the study beyond this selection process.

Using a purposive sampling strategy excluded the possibility of asking for volunteers, an option that I had already rejected on the grounds that few students were likely to come forward. I had tested out the strategy of approaching selected students directly during the pilot study, and had found students most amenable to such approaches. It was clear that maximum diversity would be achieved by making up a selection of individuals from the class to meet this criterion. However, I was also concerned about the awkwardness that being an interviewee could impose on an individual student, and so I decided to select four tutorial groups, each comprising three students. The fact that these were student-selected groups placed obvious limitations on the maximum diversity achievable, as students tended to group themselves according primarily to race and gender, and also to some extent according to previous academic performance. I had considered selecting all the interviewees from one tutorial venue, but rejected this option for a number of reasons, amongst which were the possibility that the few students not chosen would feel excluded, and the concentrated impact of my research activities on one part of the class. I decided to select at least one group from each of the three tutorial venues, and then explored possible combinations until I found the combination that ensured maximum diversity. I excluded as possibilities groups that contained repeat students. The sample finally selected is shown in Table 5.1, with descriptions of each student in terms of the characteristics upon which the sampling was based, and their assigned pseudonyms that are used in the study.
Table 5.1
Selection of interviewees according to purposive sampling technique

<table>
<thead>
<tr>
<th>Group number</th>
<th>Student</th>
<th>Race</th>
<th>Gender</th>
<th>First year marks&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Thabo</td>
<td>African</td>
<td>male</td>
<td>low</td>
</tr>
<tr>
<td></td>
<td>Jane</td>
<td>white</td>
<td>female</td>
<td>low</td>
</tr>
<tr>
<td></td>
<td>Geoff</td>
<td>coloured</td>
<td>male</td>
<td>low</td>
</tr>
<tr>
<td>2</td>
<td>Lindiwe</td>
<td>African</td>
<td>female</td>
<td>high</td>
</tr>
<tr>
<td></td>
<td>Thembi</td>
<td>African</td>
<td>female</td>
<td>low</td>
</tr>
<tr>
<td></td>
<td>Nomsa</td>
<td>African</td>
<td>female</td>
<td>high</td>
</tr>
<tr>
<td>3</td>
<td>John</td>
<td>white</td>
<td>male</td>
<td>mid-high</td>
</tr>
<tr>
<td></td>
<td>Andrew</td>
<td>coloured</td>
<td>male</td>
<td>low</td>
</tr>
<tr>
<td></td>
<td>Eddy</td>
<td>coloured</td>
<td>male</td>
<td>mid</td>
</tr>
<tr>
<td>4</td>
<td>Mike</td>
<td>white</td>
<td>male</td>
<td>mid</td>
</tr>
<tr>
<td></td>
<td>Maria</td>
<td>African</td>
<td>female</td>
<td>mid</td>
</tr>
<tr>
<td></td>
<td>Shakira</td>
<td>Indian</td>
<td>female</td>
<td>low</td>
</tr>
</tbody>
</table>

<sup>a</sup>high = in region of 70s and above, mid = in region of 60s, low = in region of 50s and fail

These four groups were approached after a lecture during the second week of term, and all agreed to be interviewed. I discussed with them what times would be most suitable and they suggested late morning and lunchtimes, and were happy with my offer to provide a light lunch (bread roll and cooldrink) for them. I agreed to approach them again with a set of possible times to make appointments.

It emerged at this stage that Jane had left the course during the first week in order to change to the Science programme, leaving group 1 with only two students. I considered approaching an individual student to fill the gap, but decided against this so as to keep with the original strategy of choosing interviewees in tutorial groups. The benefits of this strategy had been apparent in the ease with which students had agreed to become interviewees, knowing that the rest of their group had also been approached. I gave them the usual assurances of anonymity as agreed upon in my ethics application, described briefly what the interviews would entail, and handed out an explanatory statement describing the present study. As this discussion had been in a group context, I followed up in the first interview with laying out again the purposes of my study and the procedures to be followed, and
emphasised the voluntary nature of their participation and the option to leave at any stage.

Four interviews took place with each student during the first semester, and one or two in the second semester. In the usual procedure I put together a schedule with a set of possible 45 minute slots and approached interviewees either after a lecture or during a tutorial to choose a slot that suited them. I then gave them a ‘reminder card’ similar to that used when making a dental appointment, knowing that many students do not use diaries. Students seemed fairly amenable to this idea, and were generally good at remembering and turning up for their scheduled interview. On the few occasions where students missed an interview they usually came to me shortly afterwards to apologise and we made another scheduled time. Using the usual procedure to ensure ethical research practice students had been told that at any stage they were free to withdraw from the interview process. None of the interviewees elected this option at any stage, and they all took part till the end of the data collection process.

I had decided to term the interviews ‘conversations’ (Kvale, 1996) in order to emphasise the relaxed nature of what I was planning to do, and the joint social construction of the interview situation (Säljö, 1997). I used this terminology until approximately halfway in the course when I began to question the appropriateness of this term for a situation where I was the one who directed the proceedings. Kvale (1996) recognises this ‘asymmetry of power’ (p. 126) but does not find the term ‘conversation’ problematic. I however felt more comfortable changing to the conventional term ‘interview’ at this stage, which some of the interviewees had started using themselves, although even towards the end of the semester some interviewees still referred to the meetings as ‘conversations’.

The interviews took place around the table in my office in the Department of Chemical Engineering, and arrangements were made to ensure minimum interruptions. On average the interviews lasted 25 to 30 minutes. All interviews were audiotaped, and I later did verbatim transcription, usually fairly soon after the interview had taken place. A sample interview transcript is reproduced in Appendix C.
When I had decided to focus on race, gender and prior performance as variables for constructing the purposive sample, I was well aware that other variables would emerge in time that could have been used. Such variables did emerge; for example I became aware of the different experience of students who lived at home with their parents, compared to those who lived in university residence, or in private residences with other students. In that respect my sample had reasonable diversity. I also became aware early on of the different experience of students who had done vacation work at the end of first year with an industrial sponsor. Fortunately my sample turned out by chance to also be fairly diverse in that respect, although I had two interviewees with the same sponsor. In one aspect however this late emergence of variables proved to be slightly problematic. Attempting to achieve maximum diversity in race and gender had predisposed me towards tutorial groups that were highly diverse in this respect (and which was unusual in the class as a whole), for example, group 4. However, group 4 only had such a make-up owing to it being a collection of students who were newcomers to the class cohort. Mike had attended first year Chemical Engineering at another South Africa university, Shakira had transferred from a Science programme at UCT, and Maria had transferred from a Science programme at another university outside South Africa. For Mike this did not seem to make much difference to his CHE231F experience, but the idiosyncratic academic histories of the other two had a noticeable impact, as will become apparent in the analysis.

5.6.2. Interview protocols

The interview protocols were designed with the research questions in mind, and therefore in general were aimed at getting students to talk about their experience of the course as they went along. Questions were formulated around specific incidents that had happened in class, tasks that had been given, tests that they had done, and so on. The underlying intention was to get at their perceptions of the course context, their approach to learning, and their metacognitive processes, but questions were never phrased using such abstract terms, following Säljö’s (1997) critique discussed in section 3.4.1. I rather aimed at getting students to talk specifically about what they thought of what was happening in the course, and what they were
doing in response. It was therefore important to conduct each series of interviews within the same ‘window’ in the course, which I assumed to run mainly around when the tests took place. All interviews were conducted on the same side of key events, such as sitting a test, or the handing back of a marked test.

The interview protocols were formulated in response to what was happening in the course, and these were therefore only finalised shortly before each series of interviews began. The protocols were also slightly modified over the course of the series of interviews, removing questions that had not been successful, and adding new questions based on things that had occurred spontaneously in the early interviews. During each series of interviews I transcribed interviews as I went along, especially getting the first few interviews transcribed as soon as possible so as to be able to reflect on how the interview protocol and my interactions during the interview could be improved. I completed transcribing each series of interviews well before the start of the next series, so I was able to have a good grasp on what each interviewee had said in each interview, and where appropriate could also be able to follow up on specific issues.

The full interview protocols are reproduced in Appendix D, and a schedule of when the interviews took place is given in Appendix E. A brief summary of each interview protocol will be provided in what follows. In each of the first four interviews I posed ‘conceptual discussion questions’ to students. These will only be briefly mentioned in these summaries, and described in more detail in the next chapter.

**Interview 1**

At the start of the first interview I briefly recapitulated the purposes of my research and discussed ethical issues such as anonymity and stressed the interviewees’ freedom to withdraw from the interviews at any stage. I then began the taped interview with asking how things were going in general in CHE231F, and how this compared to their expectations, if they had any. In the next stage of the interview I brought up a number of different incidents from lectures and tutorials and asked them to talk about their response. These incidents included a lecture where Dr Stevens had stressed that they should not be writing down the details of the
problems, another lecture where he had said that anyone who understood the work could leave, and a lecture where he had got them to make their own list of steps for solving mass balances. I also brought up the first tutorial problem where the tutors had done a demonstration, and asked them what they had thought the purpose of the demonstration was. Then I asked students to indicate what, if anything, had made an impression on them in the lectures so far. Finally I asked them what they thought the purpose of doing mass balances was.

**Interview 2**

Once again I started the interview by asking students how things were going in CHE231F. All students responded by talking about the first test for which they had recently received their marked scripts. Following students’ spontaneous comments I followed up with specific questions on issues that had not yet been covered. These questions included how they had prepared for the test, how they had felt after the test, and after receiving their marks whether they felt they should have done anything differently. Many students also spontaneously mentioned how they were finding Dr Barnes’ lectures.

I then presented a series of recycle problems that had been done in lectures, and posed a number of conceptual questions around these. The questions will be described in greater detail in the next chapter. In these questions I decided it was of utmost importance that I did not adopt a teacher role and feel obliged to correct students where they were going wrong. In order to make this easier, especially given the tutor/ counsellor role that I was taking in the course, I explicitly explained to students at the start of these questions that because of my research purposes I would not necessarily correct any incorrect statements. Where students specifically asked me to answer a question however I did, as I felt this was only fair given the time they were committing to the interview. This situation seldom happened, and when it did it was usually only in response to my invitation for their questions at the end of each interview.

**Interview 3**

The general discussion on how things were going at the start of this interview tended to lead to a mention of the second test which students had recently written,
although they had not yet received their marked scripts. In letting students discuss this freely and dealing with outstanding issues I followed a similar procedure to that in the previous interview. In this general discussion students also tended to discuss the recent vacation week, and what sort of work they had done in that time. I then brought up one recent incident from class, in which students had been required to mark the work of one of their peers, and got them to talk about what they thought of this exercise. Following this I asked students to talk about the other subjects they were doing concurrently, both in terms of how the way they were taught differed or was similar to CHE231F, and also whether any of these subjects linked to the work being done in the latter course.

I then presented a set of photocopied sheets from recent lectures, each representing a different type of information that could be used in energy balances. These included a graph, a series of equations, and two different sets of tabulated data. The conceptual questions posed around these artefacts will be described in more detail in the next chapter.

**Interview 4**

Following my question on how things were going students tended to mention the results of the second test which they had recently received, and how this had influenced the way in which they were currently working. I had asked them to bring their journal tasks to this interview, and the next set of questions focused on their response to these, and involved a discussion of particular tasks. In this interview I also asked students to comment on a perception that I had heard in class that the pace of the CHE231F lectures was fast. I posed a brief conceptual question around the topic of energy balances with reaction, and then asked students to look back over the course so far, and to reflect on whether they had changed in any way in how they approached their studies. I also asked them what their plans were over the next few weeks of preparation for the examination.

**Interview 5**

This interview took place early in the second semester, after the June examination results were out and the rewrite examination had been announced. At the start of
this interview students needed very little prompting to discuss their experience of
the examination. I also asked them to reflect on the third class test.

I then had a number of issues to follow up from my preliminary analysis of the data
from the first four interviews. I asked particular students to clarify terminology that
they had used, including a number who had made repeated reference to ‘silly
mistakes’. I also used this interview as an opportunity to check the validity of my
preliminary conclusions regarding students’ approach to learning and
metacognitive development. As part of this discussion I tentatively offered these
conclusions, and asked students to comment on whether this seemed an accurate
picture or not. Although this strategy might seem to have invited acquiescence, the
extended nature of the discussion allowed me to identify instances where students
although initially agreeing when talking further about their development clearly
had a different view of the matter. The final set of questions described below
covered similar issues and offered a further opportunity to check that students were
giving their own opinions.

I then asked them the same question I had asked in the fourth interview, to consider
on reflection whether they had changed in how they approached their studies. I
also asked whether the experience of CHE231F was influencing the way they were
approaching the second semester chemical engineering courses. Finally I asked
them what sort of advice they would give to a new student starting CHE231F, and,
if they were the lecturer, what they would change, and what they would keep the
same in the way the course was run.

Five of the interviewees who had failed the course were preparing for the August
rewrite of the examination, and I discussed what they were doing in preparation. In
planning the fifth interview I felt a moral obligation to give any useful advice that I
could to students who were doing the rewrite examination. At the end of the
interview I therefore switched to a counsellor role and gave both examination
technique advice, as well as general advice following from my research regarding
the importance of understanding the key concepts.
Interview 6

This interview took place only with those students who had written the rewrite examination, and was brief and loosely structured around anything that they wanted to talk about. In general they reflected on their experience of this examination and talked about what they planned to do in future.

5.6.3. Other interviewee data

I obtained the interviewee's permission to make photocopies of their test scripts, and was also given their examination scripts at the end of the final assessment. I also kept copies of their journal tasks, and acquired print-outs of their full academic records.

5.6.4. Distinction between self-reflective and conceptual data

For the purposes of the analysis, the interviewee data were divided into self-reflective and conceptual data. Self-reflective data are journal and interviewee data in which students talked about what they are doing, why they are doing it and their general reflections on their progress in their studies. Conceptual data are those data in which students' conceptual understanding was explored. This distinction will be used in the chapters to come.

5.7. Data analysis

The analysis took place in four distinct stages, which are outlined below. In the description of these stages it will be seen that analysis methods of the grounded theory methodology (Strauss & Corbin, 1990) were used and adapted to suit the particular needs of the present study. Particular elements used included the intertwining of data collection and analysis, the constant comparative coding method and the focus on theory development. This section gives a broad picture of the analysis process, and further details will be given alongside the reporting of findings in the following chapters.
5.7.1. Stage 1: Analysis during data collection  
(February - May 1999)

The first stage of analysis took place at the same time as I was collecting data. An initial stage of ‘open coding’ took place during the transcription of interviews and the reading of journal submissions, when I started noting down common themes as well as things that puzzled me. These were then used in the formulation of subsequent interview protocols, where I was able to follow up some of these initial ideas.

5.7.2. Stage 2: Preliminary analysis  
(June 1999)

During the university vacation at the end of the first semester I had the opportunity to conduct a full analysis on the first four interviews and all the other data that had been collected during the semester. First of all I continued the process of open coding, and went through all the data noting down themes, relating these to the literature, and forming a preliminary set of categories describing students’ approaches to learning and metacognitive development during the course. I then took this framework and went through the data from each student, pulling out information as it fitted into the categories. This process also necessitated some reformulation and regrouping of certain categories. The end result of this analysis was an in-depth picture of each student, comprising a description of his or her approach to learning and metacognitive development. There were also a few gaps, particular points where I was lacking information, and these were earmarked for following up in the fifth interview.

5.7.3. Stage 3: Verification and modification of preliminary analysis  
(July 1999 - December 1999)

In this stage the new data from the fifth and sixth interviews were analysed alongside the categories and conclusions that had been developed in stage 2. This facilitated the adding of information in places where there had been gaps, the confirmation of most initial conclusions with some minor modifications, as well as general elaboration and strengthening of the research results.
5.7.4. Stage 4: Independent analysis of data  
(January – April 2000)

In this final stage of analysis I put the results from the previous stages to one side, and started again with the raw data, this time using the NUD*IST software package. In the earlier stages where the categories were constantly changing, I had found this software too restrictive, but now it offered an opportunity to rigorously run through the data and see whether the earlier analyses were supported. Using the categories of approach to learning that had been formulated in the earlier analysis, I went through all the data, assigning text to various categories, and firming up the theoretical properties of each category. Following this procedure, I then followed an ‘axial coding’ routine where the data in each category was assessed against the properties of that category. This allowed a double check on both the validity of the categories and the findings regarding each student. At this stage, following the disastrous course results, the research questions had been modified to look at why students’ metacognitive development had in so many instances been limited, and I undertook further analyses of students’ perceptions to attempt to answer this question. This involved analysing the data for dominant perceptions, drawing in the theoretical framing of ‘perception’ as outlined in Chapter 2. This analysis, combined with the earlier findings on students’ approaches to learning and metacognitive development, allowed for the formulation of theory explaining the relationships between these constructs, and delineating the ways these relationships operated in the 1999 CHE231F context.

5.8. Conclusion

This chapter has provided a detailed description of the methods of data collection and analysis used in the present study. The major data derived from a series of interviews held over the duration of the course with eleven interviewees. This was supplemented by other interviewee data, as well as broader course level data. The procedures by which all these data were gathered and analysed have been described in detail in this chapter. The naturalistic research methodology used here requires a rigorous examination and documentation of the ‘human instrument’ used...
in data collection, and this chapter has also provided a discussion of the multiple positions that I took up within the CHE231F course in 1999.

The material given here provides essential background against which the research findings to be presented in the following chapters can be interpreted, and also allows judgements to be made as to their trustworthiness.
Chapter 6
Introduction to the data

6.1. Introduction

This chapter provides a preliminary exploration of the data from a number of different perspectives. These summaries and analyses serve as important background to the major theoretical analyses of Chapters 7 and 8. Although the material in this chapter is not, in itself, directly focused on the central purposes of this study, it provides significant context upon which the central focus of the study depends.

Firstly in this chapter, I present summaries of the experience of each of the interviewees and also include background information relevant to this context. This serves the purpose of familiarising the reader with the individuals on which this study is centred. This is followed by descriptions of the students’ different modes of engagement with the interview situation, which is important contextual material for the interpretation of the interview data. The next section in this chapter deals with ‘commonsense’ views on student learning, and whether these are helpful in explaining the range of student achievement in the course. This points to the need for new perspectives on student experience, and provides a justification for the research focus of this study. Finally in this chapter, a general assessment of the interviewees’ conceptual understanding is conducted, and these results provide further context and motivation for the analyses in Chapters 7 and 8.

6.2. Interviewees’ experiences of the course

This section introduces the reader to the interviewees (hereafter termed ‘the students’) with a short description of each student’s ‘story’. These ‘stories’ have been compiled from background data, students’ comments on how things were going, as well as key concerns that were raised spontaneously in interviews and journals.
In the previous chapter the process of interviewee selection was described. Interviewees were chosen to give maximum diversity in terms of race, gender and first year marks. This information was summarised in Table 5.1. Instead of selecting individuals, four different tutorial groups had been approached in order to reduce any potential feelings of awkwardness about participating in the study. Further to this initial process the study did not have a specific focus on students' interactions in these groups. In this chapter the students are therefore presented as individuals, although where appropriate reference is made to their experience of the tutorial group.

In these summaries some background information is given about each student, including the nature of the school they attended. A brief explanatory note about the different schools in South Africa is necessary for interpretation of this information. Under the apartheid system all government schools were designated for pupils of particular race groups (white, coloured, Indian and African), and only private schools (usually charging high fees) were allowed to admit students of any race. Private schools, many established initially as Anglican church schools, generally offered a high standard of education. Of the government schools, white schools tended to be the most privileged in terms of facilities and teachers, and African schools the least privileged, with coloured and Indian schools somewhere in between. Within each group there was also a range of schools in terms of quality of schooling. With the political changes in South Africa in the early 1990s this system was dismantled although schools tended to continue to reflect their former level of privilege. Students in this sample who attended South African government schools had generally experienced these post-apartheid, technically but not practically equal, schools in the latter parts of their schooling. Most government schools in South Africa are co-educational, and as this arrangement applies to all government schools attended by the interviewees it is not specifically stated in the summaries.

Table 6.1 at the end of the present section on page 130 provides a summary of each individual's test and examination marks and may be useful for reference in the descriptions that follow.
6.2.1. Thabo

Thabo had attended a private co-educational school in Cape Town together with Geoff, and the two were still good friends. Thabo lived in a student residence and received sponsorship from a research organisation. He was a highly extroverted and sociable student who was easily noticed and well known in the class. His mantra, frequently repeated in interviews, seemed to be ‘no stress’. He liked to give the impression of not doing too much work, of being very laid back, although in reality it seemed that he was fairly conscientious. He certainly attended virtually all lectures, worked hard in the tutorials, and said that he read over his lecture notes daily.

At the time of the first interview Thabo said that so far the course was easy. Other students had warned him about CHE231F, but he had learnt not to take these sorts of warnings too seriously. He said that he did not work too hard for the first test, and when he scored 40%, he ascribed this to stupid mistakes, and asserted that he understood the work. After he achieved 25% in the second test he said that ‘the finger is edging towards the panic button’, writing in his journal that he had not worked hard enough for this test. Soon afterwards though he started ‘working like a madman’, mainly on assignments on other subjects, but also on developing his approach to material balances. He was not looking forward to the unlimited time of the third test, and when this came around he found it ‘mentally draining’, as he expected, although he managed to achieve 56%. By this stage of the course he was clearly ‘stressing’, and although he asserted the value of a support system he said that he had isolated himself somewhat and was generally moody.

He worked much harder for the examination than he had done during the semester, and when he scored a final course mark of 50% he indicated that he was pleased to have passed. Like many students he struggled with the length and format of the last question. His final philosophy on CHE231F was that it was just a question of ‘pass and move along’, although he did recognise the importance of what he had learnt in CHE231F for application in his career one day. He had really enjoyed the vacation work offered by his sponsor, and made fairly frequent reference to becoming an engineer.
6.2.2. Geoff

As indicated above, Geoff had attended a private co-educational school in Cape Town. He lived at home with his parents and received sponsorship for his studies from an educational fund but was considering applying for an industrial bursary. At the start of the year he was feeling positive and confident about the course, commenting that ‘maybe I’m beginning to think like an engineer’. He liked the journal task which had required him to think about his future career, and often talked about this issue.

Geoff was a genial and sensitive student, and was a very involved member of the class. He was outspoken in lectures, often asking the lecturer to clarify or go over a point, and commented that he ‘always felt like [he] was part of the discussion’. He also interacted with a wide range of students, and had fairly close relationships with a number of them.

Geoff recognised that he tended to get adversely affected by stress, both in and out of the test situation, and was feeling at the start of the course that he had this under control. He found Dr Stevens’ classes very relaxed, was keeping up with his lectures every day, and liked the structure of the CHE231F course. He was pleased to achieve 60% for the first test, as he had worked consistently and had not even felt the need to cram on the night before. Geoff struggled to adjust to Dr Barnes’ lectures, finding that he needed to ‘unlearn everything I’ve learnt’ in order to learn how to use input-output tables. He also found these lectures not as relaxed, and he struggled to keep up with the pace. After the second test he said he felt that: ‘It’s a disaster!’. He knew that he had failed the test even before the marks were out, as he had panicked, left out two questions and made other errors which he termed ‘stupid conceptual errors’. When the test scripts were returned, and he achieved 37%, he was partly surprised to have got some things right. But he was starting to feel tired all the time with the load of assignments. The vacation week he said was a ‘joke’, as he had worked harder than he usually did during the semester. He was not even considering doing the homework tasks that were given in CHE231F as he had so much other work to do. He became obsessed with time management, something he had been concerned about since the start of the year. At this stage Geoff made the
striking comment: ‘To stop and think... at the moment I don’t have time to do that’. He was worrying about failing the course, and was questioning whether he deserved to be in chemical engineering.

During the third test he did manage to achieve 52%. However, the June examination did not go well, and he got very confused while writing it. Later when he went over the paper he realised that he had some fundamental misconceptions. In studying for the August examination Geoff had a complete rethink about what to do, and started tackling his understanding head-on. He regretted having focused on trying to do lots of problems, as he had been advised by senior students, and started rather doing fewer problems but trying to understand what he was doing. Unfortunately he found the August examination even more difficult than the June one. He did not feel confident on energy balances, and also struggled with what he termed ‘first question syndrome’ where he panicked on the first question. Consequently he did not manage to improve his final course mark of 45%, and continued to reconsider his career choice.

6.2.3. Lindiwe

Lindiwe came from a neighbouring country to South Africa, which like South Africa also offers English medium education. She had completed A-level examinations there, the usual qualification in that country for students intending to study at university, some of whom go overseas. The A-level examination is approximately equivalent to a first year level at a South African university. She had received funding from her country’s government to study chemical engineering, a course she had initially chosen by process of elimination, but was now starting to find interesting. Although her first year UCT results were excellent, she did not feel very confident in her abilities. Like many A-level graduates, she had covered much of the science content before, but was particularly surprised to have done well in CHE104W, a course she had found very challenging. She recognised that she needed to improve her confidence levels, and was determined to draw motivation from her first year experience. In class she came across as quiet and withdrawn, even to the point of often seeming to be in a bad mood. Part of her anxieties did seem to stem from worrying about an illness in her family, although she had
mentioned this only once in a journal entry. She was living in a student residence, in the same ‘flat’ (subsection of the residence) as Thembi. Together with Nomsa, the three students in this tutorial group had been working together since first year, both in and out of class.

Lindiwe had been apprehensive about CHE231F after hearing about the course from senior students. And indeed, from the start of the course, she found the going tough, struggling to solve the tutorial problems, although she worked diligently to try to resolve any confusion that had occurred. In the first test she scored 48%, and was cross to discover that a solution that she had erased had in fact been correct. After the second test, where she scored 40%, she felt that she did not understand anything. She said that this was the first time where she had to start seriously worrying about failing a course. This experience however spurred her to action, and she started working even harder than she had already been doing. She said, ‘Test 2, surprisingly, taught me that 231 is passable. If I got 40% then surely I can only improve and pass the exam’. She spent a lot of time outside class working through problems on her own and was also trying to be more positive in her attitude, ‘to lose the belief that mass balancing is an impossible thing to do’.

The workload outside CHE231F had also increased considerably and she was feeling constantly tired. She said that there was ‘no life whatsoever outside class’. Time management for her meant saying ‘no’ to going out with friends, and not even watching television. However, she was feeling positive about energy balances, and finding this section of the work easier to grasp. She was also working through textbook problems on her own and pleased to find that she was getting some of them right. The third test she found much more relaxed due to the unlimited time, and was encouraged by the 59% she achieved. In preparing for the examination she did numerous problems from past papers. During the examination she struggled with the long fourth question, and had sleepless nights during the vacation thinking that she had failed. When she heard that she had achieved a final course mark of 54%, she ascribed this to the marks she achieved in the first three questions of the paper. Now she felt that she had really accomplished something, and said that she had been ‘stretched’ by the experience of CHE231F.
6.2.4. Thembi

Thembi had attended a private girls’ school in another major South African city, and had come to UCT on a mining company bursary. As stated earlier, she was living in the same student residence as Lindiwe. Her first year she described as ‘terrible’, as she was not enjoying her chosen course of study, and ended up failing one of the courses, Physics I. However, she really enjoyed the chemical engineering vacation work that she did at the end of first year, and this led her to decide to continue with the course. She was determined to have a more positive attitude to her studies, was trying to improve her note-taking skills in lectures, and was conscientiously tackling extra work outside class. During lectures the group of Thembi, Lindiwe and Nomsa often sat together within a larger group of students, and in this group Thembi was confident and outspoken.

Thembi achieved 60% for the first test and felt ‘pretty pleased’ about this, although she felt that she could have done better. She had been nervous and had consequently made silly mistakes, getting confused after erasing work she had done in pencil. ‘Time is always an issue with me’, she said, having struggled to finish tests ever since high school. She felt the time pressure even more in the second test than the first, and did not get to attempt all the questions. The 33% she scored was even worse than she expected. Now she said, ‘I’ve pretty much made peace with the fact that I will never complete a test’. At this stage of the course she started to feel her initial positive feelings subside. She had struggled to adjust to Dr Barnes’ new methods and found herself getting lost in the lectures. The workload from other subjects had increased tremendously and she was working many late nights just to complete assignments. During the vacation week she did not do as much work as she had intended. She was feeling apprehensive about the third test, and felt that the unlimited time might not necessarily be beneficial.

When she wrote the third test she said that she had not felt too comfortable about energy balances, and she scored 46%. This experience however did help her to identify and sort out some conceptual problems. When the examination came around she was still incredibly nervous, struggled again with the time pressure, and only managed to attempt a bit more than half of the paper, scoring a final course
mark of 45%. She also found the questions unfamiliar, saying that she ‘can pretty much do anything that’s normal’. Returning at the start of the second semester, she got together with Nomsa to study for the rewrite examination. Now that there was more time available she found herself being able to work on her conceptual understanding and develop her own methods for solving problems.

She did not manage to be any less nervous for the rewrite examination than before, to the extent of leaving her calculator at home in the panic, and having to borrow one at the last minute. Once again she found the paper too long, and this time instead of too few large questions, she felt that there were too many small questions. She did not manage to improve her mark and the experience left her tremendously despondent, especially around her inability to cope with time pressure and nervousness during examinations. She said, ‘I’ve tried different things … but it just never seems to work. I’ve no idea what to do any more’.

6.2.5. Nomsa

Nomsa had attended boarding school at one of the relatively better resourced government schools formerly designated for black students. She had received funding to study chemical engineering from a large petrochemical company, and they had encouraged her to enter the five year ASPECT programme because of her school background, even though she easily met the regular chemical engineering entrance requirements. Upon starting first year the ASPECT staff suggested she attempt the full first year programme, because of her excellent school results, and she subsequently achieved a good set of first year marks, scoring a first class pass in Mathematics I. She was living in student residence, and although softly spoken she engaged readily and comfortably with a wide range of students in the class.

In her study habits Nomsa came across as the ‘ideal student’, working extremely hard, consulting with peers, asking for advice, and generally doing everything that would be advised in a study skills course. She had even revised her first year notes in the week before the course started. From the start of the year she was concerned that she was not managing her time well enough, and tried to fit even more into the day than she was already doing. She was struggling to understand the problems
that were presented in lectures, and had plans to do more problems and to read the
textbook. During tutorials she compared herself to her peers and worried that she
was not thinking fast enough and questioned whether she was 'fit to become an
engineer'. At the end of most interviews when I gave her an opportunity to pose a
question she asked me for advice on what was the best way to understand the
current CHE231F topic.

Nomsa scored 47% in the first test and felt very bad about this, having not
understood some of the questions, and having also lost marks through careless
mistakes. Long before the journal tasks were due she had worked through the fifth
task in order to analyse what had gone wrong in this test. During the vacation week
she had tried to work hard, but found that she was very tired, and although she
worked throughout the week she did not achieve as much as planned. After writing
the second test she felt that this test had gone better, that she had been confident,
and had understood the work. She was disappointed then to discover that she had
only scored 40% on this test. This mark she ascribed to silly mistakes and poor time
management. She was somewhat happy with the 51% that she scored for the third
test as she had passed CHE231F for the first time, although she felt with the time
available she should have achieved better. It seemed to her that she did not
understand her work as well as she had thought. Once again she started worrying
about whether she was fit to be an engineer.

In the June examination she left out most of the long fourth question, and felt that
this was due to not practising sufficiently with time pressure. She also recognised
that her practice of writing everything in pencil first was very time consuming. She
worked hard in preparing for the rewrite examination, and was one of the few
students in the class who managed to improve their mark on the rewrite, from 29%
to 45%, but this was still not enough to pass the course as she achieved a final course
mark of 47%. She had been really depressed to receive this news, but almost
immediately had decided to pull herself together and move on to the next challenge.
6.2.6. John

John had attended a co-educational private school in Cape Town, and his first year marks were reasonably good. The first comment he made in the interview was to talk about the possibility of changing the timetable so that free time would be consolidated in a block on Monday mornings. This introduced an ongoing concern for John: how to minimise the hours spent on campus and on university work so that he could have more time for socialising with his friends. John’s life was not centred on the university; he lived at home, and had an active social life off campus, with friends who did not necessarily study the same course, or even study at UCT. While many other students tended to burn themselves out during the vacation week, John said he had a ‘chilled holiday… very relaxed’. To earn extra money (his parents paid for his studies) he tutored school students in Mathematics, saying that not only did this keep his weekends free (compared to other job options) but that he actually enjoyed it. This description of a substantial off-campus life is not to suggest that John was unenthusiastic about his studies: on the contrary, he had chosen this course primarily because he enjoyed it, and vocational concerns were simply not very prominent at this stage. He thought he might like to do research one day, something ‘groundbreaking’ and hopefully involving travel. He particularly enjoyed courses which involved problem-solving and logical thinking, and disliked having to memorise ‘theory’.

John displayed a high degree of independence in his studies, both from his peers and from lecturers. In tutorials he tended to work on his own, occasionally consulting Eddy, but more often explaining to others what he had done. He was quite friendly with Andrew and the two of them often sat next to each other in class, but he did not seem to make much use of peers in his work outside class. He was unconcerned about the change in lecturing styles from Dr Stevens to Dr Barnes, reckoning that all lecturers are different. But he was positive about the CHE231F lectures, describing it as a ‘comfortable class’ where people were free to ask questions and were given good explanations. He frequently asked questions and volunteered responses in class.
He said he was being ‘good’ this year compared to first year, where he had missed a large proportion of classes, and had a lot of cramming to do for the final examinations. However, he still missed the odd lecture here and there. On the day that was initially scheduled for the second interview he was not present, and the next day he explained that he had needed to ‘take a day off’ as a ‘reward’ after a busy time submitting assignments and writing tests. He had planned to study the night before for the first test, but something else ‘came up’ and so he ended up just looking over his work briefly. However, this did not concern him overly, as he reckoned it was not a ‘study test’. He had found the main test questions very easy and was concerned that he had misinterpreted them, however, after achieving 88% in this test he felt that his own methods of solving the problems had been justified. For the second test he also did not do too much special preparation, having a quick look through the workbook, and working through one problem. This test he also found quite easy, but when interviewed before the marks were out he was a bit concerned that he might not have so well as in the first test, although he did not think he had failed. He was quite shocked on getting the test back and finding that he had only achieved 43%. This result made him think that he needed to put a bit more work into the course, and he started doing more work outside class. His efforts seemed to be justified when he achieved 79% in the third test, and he commented later that this had restored his confidence a bit. He was aiming for a first class pass (75%) in the examination, but he got stuck in the long fourth question and found that he had to ‘fight to come back’ in order to ‘maximise his marks’. He was slightly disappointed with missing his goal, but also happy with the 71% he had achieved as a final course mark as he had worried that he might have failed. When the opportunity came up to improve his mark through the rewrite examination he seized it and managed to pull his final mark up to 75%.

6.2.7. Andrew

Andrew had attended an average formerly white government school in Cape Town, and lived at home. He did not voice any particular motivation for studying chemical engineering although he did say that he was not sure what else he would do. He had sent off one or two bursary applications but did not know what had happened
Andrew was a laidback and relaxed student. By his own admission he had scraped through his first year courses, passing Chemistry I only after a supplementary examination. In a way he was pleased with this achievement, but expected that he was going to have to do more work this year. In his first journal entry he wrote that ‘Commitment and motivation have always been one of my weaknesses – I think the root of my problem is actually getting anything started’. Right from start of the course he was regularly absent from lectures, and did not seem to be catching up. When I asked about a particular lecture he said he had missed it ‘but I got the paper’, and then in response to a question based on another lecture he could not remember if he had attended it or not. In the first journal task he had indicated that his work strategy would involve trying to leave the weekends work-free, and after the vacation he said that he had not worked too hard as he did not want to ‘stress out’.

Andrew failed the first test with 30% and said afterwards that he felt bad about this. He reckoned that he had not studied enough, and that he ‘wrote nonsense’. He also struggled with time and was not able to understand some of the questions. At the time of the interview he was still puzzled over how he had lost marks in some of the questions. He achieved 24% in the second test, and yet again he felt that he should have studied more, and that he had struggled with time pressure and with understanding the questions. At this stage Andrew made drastic changes to his work efforts: his lecture attendance improved noticeably, he was already studying for the third test a week before it took place, and he submitted an excellent set of journal tasks. These efforts seemed to pay off in that he achieved 52% in the third test, and was visibly pleased with himself. He commented that now that he was working ‘I feel actually quite good with myself, it’s quite nice’.

He achieved 44% in the June examination and was cross that he had not had sufficient time to finish the paper. Afterwards he had tried the questions again and said that they were not difficult, but that the long question had just caught him out.
In preparation for the rewrite he focused on improving his time management. After the rewrite examination, he was particularly unhappy, as he had misinterpreted a question that he thought was ambiguous, had wasted a lot of time on it, and subsequently not managed to improve his final course mark from the 43% he had originally obtained. He felt that maybe he could have passed this examination, and commented that ‘it’s unfair’. When I asked what he planned to do differently when repeating this course he said ‘nothing’, just more practice. At this stage he also queried whether he should be doing chemical engineering, seeing that he had failed this course.

6.2.8. Eddy

Eddy came from another South African city, and had attended one of the top coloured government schools in his area. He had received funding from a national research organisation, and hoped eventually to follow a research career. After a year at UCT he had a very good set of first year results under his belt. He lived in a student residence, and in his quiet unassuming way seemed to have a lot of interaction with other chemical engineering students there, both peers and seniors. He had a close friend whom he sat next to in all lectures, and only met Andrew and John when they formed the tutorial group.

From the start of the course, Eddy saw CHE231F as a course where you needed to get involved in class, and work on your own out of class, both of which he was clearly managing to do. He felt that he was more of a ‘guy to sit down and work on something than go into the theory’ and so he preferred doing examples to reading the textbook. From the start of the course he was feeling challenged, initially by the standard of the tutorials, and then by the tests. All along he described as ‘stressful’ the load of assignments and other work that he was experiencing. In the first test he scored what he judged a ‘lucky’ 50%, and although he was happy to have passed, he felt this was not up to his standards. He had found himself pressured by time in the test, and felt that ‘his brain had switched off’. He decided to work harder for the second test, which he seemed to do, although once again he felt it was ‘the time thing’ that had caused him to score only 27%. Now he started to worry that he might fail the course, and described this as a real ‘wake up call’. During the fourth
interview he said he was ‘a changed person’ and working much harder. He said that he had been lazy in not really using the textbook, and now he was actually using it as a ‘learning guide’, not just a source of problems. These efforts seemed to be rewarded when he achieved 80% in the third test.

At the time of writing the examination he said he had felt confident, especially that he had done so much more work than for the tests, and felt that his time management was more under control. He whizzed through the first three questions, and then got stuck on the last question. He had expected a better final course mark than the 60% which he finally achieved, as he felt that this did not really reflect his understanding.

6.2.9. Mike

Mike had attended school at a boys’ private boarding school and had done his first year of chemical engineering studies at another university in a major South African city. At the beginning of his second year he transferred to UCT. He was pleased to be in Cape Town and was sharing a flat with some other (non chemical engineering) students. A confident and easygoing student, he seemed to quickly fit into the social scene. In the CHE231F class he made friends with a group of mainly white students from a similar background, and although he interacted well with Shakira in their tutorial group, they did not seem to have any contact outside of the tutorial afternoons. He was receiving sponsorship for his studies from a private trust, and was reluctant to get an industrial bursary as he wanted to pick the best job (assessed by him as best paying) when he graduated, and not necessarily to have to work in a ‘dirty plant’.

Although the methods he had learnt for solving mass balances differed slightly to those taught at UCT, Mike was not too concerned. He continued to use these methods where he could, and gradually picked up the new ones. Early on in the semester he missed a week’s lectures owing to illness, but was not bothered as he frequently missed lectures for other reasons, such as waking up late in the morning. What he did try to do was never to miss two lectures in a row. When he was in
lectures he said he often sat back and relaxed, even though he recognised that doing
the problems given in class might be beneficial.

While waiting to do the first test, for which he had done minimal preparation, Mike
panicked when he saw how much work other students had done on their ‘crib
sheets’. During the test he ended up having what he described as a temporary
‘blackout’, where he could not remember what to do, but he managed to recover
from this in the last half hour. He ended up scoring 72%, and although he was
obviously pleased with this excellent result, he felt that he should have worked
harder in order to avoid the panic. Despite these good intentions, he did not
manage to work any harder in preparation for the second test. He really struggled
with this test, felt that he ‘couldn’t seem to do it’, ‘couldn’t focus’, and felt nervous
and time pressured. He knew immediately that he had failed, and indeed he had,
scoring only 28%. Nonetheless, he still said he was not too worried about CHE231F,
as he thought he had a ‘feeling’ for the subject, and he was concentrating on the
assignments in other subjects. Because of this workload he said that he did not have
time to do work on CHE231F, although he admitted that ‘I suppose to have time
you have to make time’. He just glanced through his work for the third test, and
scored 56%.

Mike did not work particularly hard for the examination, but felt that what
mattered was that he had understood the work. Once again he had the experience
of ‘blacking out’ during the examination, but managed to remember what to do
towards the end. He scored a final mark of 52% for the course and said that he was
happy to have scraped through. He admitted that he had ‘cut it close’ in this
semester, and planned to work harder in the second semester courses.

6.2.10. Maria

Maria came originally from a non-Anglophone African country, but had done her
schooling and the first two years of a BSc programme in English in a neighbouring
country to South Africa. At the start of 1999 she had transferred to UCT to do
chemical engineering, and was given permission to enrol in CHE231F even though
she had missed the special re-run of CHE104W provided for transferees before the
semester started. The specific content from that course was recapitulated in the first two weeks of CHE231F, and although initially she felt gaps in her knowledge, she seemed to be managing adequately to make up the backlog in content. What seemed to be of more concern to her was fitting in with the class. She repeatedly expressed the need to interact with other students, but really struggled to do so, sadly not an uncommon experience for non-South African students. The friends that she did make at UCT were other foreign students, and she admitted in the second interview that she had never even talked to the student sitting next to her in CHE231F lectures. During tutorials she tended to work completely on her own, and to ask the tutors directly for help.

She found engineering studies very different to the Science courses she had previously done. Initially she said that she had expected CHE231F to be more technical and was pleasantly surprised that it was quite theoretical, but then later on she commented that one was constantly being required to make links to the real world. She spoke of having to ‘think about the words in the practical sense’. She also talked about the need to get involved in the work both in and out of class. Despite these realisations though, she seemed to approach the learning of CHE231F in ways similar to her past experience, learning definitions and theory, rather than actually working through problems on her own. Right towards the end of the course she recognised that this had been a problem, and also started to come to grips with the huge workload. In her past experience she had been able to learn for a test by looking at her notes the night before, and this approach did not serve her well in CHE231F.

Maria failed every class test, achieving 10%, 16% and 29% respectively. However, she did feel that the marginal improvement represented here reflected her progress to some extent, noting that she had worked much harder in preparation for each successive test. Her class mark was not sufficient for her to meet the course requirements for gaining admission to the examination. She was understandably upset at this situation, and pleaded strongly with the course coordinator for a chance to write the examination, which was not granted.
Maria's academic experiences prior to commencing CHE231F were clearly very unusual. At various stages of the analysis I had considered dropping Maria's data from the sample, due to the idiosyncratic nature of her experience, particularly in that she had missed out on the CHE104W course, which must have contributed to her lack of success. However, her comments were often perceptive and revealing, and her comparisons with her past Science experience were useful. For these reasons it was decided to retain these data, although always bearing in mind that hers was an extremely atypical CHE231F experience.

6.2.11. Shakira

Shakira came from a small South African city and had attended school at a formerly Indian government school. She had spent two years on the first year of a Science degree before transferring to chemical engineering. This move followed encouragement from her industrial sponsors, who were looking to train more engineers. She was positive about this change, feeling that engineering was far more interesting work than science. In 1998 she had done the CHE104W course while continuing to do other second and third year courses in the Science programme. She had been staying in student residence until 1999, when she had moved into a flat with other students.

She was quite apprehensive about CHE231F, having heard the CPA horror stories from older students. However, she was feeling positive and motivated at the start of the course, having done interesting vacation work with her industrial sponsors. As part of her project she had been required to do a mass balance, and so the course had a strong sense of relevancy for her. Shakira was a bubbly and positive student, and was enthusiastic about all aspects of the course. She was liked working with Mike in their tutorial group, and she also interacted with many different students in the class. She liked Dr Barnes' lectures, particularly that they were free to ask questions and time was taken to give explanations, even though she admitted that she did not have time to think in class, and tended to copy down work with the intention of reading it at a later stage.
Shortly before the first test, she lost some close friends in a car accident, and the resultant trauma meant that she did not have enough time to prepare for the first test as she had planned. She was however at pains to stress that she was not trying to excuse her poor performance of 30%. She did a lot more work in preparation for the second test, and felt good while writing it. Immediately after the test however, she began to worry that she might have failed, and felt demotivated especially after having worked so hard. When the results came out, and she achieved 41%, she was pleased as this was better than she expected, and she was particularly proud at having achieved full marks in one question. In the third test, even though it was ‘untimed’ she did not feel that there was enough time to think through the questions. She was disappointed again with her failure in this test (36%), but still felt that it did not reflect her understanding.

The June examination she described as ‘the worst thing in my whole life!’ She was partially consoled by finding out that others had also found it difficult. She said that ‘Nothing that I knew actually came out’. She knew she had failed, and during the vacation she broke this news to her parents and had long discussions about her career future. She was therefore overjoyed to find out that a rewrite was on offer: this was ‘the best thing ever!’ She had not had much time to study for the first examination, having not even looked through her tutorials, and in the preparation for the rewrite she started actually discovering how much she did not understand. When she opened the rewrite paper she was delighted to recognise the first question as being similar to a past tutorial. She was strict with her time, and felt pretty good about most questions. In fact she had not improved at all on the June mark, and her final course score was 22%. At the end of the course she felt that something she should have done differently was to actually work through problems on her own instead of just looking at the solutions. She had only started doing this in preparation for the rewrite and it had shown her just how much she did not know.

6.2.12. Summary of interviewee marks in CHE231F

The following table provides a summary of the marks each interviewee obtained in the three class tests and the examinations. The average of the three test marks plus the addition of the journal bonus marks was used to calculate the class mark. The
final mark is a combination of the class mark and the best of the two examination marks, in the ratio 30:70.

Table 6.1
Marks obtained by interviewees in CHE231F assessments

<table>
<thead>
<tr>
<th>Student</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>June Exam</th>
<th>August Exam</th>
<th>Final mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thabo</td>
<td>40</td>
<td>25</td>
<td>56</td>
<td>52</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>Geoff</td>
<td>60</td>
<td>37</td>
<td>52</td>
<td>40</td>
<td>27</td>
<td>45</td>
</tr>
<tr>
<td>Lindiwe</td>
<td>48</td>
<td>40</td>
<td>59</td>
<td>55</td>
<td>-</td>
<td>54</td>
</tr>
<tr>
<td>Thembi</td>
<td>60</td>
<td>33</td>
<td>46</td>
<td>42</td>
<td>20</td>
<td>45</td>
</tr>
<tr>
<td>Nomsa</td>
<td>47</td>
<td>40</td>
<td>51</td>
<td>29</td>
<td>45</td>
<td>47</td>
</tr>
<tr>
<td>John</td>
<td>88</td>
<td>43</td>
<td>79</td>
<td>70</td>
<td>76</td>
<td>75</td>
</tr>
<tr>
<td>Andrew</td>
<td>30</td>
<td>24</td>
<td>52</td>
<td>44</td>
<td>25</td>
<td>43</td>
</tr>
<tr>
<td>Eddy</td>
<td>50</td>
<td>27</td>
<td>80</td>
<td>61</td>
<td>-</td>
<td>60</td>
</tr>
<tr>
<td>Mike</td>
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<td>28</td>
<td>56</td>
<td>51</td>
<td>-</td>
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</tr>
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<td>16</td>
<td>29</td>
<td>-</td>
<td>-</td>
<td>DPR</td>
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<tr>
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<td>41</td>
<td>36</td>
<td>13</td>
<td>12</td>
<td>22</td>
</tr>
</tbody>
</table>

Note. ‘DPR’ indicates a situation where the class mark was not sufficiently high (30%) to gain admission to the examination.

6.3. The social situation of the interviews

In section 3.4.1 it was asserted that any interpretation of interview data needs to take into account the social situation in which these data were produced (Fleming, 1986; Säljö, 1997). In order to facilitate this kind of interpretation in the reading of the analyses in the next two chapters, this section provides a brief description of the nature of the interactions between the interviewees and myself.

All interviews were held around a table in my office in the Department of Chemical Engineering, with a ‘meeting in progress’ sign on the door and the phone redirected to reception, in order to minimise interruptions. Most interviews took place either in the late morning or during the lunch break, and, as promised, I provided each interviewee with some light refreshment. On almost all occasions they chose to take this with them afterwards, rather than eat during the interview, although I encouraged them to do so if they wished.
In their body language and degree of ‘chattiness’ the interviewees showed differing degrees of relaxedness with the situation. This also changed for many as the interviews progressed and they appeared to become more familiar with the context. In reflecting on these issues it appeared that gender had a significant influence on students’ interactions with me. With significant exceptions, on the whole the male students seemed generally more visibly confident and relaxed in the social situation, and less intimidated by my relative seniority. The female students in general tended to appear less secure and more aware of me as an authority figure, yet this was often accompanied by a greater degree of talking about their problems.

John and Mike displayed a high degree of confidence from the start, evidenced by body language such as sitting back in the chair and sometimes putting a knee on the table, and electing to drink the cool drink during the interview. Both of them appeared to relate to me as if I was part of their social circle, and did not seem in any way intimidated by any potential power relationships. Mike even teased me at one stage that I did not know much about chemical engineering as I was only a chemist. Thabo and Andrew were also relaxed from the start in the interview environment, although (compared to John and Mike), seemed to relate to me more as a teacher than as a peer. Eddy and Geoff also seemed comfortable in the interview situation from the start, but differed markedly from the other males in that they seemed more willing to ‘let down their guard’, talking easily about personal things and admitting to problems.

Shakira seemed visibly enthusiastic about the interview situation from the start, and launched easily into animated discussions of how she was feeling. Thembi came across initially as highly defensive and almost suspicious of the interview, but gradually over the semester seemed to become more relaxed and willing to talk about problems. Although Nomza was very softly spoken, she seemed quietly confident in the interview situation, and very eager to gain maximum benefit from the interaction. She appeared to view me as a counsellor or tutor, and took frequent opportunities to ask me for study advice. Maria was least fluent in spoken English of all the interviewees, but this did not seem to affect her confidence about the interview situation. She was forthcoming and engaging, even when she was
struggling to express herself. Lindiwe came across as the most withdrawn and shy of all the interviewees, almost seeming on occasions to be in a bad mood. She often tended to very short answers and seldom gave extended responses without prompting. From observing her in the class and tutorial situations it seemed that this was not specifically due to the interview situation. In the first journal task she indicated that she was trying to be more outgoing and confident in public situations.

6.4. An interrogation of ‘commonsense’ study advice

The ‘stories’ presented in section 6.2 can be seen as the kind of information that an informed lecturer might hold about a particular student, someone whom they have seen on a number of occasions over the course, with whom they have interacted in lectures and tutorials, and whose work they have marked. This gives an interesting opportunity at this stage of the thesis to consider the sort of advice that would usually be given to such students. For those like Andrew and Mike who seemed to be taking it a bit easy, as a lecturer one would be inclined to tell them to work harder: not to miss lectures, to sacrifice some of their social time towards working on weekends. For students who seemed to be experiencing stress from overwork, such as Lindiwe and Geoff, the advice would be to relax a little, and to take time out to do sport and spend time with friends. Some of these students would be given advice about examination technique: laying out your work clearly, and calculating the amount of time to be allocated to each question. And so on. We all know from past experience that in some instances this sort of advice can be beneficial, yet often it seems to fall short.

From the theoretical framework presented in Chapter 2, it is clear that the present study has a different view on student learning. Nonetheless, before proceeding it will be useful to interrogate some common student/lecturer beliefs, using the data in the present study. The chief aim of this section is to firmly debunk any myths about student learning, in anticipation that these might be raised in response to the findings of this study. From my own experience with students I have already seen the limitations of such beliefs, and consequently embarked on the present study, but I am well aware that long-held beliefs tend to be tenacious. This analysis is
therefore provided chiefly as motivation for the approaches taken in the present study. It also provides further background material against which the findings can be interpreted.

6.4.1. Working hard

From the summaries of data presented in the previous chapter it will be evident that the perceived need to ‘work hard’ was without exception a prominent concern of all interviewees. This was voiced in response to expectations of the course, statements on how they were preparing for tests, journal reflections after the test, and in fact in response to any perceived difficulties or problems in the course. This position is in line with much that lecturers and counsellors say to first year students when they start university, and also consistent with general belief system of more senior chemical engineering students who have been through the mill of the second year courses. In some ways this was also backed up by statements made by the lecturers during CHE231F. For example, consider these so-called ‘Keys to Success’ that were presented in the first lecture, as a set of broad issues to address in approaching the subject:

- a) get your life situation together
- b) commitment and motivation
- c) know why you want to be an engineer
- d) learn how to be effective as a student

It will now be considered whether simply working hard was linked to successful learning outcomes in CHE231F. For the purposes of answering this question ‘working hard’ was defined only in terms of time and effort invested in the course, not considering the quality of how this time was used. The main focus here was on work done outside class, although lecture attendance was also assessed. Evidence was gathered from a number of different sources, including self-reflective data from interviews and journals, fieldnotes from classroom observations, and records of journal hand-ins. Some of this evidence will now be presented by way of illustration.
I sat in on most lectures and usually noticed if any of my interviewees were absent from the class. The only students whose absences I noted at any stage were John, Andrew, and Mike, and this was confirmed by spontaneous comments made during the interviews. In order to gauge the extent of out of class work I considered asking the interviewees to keep a record of time spent on various activities, but decided against this partly because of the way it might change theirs from a ‘normal’ experience of CHE231F, but also because I was not sure that this extra effort on their part would add much to what I already knew from what they said in interviews.

One view on the extent of out of class work could be obtained by considering the sorts of activities that students said they engaged in regularly. Evidence on this from journals and interviews is summarised in Table 6.2, together with the lecture attendance data discussed above. In this table, ‘1&2’ indicates that the activity was performed regularly throughout the course, while ‘2’ indicates that the student only started doing this in the second half of the semester.

Table 6.2
Analysis of activities which were regularly performed by interviewees

<table>
<thead>
<tr>
<th>Student</th>
<th>Attending almost all lectures</th>
<th>Looking over lecture notes</th>
<th>Working through examples</th>
<th>Using the textbook</th>
<th>Consulting peers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thabo</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
</tr>
<tr>
<td>Geoff</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
<td></td>
<td>1 &amp; 2</td>
</tr>
<tr>
<td>Lindiwe</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
</tr>
<tr>
<td>Thembi</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
</tr>
<tr>
<td>Nomsa</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
</tr>
<tr>
<td>John</td>
<td></td>
<td></td>
<td></td>
<td>1 &amp; 2</td>
<td></td>
</tr>
<tr>
<td>Andrew</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Eddy</td>
<td>1 &amp; 2</td>
<td></td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
</tr>
<tr>
<td>Mike\textsuperscript{a}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maria</td>
<td>1 &amp; 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shakira</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
<td>1 &amp; 2</td>
</tr>
</tbody>
</table>

Note:
\textsuperscript{a}Mike did not perform any of these activities regularly in either semester
1&2 activity was performed regularly throughout the course
2 student only started doing this in the second half of the semester
Another view of out of class work was obtained from students’ comments on how they were spending their time out of class. Students such as Lindiwe and Thabo indicated that they had cut out most of their social activities to concentrate on their studies. Nomsa and Geoff spoke of having put in long hours on every day of the vacation week. Geoff, Lindiwe and Thembi spoke of repeated late nights. There was also physical evidence of exhaustion, and both Geoff and Lindiwe looked noticeably tired on more than one interview occasion.

The record of journal submissions and marks was another piece of evidence and is given in Table 6.3 below.

Table 6.3
Record of journal submissions and marks obtained by interviewees

<table>
<thead>
<tr>
<th>Student</th>
<th>Hand-in 1</th>
<th>Hand-in 2</th>
<th>Hand-in 3</th>
<th>Hand-in 4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thabo</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Geoff</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>Lindiwe</td>
<td>2</td>
<td>-</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Thembi</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Nomsa</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>John</td>
<td>2</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Andrew</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Eddy</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Mike</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Maria</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Shakira</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>7</td>
</tr>
</tbody>
</table>

Note. - = no hand-in; 0 = inadequate; 1 = adequate; 2 = well done.

The journal evidence would seem to suggest that John and Mike put in the least amount effort in this part of the course, each submitting only two hand-ins. On the other end of the scale are Nomsa and Shakira who submitted all four hand-ins, and got excellent assessments for all except one. Eddy and Geoff each missed one hand-in, but those that they did submit all received top marks. In the interviews they had both said that they would rather not hand in anything if it was not their best work. Maria and Andrew submitted all four hand-ins but only once received an assessment that was anything more than adequate.
Drawing together the evidence from all these sources it was found that students could be divided roughly into two groups according to the amount of time and effort that they invested in the course.

a) There was a group of students that worked extremely hard from the first day of the course (termed here the ‘hardworkers’). They were organised and extremely committed, and worked non-stop to the exclusion of their social lives, a sacrifice they were prepared to make in pursuit of their goal. They had study timetables which they stuck to rigorously, worked hard at managing their time, and were religious in their attendance of lectures and tutorials. The majority of the interviewees fitted this description: Nomsa, Lindiwe, Thembi, Geoff, Thabo, Shakira and Eddy.

b) The second group of students (termed here the ‘slackers’) were those who placed a high priority on their social lives, and were unwilling to let coursework make inroads into their weekend’s entertainment. They did not mean to miss lectures, but this was something that just tended to ‘happen’. They did the minimum of work outside class that they could manage whilst still achieving their goals (which ranged from merely passing to doing well). This group comprised Mike, John and Andrew.

Maria was difficult to place within these groupings. She was diligent in her attendance of lectures, but as a new transeree had a poor idea of the work requirements for chemical engineering at UCT, and so in her work outside class she tended to match the behaviour of the last group, although for different reasons.

Students in both groups recounted the experience of ‘waking up to the demands of the course’ at various stages during the course, especially in response to poor test results, and feeling that they had to work harder. This experience noted by both those in the first group who were already working at what seemed to be their capacity, and also those in the second group who had the potential to put in considerably more time and effort.

What is the relationship between working hard and success in CHE231F? If one looks at the examination results there would appear to be no correlation between
working hard and passing CHE231F: Lindiwe (hardworker), Eddy (hardworker),
John (slacker), Thabo (hardworker) and Mike (slacker) passed, while Nomsa
(hardworker), Geoff (hardworker), Thembi (hardworker), Andrew (slacker), Shakira
(hardworker) and Maria failed.

Another common piece of study advice in the area of examination technique is briefly considered in the next section, and it will be seen that similar shortcomings are encountered.

6.4.2. Examination technique

Another strong focus demonstrated by many of the interviewees was on ‘examination technique’. First of all there was a concern with laying out one’s work clearly and communicating what you had done to your marker, termed ‘layout’ by students and lecturers. Shakira, Nomsa and Thembi were obsessed with this issue, to the extent of doing things like writing first in pencil, or doing rough work off the examination script. Clearly these practices were counterproductive in terms of managing time, and towards the end of the course they managed to drop them, although still focusing clearly on laying out their work properly. Maria also frequently mentioned layout as the reason she failed the assessments and the thing she was working on improving. Geoff, Eddy, Mike, Thabo and Lindiwe all laid out their work very clearly and communicated their assumptions and calculation methods effectively, although for none of these students was layout a major focus. John and Andrew both had virtually illegible handwriting and extremely poor communication with the marker. It would seem from this brief analysis that examination layout, although important, was secondary to other issues when it came to passing and failing the course.

Another aspect of examination technique was managing the time constraints in the tests and examinations, and most interviewees were frequently concerned with this issue. There was much talk of using the usual practices such as allocating time for each question, and practising under time pressure. Students also had their own individual ways of dealing with this issue, such as starting with the short questions (Shakira and Maria) or trying to remember solution methods from similar problems.
(Thembi). And many students did improve in how they managed the time pressures, especially in the rewrite examination (with the exception of Thembi), yet this still did not relate strongly to success in the final course outcome.

6.4.3. Concluding remarks on ‘commonsense’ study advice

It seems that there is a need to move beyond commonsense beliefs about good study practices in order to find a plausible explanation for success and failure in the course. The superficiality of many of these commonsense beliefs can be noted: working hard does not specify working hard at what; and improving examination technique does not deal what sort of knowledge is to be demonstrated during the examination. A comment from Geoff during interview 5 suggests another route of inquiry, which will be followed in the next section.

Cos I know the guys that do well in 231 are some of the laziest guys...
With all due respect to them. But those are the guys that understand what is going on, first time, and there's no need for them to go and go through Himmelblau [the textbook], whatever. It's just understanding.

(Geoff, Interview 5, lines 570-575, emphasis added)

6.5. Conceptual understanding

In this section student responses from the content-based interview questions will be used to develop a preliminary assessment of each interviewee's conceptual understanding. It must be stressed again that this analysis of conceptual understanding does not reflect the chief aim of the study. The present study is not primarily a study of students' conceptual understanding in chemical engineering. Nonetheless, substantial data were available for such an assessment, and these results provide highly significant individual context for the major focus of the study, to be addressed in the following two chapters.

In the first part of this section, the conceptual questions used in the interviews are described in detail. This description will serve as reference for later use of the conceptual data in Chapter 7. In the next part of this section individual responses have been analysed to provide a conceptual ‘score’ for each student. These are then
compared to CHE231F final assessment marks to obtain an indication of the importance of conceptual understanding in passing the course.

6.5.1. Description of conceptual interview questions

In Chapter 5 reference was made to a series of conceptual discussion questions that were part of the first four interviews. The purpose of these questions was to obtain data on how students approached the conceptual demands of the course. These questions were non-numerical in format and were framed around particular contexts in lectures and tutorials. They were intended to gauge students' understanding of key concepts in the course, their perceptions of the purposes of certain exercises, as well as providing evidence of students' approaches to learning as they dealt with conceptual problems.

In this present section the questions will be described in detail. For each interview the set of questions is described, followed by summary statements of the particular concepts that were being targeted (termed 'target concepts').

Interview 1

On the first tutorial afternoon students were given a mass balance problem involving a process to make instant coffee. The tutorial handout is reproduced after the first interview protocol in Appendix D. During this process ground coffee is mixed with water, resulting in a coffee solution with insoluble grounds (similar to what you see in a coffee plunger). The grounds are then separated from the solution, although some solution comes along with the grounds. The pure solution can then be spray-dried to make instant coffee. The first things that students had to be able to do was to differentiate between coffee grounds and soluble coffee, a surprisingly difficult concept for a generation of instant coffee drinkers! The next critical step was to recognise that the concentration of the pure solution coming off from the separator is the same as the concentration of the solution that goes along with the grounds. In order to help students picture this, the lecturer had a glass of orange juice (representing the solution) with some nuts and bolts in the bottom of the glass (representing the grounds). When some of the orange juice was poured off into another glass students could see that the concentration was unchanged as there
was no change in the colour intensity. Tutors went from group to group during the afternoon presenting the demonstration and discussing it with students, although not explicitly explaining the analogy.

In the first interview I asked students to recall this demonstration, and asked them what they thought was being represented, asking, for example, ‘What do you think they were trying to get at?’

**Target concept 1:** The demonstration shows that the concentration of the pure solution coming off the separation is the same as the concentration of the solution that goes along with the grounds.

**Interview 2**

During the lectures on recycle a series of worked examples had been presented, all based on a simple recycle process involving the ethylene oxide reaction. These examples are reproduced after the second interview protocol in Appendix D. During the presentation of these examples I had started to suspect a divergence between the lecturers’ intentions and the students’ perceptions of the purposes of these tasks. The lecturer was hoping to develop students’ conceptual understanding of recycle by presenting systems that differed slightly from each other in critical respects as well as giving an opportunity to refresh their knowledge of the calculations, while it seemed to me that students were focused purely on the mechanics of the calculations and the use of the input-output table, and were missing some of the key concepts. I decided to follow up this idea in the second interview, using these examples as a basis for discussion.

The worked examples were all based on a system using the reaction in which ethylene reacts with oxygen to form ethylene oxide:

\[
\text{ethylene (E)} + \frac{1}{2}\text{oxygen (O)} \rightarrow \text{ethylene oxide (EO)}
\]

The symbols for the various chemical species are those commonly used by chemical engineers, even though they do not conform with standard IUPAC terminology.

The discussion began with a consideration of the second worked example, for which the system is represented below in Figure 6.1.
In this system the chemical reaction given earlier takes place in the reactor. However, not all the reactants are converted to products, hence the mixed composition of the reactor product (RP) stream. In order to improve the overall yield of product, some of the RP stream is split off by the splitter and diverted back into the reactor via the recycle (RC) stream. The process given here is defined as having reached steady state, that is, there is no change in the concentrations of the various streams with time.

The term ‘conversion’ refers in general to the percentage of reactants (E and O) that are converted to products (EO). Overall conversion is the nett conversion over the whole process (comparing the amounts of E and O in the fresh feed with the product stream) and conversion per pass is the conversion over one pass through the reactor (comparing the mixed feed with the reactor product stream). These are all concepts that students had been introduced to in lectures over a period of some weeks.

The discussion began with my asking students to explain the difference between overall and per pass conversion, using the diagram. In the worked example the per pass conversion had been given as 50%, and the overall conversion as 75% in 2a, and as 90% in 2b. Students were asked whether these two quantities always differed like this, and if so, whether overall conversion was always greater than per
pass conversion. They were then asked to suggest what could be done to the system in order to increase per pass conversion, and also what could be done in order to increase overall conversion. (The latter point had been illustrated in problems 2a and b.)

The discussion then moved back to the first worked example, which was based on the system given in Figure 6.2 below. In this system the splitter has been replaced by a separator in order to give a pure ethylene oxide product stream, and a recycle stream composed only of unused reactants.

![Diagram of worked example](image)

Figure 6.2 Worked example 1: Recycle system with ideal separation
(CHE231F workbook, Lecture 20, page 2)

Students were asked what the overall conversion was in this system, and to explain why.

In the final part of the discussion reported here students were asked to consider the third worked example, which was identical to the second one (Figure 6.1) except that the fresh feed stream now contained an equivalent amount of oxygen coming in the form of air. Students were asked whether the large amount of nitrogen in the recycle stream meant that nitrogen was building up in the system.

Students were also asked before and after this discussion what they thought the lecturer’s purpose had been in presenting this particular set of worked examples in class.
**Target concept 2:** Overall conversion is conversion measured over the whole system (compare FF to P), while conversion per pass is measured over the reactor (compare MF to RP).

**Target concept 3:** Overall conversion will always be greater than per pass conversion (that is the purpose of having a recycle in the first place).

**Target concept 4:** Conversion per pass can be increased by changing the conditions in the reactor.

**Target concept 5:** Overall conversion can be increased by increasing the purge ratio (splitting off a greater proportion of the RP to the RC stream).

**Target concept 6:** In worked example 1 (Figure 6.2) the overall conversion is 100% as there are no feed components in the product stream.

**Target concept 7:** Even though there is a high concentration of nitrogen in the RC stream this does not imply a build-up in the system, which is in steady state (the flow rates given in the input-output table are constant; nitrogen in = nitrogen out).

**Interview 3**

Prior to this interview students had learnt to conduct energy balances over closed steady state systems. Using the first law of thermodynamics, the energy balance equation can be formulated as

\[ \Delta U + \Delta E_k + \Delta E_p = Q - W \]

where \( \Delta U \) is change in internal energy; \( \Delta E_k \) is change in kinetic energy; \( \Delta E_p \) is change in potential energy; \( Q \) is heat transferred to the system and \( W \) is work done by the system.

The same equation can be arranged as

\[ (U + E_k + E_p)_n + Q - (U + E_k + E_p)_o - W = 0 \]

A more useful form of the energy balance for flow systems uses the quantity enthalpy (H), which is related to internal energy by the equation

\[ H = U + PV \]
where $P =$ pressure and $V =$ volume, and the product $PV$ represents flow work.

The energy balance, in differential form, and with kinetic and potential energy terms expanded into $\frac{1}{2}mv^2$ and $mgz$ respectively, is now given as follows:

$$
\sum_j (\frac{1}{2}v_j^2 + gz_j) \frac{dm_j}{dt} + dQ/dt - \sum_k (\frac{1}{2}v_k^2 + gz_k) \frac{dm_k}{dt} + dW/dt = 0
$$

where the incoming streams are denoted by the index $j$, and outgoing streams are represented by $k$, and $dW/dt$ now refers only to non-flow (shaft) work.

Performing an energy balance involves determining values for all these various terms and then performing the appropriate calculations to determine unknowns. Most of the work in an energy balance revolves around the enthalpy terms. The relation between enthalpy and temperature is given in the following graph.

![Graph of enthalpy versus temperature](CHE231F_workbook, Lecture 30, page 3)

The change in enthalpy over a phase change is known as latent heat, and this information can be obtained in a variety of forms, one of which is the steam table (for systems containing only water). Enthalpy changes where no phase change occurs, are known as sensible heat changes. In the case of water (steam), these can
also be read off the relevant part of the steam tables. For other substances, heat capacity ($C_p$) data can be used as follows:

$$\Delta H = \int C_p \,dT$$

In some systems one can assume a constant heat capacity value over a range of temperatures, but often this is not possible. In that case one needs to use either heat capacity equations, or tables of molar and mean molar heat capacity. Tabulated mean molar heat capacity data are particularly useful as the integration has already been computed over a variety of temperature ranges starting at the reference point of 25°C, and the calculation merely involves looking up two values and using the following equation:

$$\Delta H = nC_{p\ mean}(T_{\ final} - 25) - nC_{p\ mean}(T_{\ initial} - 25)$$

In the third interview I produced photocopies of four sets of information that had been presented during the lectures covering this work, namely

a) A graph of enthalpy versus temperature (H-T) over the range from ice to superheated steam;

b) A table of mean molar heat capacity ($C_p$) data;

c) A steam table detailing enthalpies of subcooled liquid and superheated steam, as well as a summary of phase transition data; and

d) A page of the lecture notes giving energy balance equations in terms of U (internal energy) and H (enthalpy).

Copies of these items are reproduced after the third interview protocol in Appendix D.

My first question to students was to ask them what links they could make between these different things. The most obvious link of course is that they all deal with enthalpy: in the H-T graph the enthalpy changes when heating a solid until superheated vapour are graphically illustrated, the steam table and heat capacity data both give the means of calculating various enthalpy changes, and then the energy balance equation is where enthalpy changes in a particular system are linked to other quantities such as heat and work.
Following on students’ responses to this initial prompt I asked them to discuss and explain in detail each piece of information in turn. Specific questions posed in the course of these discussions were:

1. Explain what is happening in the vertical and flattish sections of the H-T graph.
2. How could you use heat capacity data in the calculation of the enthalpy change between two particular points indicated on H-T graph (these points on opposite sides of the phase change)?
3. What does the jagged block in the steam table refer to? Can you find data for the phase change on this table?
4. Why do we seem to be making more use of the energy balance equation given in terms of enthalpy (H), rather than that with internal energy (U)?
5. Explain in your own words what the term enthalpy means to you.

**Target concept 8**: In the H-T graph the vertical sections refer to phase changes and the flatter sloping sections to increases in temperature within the same phase (termed ‘sensible heat’)

**Target concept 9**: Heat capacity ($C_p$) data can only be used for sensible heat changes. In order to determine the enthalpy change between two points which span a phase change, latent heat will need to be added to the calculation.

**Target concept 10**: The jagged line in the steam table refers to a phase changes between the liquid and vapour phase; the part of the table with the smaller enthalpy values refers to the liquid phase.

**Target concept 11**: The form of the energy balance equation with enthalpy values is more frequently used as the data are more readily available.

**Target concept 12**: Enthalpy refers to the total amount of energy within a part of a flow system, both internal energy and energy due to flow.

**Interview 4**

In the lectures preceding the fourth interviews students had been presented with energy balances in situations where a chemical reaction was taking place in the system. In such instances the energy taken up or given off in the reaction, termed
‘heat of reaction’, needs to be included in the energy balance calculations. Tabulated standard heat of reaction ($\Delta H^\circ_r$) data are available for some reactions, but where these are not available heats of reaction are calculated using standard heat of formation ($\Delta H^\circ_f$) data. The heat of formation of a particular compound is defined as the energy required to produce it from its elemental components under specified reference conditions.

Hess’s Law states that the difference between the heats of formation of the products and reactants is equal to the heat of reaction, for example, for the reaction

$$\text{CO (g)} + \frac{1}{2}\text{O}_2 (g) \rightarrow \text{CO}_2 (g)$$

the standard heat of reaction can be calculated as follows:

$$\Delta H^\circ_r = \Delta H^\circ_f (\text{CO}_2) - \Delta H^\circ_f (\text{CO})$$

as the standard heat of formation of elements such as oxygen is equal to zero.

Since all heats of formation are given for the specific reference conditions of 25°C and a pressure of 1 atm, energy balances using these data need to use these same reference conditions in all parts of the calculations.

In the fourth interview I posed only one conceptual question to students: what had changed now that they were considering energy balances in systems where chemical reactions were taking place?

**Target concept 13:** For energy balances with reaction one needs to take account of the energy used or generated during chemical reaction (heat of reaction), and this is calculated by using heat of formation data for the various components of the reaction. These data require that a particular reference point is used.

**6.5.2. Assessment of conceptual understanding**

In a preliminary analysis of the data resulting from the above questions, students’ responses were analysed and judged to be either adequate (1) or inadequate (0) in terms of the target concept. This basis for this classification was made with input from two chemical engineering lecturers. Because of the way that certain questions developed over the course of the interviews, on some occasions a student was not
presented with a particular question and these have been indicated with ‘-‘. These scores have been summed, and a percentage calculated on the maximum achievable score in each case.

Table 6.4
Initial analysis of interview conceptual data

<table>
<thead>
<tr>
<th>Target Concept</th>
<th>1</th>
<th>1</th>
<th>-</th>
<th>1</th>
<th>0</th>
<th>1</th>
<th>0</th>
<th>1</th>
<th>1</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Orange juice demonstration</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2 Difference between overall and per pass conversion</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3 Overall &gt; per pass conversion</td>
<td>1</td>
<td>0</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>0</td>
<td>1</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>4 How to increase per pass conversion</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>5 How to increase overall conversion</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6 Recognising 100% conversion</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>7 The effect of inerts - understanding of buildup</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>8 Understanding H-T graph</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9 Use of Cp to calculate ΔH</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
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<tr>
<td>10 Parts of the steam table</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11 Why H eqn preferred to U eqn</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
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<td>12 Definition of H</td>
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<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>13 What changes when energy bal. with reaction</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>0</td>
</tr>
<tr>
<td>Total score attained</td>
<td>7</td>
<td>4</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>13</td>
<td>6</td>
<td>10</td>
<td>7</td>
<td>3</td>
<td>3</td>
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<td>Maximum possible score</td>
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<td>10</td>
<td>11</td>
<td>13</td>
<td>12</td>
<td>13</td>
<td>12</td>
<td>13</td>
<td>13</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Percentage score</td>
<td>64</td>
<td>40</td>
<td>73</td>
<td>62</td>
<td>50</td>
<td>100</td>
<td>50</td>
<td>77</td>
<td>54</td>
<td>25</td>
<td>23</td>
</tr>
</tbody>
</table>

Note: 1 = Response judged adequate; 0 = Response judged inadequate; - = Question not asked.

It must be stressed that this is, and is only intended to be, a rough analysis. It should be seen as only providing a broad picture of students’ conceptual understanding as demonstrated in the interviews. Nonetheless, when these total scores are compared to CHE231F final marks, as in Table 6.5, there is a clear general
trend for those with greater conceptual understanding, as represented by the above analysis, to be much more likely to have achieved a passing grade.

Table 6.5
Comparison of conceptual scores with CHE231F final marks

<table>
<thead>
<tr>
<th>Student</th>
<th>Conceptual score</th>
<th>Final mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>John</td>
<td>100</td>
<td>75</td>
</tr>
<tr>
<td>Eddy</td>
<td>77</td>
<td>60</td>
</tr>
<tr>
<td>Lindiwe</td>
<td>73</td>
<td>54</td>
</tr>
<tr>
<td>Mike</td>
<td>54</td>
<td>52</td>
</tr>
<tr>
<td>Thabo</td>
<td>64</td>
<td>50</td>
</tr>
<tr>
<td>Nomsa</td>
<td>50</td>
<td>47</td>
</tr>
<tr>
<td>Geoff</td>
<td>40</td>
<td>45</td>
</tr>
<tr>
<td>Thembi</td>
<td>62</td>
<td>45</td>
</tr>
<tr>
<td>Andrew</td>
<td>50</td>
<td>43</td>
</tr>
<tr>
<td>Shakira</td>
<td>23</td>
<td>22</td>
</tr>
<tr>
<td>Maria</td>
<td>25</td>
<td>DPR</td>
</tr>
</tbody>
</table>

Note. All marks are given as percentages.

In this analysis the emphasis is on the pass/fail distinction in the final assessment, indicated by the solid line, rather than actual marks obtained. There does seem to be a reasonable distinction in conceptual understanding scores between students above and below the line, with the only clear outlier being Thembi. Her situation will be discussed later on in the thesis, as there were other significant factors impacting on her examination performance.

Another conclusion that can be drawn from this comparison is that the CHE231F assessment actually did assess what it set out to assess, namely conceptual understanding. This was already evident from the kinds of assessment questions as illustrated in section 4.4.3, but is further supported by these findings.

6.6. Conclusion

The summaries presented in the first part of this chapter showed that students differed in their experience of the course, and in their final achievements. Later on
in the chapter, a commonsense view on student learning was considered, in order to see whether this could provide a reasonable explanation for these different learning outcomes. It was shown that ‘working hard’ was not sufficient and possibly not even necessary (consider Mike and John) for success in the course. At the end of the chapter it was shown that what did matter was the extent of conceptual understanding.

These preliminary analyses have provided the background for the major focus of the present study. The analyses to be presented in the following two chapter seek to uncover what lay behind the difference in learning outcomes displayed so clearly both in the course marks and the conceptual assessment presented above.
Chapter 7
Approaches to learning
and metacognitive development

7.1. Introduction

In the previous chapter the interviewees were introduced by way of ‘stories’ which described, from their point of view, how they had experienced the course. These data were then considered from a ‘commonsense’ view on teaching and learning, to see whether this could provide any explanations for the different degrees of success or failure that students demonstrated in the overall course assessment. This viewpoint was shown to be of limited use, but an analysis of the conceptual interview data suggested that students had indeed reached different conceptual outcomes in the course.

These preliminary analyses have now set the stage for a deeper analysis of the data which focuses on the research questions given in Chapter 1, and draws in elements of the theoretical framework which was established in Chapter 2. The present chapter focuses on the first research question posed, namely an investigation of students’ approaches to learning and whether there were any changes in approaches used (conceptualised as metacognitive development). The next chapter will address the remaining two research questions which deal with students’ perceptions of the learning context.

As discussed in Chapter 2, the student learning literature suggests that differences in learning outcomes are related to differences in approaches to learning (Marton & Booth, 1997; Marton & Säljö, 1976b). As a starting point in the present study I assumed the validity of the construct of ‘approach to learning’, noting that this is defined primarily not in terms of actions, but in terms of the intentions behind those actions (Biggs & Moore, 1993). Following the approach of Booth (1992) I did not impose any model of specific approaches (for example, deep and surface) on the work from the outset, but rather allowed these to emerge from the data.
During the first phase of the data analysis I began noting instances where approaches to learning were apparent in the data, and started categorising these according to the underlying intentions that they displayed. This process was refined in the second stage of analysis, by the end of which I had managed to identity three qualitatively different and distinct approaches to learning in the context of CHE231F.

These were:
1. a conceptual approach, where the intention is to understand concepts;
2. an algorithmic approach, where the intention is to remember calculation methods for solving problems; and
3. an information-based approach, where the intention is to remember information that can be supplied in response to assessment questions.

The designations ‘algorithmic’ and ‘conceptual’ were given to these approaches following the common use of these terms in the literature, as illustrated in a series of articles about a decade ago in the Journal of Chemical Education (Nakleh, 1993; Nurrenbern & Pickering, 1987; Pickering, 1990). Although in this instance the writers were using the terms primarily to describe different kinds of assessment items, it can be argued that the use in this chapter matches the intentions in their work (to distinguish between different modes of engagement with the items). I formulated the term ‘information-based’ as an ‘in-vivo’ code (Strauss & Corbin, 1990) based on Nomso’s repeated references to ‘gathering information’ when describing how she approached her studies.

If these approaches are compared with the early and influential conceptualisations of deep and surface approaches (Marton & Säljö, 1976a), it would seem that the conceptual approach is almost identical to a deep approach. The information-based approach is most similar to the original formulation of the surface approach, although I would suggest that both the algorithmic and information-based approaches could be seen as forms of the surface approach particular to this context. Despite these similarities, in this study I decided against using the terms deep and surface in naming these approaches for a number of interrelated reasons. The main reason was that the formulations are not identical, that is, ‘conceptual’ in this study
is not completely equivalent to ‘deep’ as formulated in earlier studies, a point which will become apparent in the descriptions of these approaches in the rest of this chapter. The current terminology was also chosen in order to emphasise that these are categories that emerged independently from these data, and to provide names that are more meaningful and descriptive in the chemical engineering context.

In section 5.6.4 the distinction was made between self-reflective data, where students reflected on their experiences, and conceptual data, where they responded to conceptual tasks. Self-reflective data came from the interview transcripts and certain journal tasks, while the conceptual discussion questions in the interviews, conceptual journal tasks, and assessment items provided conceptual data. In the various stages of analysis I moved from self-reflective to conceptual data and back again, each time refining the categories and classifications. In the presentation of these findings however I will first give those derived from the self-reflective data, followed by the findings from the conceptual data. This provides a form of triangulation for verification of the final results. The self-reflective data draw a picture of what the students said they did, while the conceptual data gives evidence of what they actually did in response to conceptual questions. In order to allow for maximum readability of this large mass of data and interpretations, the findings are presented as follows. The self-reflective data are presented student by student, and the conceptual data are generally presented task by task. At appropriate stages in the reporting the findings are summarised and compared with previous summaries in the chapter.

7.2. Analysis of self-reflective data

In this section the approaches to learning identified in the self-reflective data will be described. Given the ‘naturalistic’ style of the interviews (Lincoln & Guba, 1985), it was not always easy to deduce approach from student comments, and so in interpretation I tended to err on the cautious side. A word that presented particular difficulty was that of ‘understand’ – almost all students spoke about ‘understanding their work’, ‘not understanding’ – but I would suggest that this does not automatically imply a conceptual approach (see Case et al., 2000, for a case study
which illustrates this point clearly). I have looked for a broader and deeper discussion than the mere existence of particular words in order to infer approach.

In this analysis it was also critical to bear in mind the focus on intention and not on actions in the construct of approach to learning, as some actions can be used to different ends. Doing problems can be used either to develop understanding or to remember calculation methods, and using the textbook and lectures can be either with the intention to develop conceptual understanding or to gather information.

These results will be presented student by student, with these presentations adding detail to the categories of approach to learning that have been described in broad terms in the introduction.

7.2.1. Thabo

Thabo strongly stated his preference for working towards understanding (conceptual approach) on a number of separate occasions, for example:

I just hate it when I do something and I can’t understand exactly what it is I’m doing. I’d rather leave something and not do it than do it and not understand what I was doing. (Interview 5, lines 339-341)

Although he felt this way, in some courses he had found himself having to having to both remember information (Chemistry II) and do calculations (Physics I) without understanding. It appeared that the CHE231F context allowed him to do what he liked most, that is, use a conceptual approach. He often mentioned that one day as a chemical engineer he was going to have to be able to understand concepts rather than remember information or solution methods. In this vein he also asserted the need to see the relevance of what he was learning, to be able to see how you would use a particular concept in the real world.

So the way I see it is: if you don’t understand 231, when you need to apply it later in life, where are you going to start? (Interview 5, lines 375-377)

At the start of the course in an informal conversation at the end of the lecture, Thabo said to me that all he did in lectures was to copy down notes. He said that all he planned to get at this stage was a rough idea of what the lecture was about, and
then he used a conceptual approach at home, making sense of the notes. A week or two later, in the first interview, he said that because of the way the lectures were structured, he was now actually managing to understand during the class, and this motivated him to get more involved. However, he still made a distinction between picking up the 'main concepts' in class and filling in the 'details' at home. The main concepts, with an understanding of how they linked, were what were necessary in order to pass the course, while knowing the details, acquired through 'polishing' (by practising examples) would allow you to achieve more than a pass. Part of a conceptual approach for Thabo also entailed developing his own approach to solving problems, which he often talked about. He explained how the journal tasks, which he had initially been rather dismissive about, had helped him in his development of these various aspects of a conceptual approach.

But the journals, they show you some pretty interesting things. Because certainly, if it wasn’t for the journal, I would not have developed my own standard approach, my own personalised approach to these type of problems, because they motivate you to look at things, and you know, read over problems, look at the test again, link certain terms and definitions. (Interview 3, lines 180 – 186)

Thabo was critical of what has been termed in this study an algorithmic approach, and said that since school he had been ‘one to go for understanding rather than tons of practice’ (Interview 5, lines 423-425). He was also critical of information-gathering, for example asserting that:

You don’t deal with a concept by sitting there and just writing out or memorising things, you have to actually think about it. (Interview 4, lines 736-738)

7.2.2. Geoff

From early on in the course Geoff was able to articulate the essential features of an algorithmic approach, and recognised that he was using such an approach, especially when under stress.

I don’t like doing that, but when I’m stuck, that’s my saving grace, I know the equation, just punch it in. (Interview 3, lines 522-524)
He also knew that CHE231F was requiring him to use what has been termed here a conceptual approach, yet this was something that he seldom managed to achieve. Early on in the course he felt that he was building a good understanding of the work, yet as soon as the pressure was on he found himself reverting to an algorithmic approach, focusing on calculations and methods. After he wrote the June examination, he realised that, despite all his hard work, he still had grave misunderstandings in many important conceptual areas. In preparing for the rewrite examination he did finally manage to implement his intentions and focus on understanding. During the fifth interview he spoke at length of this new approach, for example:

That’s why I’m trying to get this understanding thing in the bag. Because if I can understand it I can do a problem. Rather than if I’m sitting there doing hundreds of problems and getting tired and irritable and whatever. (Interview 5, lines 426-429)

He had been advised by senior students to do as many problems as possible during the course, and he now regretted taking this advice. He had worked through countless problems, trying to train himself to remember solution methods and recognise familiar problems, and after the course had ended (in the fifth interview) he realised that this had not helped him in the final assessment. He said that he would now advise CHE231F students to focus on developing understanding, and described a different way of doing problems where you took one problem and tried to get as much understanding out of it as possible. He had also shifted from looking for a single method of solving a problem, to wanting to explore as many different ways as possible.

Nonetheless he still did not feel that he could achieve anything other than an algorithmic approach in Mathematics, and that this approach would be sufficient to ensure a pass in the assessment.

[In] Maths I’ve just got to do problem after problem after problem [clicking his fingers to indicate rapidity]. ‘Cos often the concepts I don’t understand are things I don’t think I ever will. That’s a very frightening thing to say, but you know to sit [and figure] out what is going on - rather do a problem and then they [the examination questions] come up year after year for you. (Interview 5, lines 447-452)
However in the forthcoming chemical engineering courses he knew that he was going to have to take a conceptual approach, although he was daunted by all the gaps in his understanding that this had started to reveal.

7.2.3. Lindiwe

Lindiwe’s main concern from the start of the course was with being able to solve the given problems, which she found most challenging. As early as the first interview she recognised that these were problems that did not have set formulae, and that there was no alternative but to ensure that she understood the work. The type of problems presented in CHE231F assessments provided the main motivation for her to use a conceptual approach in the course, something which she articulated clearly in the last interview.

‘Cos you’re never going to get the same questions over and over again. So the only way you’re going to do them is if you actually know what you’re doing. (Interview 5, lines 234-237)

Although Lindiwe showed evidence of this awareness early on in the course, she found herself ‘just doing questions’ (using an algorithmic approach) in preparation for the second test and consequently felt that she had not really understood the work (Interview 3, lines 14-16). After this test she started working a lot harder, and it appeared with a more clearly defined conceptual approach, where she was doing problems to develop and test her understanding.

It seemed that she had used a conceptual approach before in her studies, as she commented at the end of the course that she was not working differently in CHE231F, only harder. Yet her choice of approach appeared to be strongly influenced by context. In CHE231F, as mentioned earlier, she came to see a conceptual approach as essential because of the type of questions in the assessments, and managed to implement this during the course. However in her other second year courses she was not using this approach, mainly due to the teaching style and/or the assessment requirements. In Chemistry II, she said, ‘I just write down notes, page by page by page. And I don’t get it. I don’t’ (Interview 3, lines 121-122). In Mathematics she said:
Sometimes I feel like I’ll just cram this, and I don’t have to understand anything and then I’ll be fine. .... There are some sections in Maths where you can just [say]: this is how you do this, and you don’t like [know? – tape unclear] what it is you’re doing.

(Interview 5, lines 251-256)

7.2.4. Thembi

Thembi made frequent references throughout the course to her preference for what has been termed in this study a conceptual approach, often describing this in terms of thinking logically while working through a problem. However, her actual focus for most of the course appeared to be more on remembering solution methods (indicating an algorithmic approach). She said she was looking for a common approach that would work for a certain type of problem, in order to make future problems seem familiar. She was convinced that this, rather than working through problems logically, would be a more effective way of coping with the assessment demands of the course. This strategy also appeared to be related to the time pressure she felt during the course.

I think it’s always been coupled with understanding but the less time you have to prepare and get comfortable with stuff, the less you think about understanding and the more you think about ‘I’ve just got to be able to do it’. It’ll come with time but I’ve just got to be able to do it.

(Interview 5, lines 215-219)

Towards the end of the semester she appeared to grow more critical of this algorithmic approach, and started to focus more on developing conceptual understanding. This assessment is supported by her comments in the fourth interview when I asked her whether she had changed her approach to her studies this year. Although she initially said ‘No, not really’, she went on to describe a significant change.

Last year I think I was pretty much a lot more textbook-orientated. This year I find it more, OK, we still use the textbooks and do examples and stuff like that. But it’s like if you put down things in your own way, it’s a lot easier to remember, than doing things exactly like in the textbook, or going by the textbook or whatever.

(Interview 4, lines 401-406)

With the time she had available to prepare for the rewrite examination she finally managed to implement fully a conceptual approach. In the fifth interview she spoke
at length about this change from trying to remember set solutions, to working through problems using her own understanding and logic.

I generally do prefer to understand ‘cos then usually I can then logic things out. And that’s what I find right now, because now that I’m doing a lot more and we’re not covering any more material in 231. I’m now finding my own methods which work perfectly well, twice as fast. ‘Cos I’m actually using logic to work them out, rather than like going through tut solutions and seeing how they are done and then trying to model my way along those lines. ‘Cos there are a lot of, you’re actually trying to learn a whole new language, instead of using your own language to do the same thing. (Interview 5, lines 228-237)

In the same interview she mentioned that she had been ‘shocked into trying to learn methods’ (lines 435-437), thinking that if she did this she was guaranteed to get the marks for her solutions.

7.2.5. Nomsa

Nomsa showed evidence of using both information-based and algorithmic approaches in CHE231F. The former approach she had used since school, and, when I asked her in the fifth interview to clarify what she meant by getting ‘information’, she described this approach in detail.

By information I usually refer to material which will give me some idea of what's going on in the topic. You know more about the topic, instead of just having a definition like enthalpy this and this and this. More about enthalpy, like they tell more, give examples and stuff like that. (Interview 5, lines 187-190)

Later on in the discussion when I asked if this approach had worked in CHE231F she said that maybe she had not looked for enough information. She briefly questioned whether the method itself was faulty, but then reassured herself that it had worked well both in school and in first year, and ended by concluding that she most probably had not implemented it properly in CHE231F.

A strong focus for Nomsa during the course was on being able to tackle the complex problems that were presented. She put considerable effort into actually trying problems on her own, and described her development in problem-solving skills as follows:
I have learnt that problem solving is not all about formulae and ready to solve equations. It is all about thinking and devising an approach to solving the problem. It is about drawing diagrams where a process is involved. It's about making sound assumptions where necessary in order to simplify the problem. (Journal task 7, lines 9-14)

From this quote though one can see that although this was an area of considerable development for Nomsa, she was still looking for solution methods, that is, using an algorithmic approach, rather than focusing on understanding.

As with other students, at the end of the fifth interview I had given Nomsa some advice for her preparation for the rewrite examination. In her case this was my preliminary research findings about the shortcomings of both algorithmic and information-based approaches. I was interested then to read Nomsa's entry in the first journal of the new semester, in which students were asked to describe (a) what things they had learnt to do differently in CHE231F; and (b) what they think they should have done differently in CHE231F.

(a) CHE231F taught me to approach every problem as unique but a general understanding to the concepts involved in solving it. I strongly feel that I have to pursue [sic] this approach in CHE235S and CHE236S [second semester chemical engineering courses]. This is because grabbing a general idea behind solving each problem enables one's problem-solving skill to develop and improve with more practise [sic].
(b) The most important thing that I should do is understanding the concepts and relate them to what I know instead of reading more about them. This because [reading?] is time consuming and also because different authors give different explanations which might lead to confusion. (Journal 1 Semester 2, lines 36-30)

On the face of it this may seem to indicate a significant shift away from algorithmic and information-based approaches towards a more conceptual approach. However, on a closer look it seems that Nomsa might have been repeating some of my advice, but still within the same framework that she had been using in CHE231F. Although she has picked up on my criticism of trying to look for standard solutions, her primary motivation is still about developing problem-solving skills rather than conceptual understanding. Her second response is even more telling. She says that understanding concepts is more important than trying to read more about them, yet for her the problem with reading textbooks is having to reconcile the different authors' explanations. (Using a conceptual approach this could be viewed as one of
the most useful things to be obtained from a textbook.) From the analysis of these data it appears that Nomsa was merely repeating what she thought I wanted to hear, rather than having really made a transition to a conceptual approach, and being able to describe this change in her own words. Supporting this interpretation was Nomsa’s exceptional eagerness to please her superiors, noted from early on in the course, and could be partly related to her being a year younger than her peers.

7.2.6. John

John showed a consistent use of a pure conceptual approach right through CHE231F. Since school he had preferred subjects which allowed him to use such an approach, and this was in fact the main reason he had chosen to study chemical engineering.

I enjoy understanding things, I don’t enjoy just mindlessly learning things off by heart. (Interview 5, lines 406-407)

In journal submissions and in interviews he repeatedly asserted that this was his focus. His chief method for developing understanding was to work through examples, rather than using the textbook, which he termed ‘doing theory’. Even in Chemistry II, described by him as a course which concentrated on theory, he preferred to learn by doing examples.

He remembered occasions in first year where he had not been able to understand a problem, and had remembered particular solutions in case the question came up in the examination, but had not been doing this in CHE231F.

In the second half of the course he found that he had to put in a lot more effort outside class in order to reach an acceptable level of understanding, as his failure in the second test had shown him that his efforts in the first half of the semester had not been sufficient. When I asked in the fourth interview whether he had changed in his approach during CHE231F he replied:

Ja, no, OK, I should have changed a little bit, with energy balances. Mass balances sort of came to me very naturally, very easily... And then I suppose with energy balances, as soon as you start missing out
sections, and then it starts to fall away a little bit, the foundations, so I have to put in a little bit more work now.  (Interview 4, lines 396-403)

7.2.7. Andrew

From early on in the course Andrew was aware that he was frequently using what has been termed in this study an algorithmic approach, and also that this approach was not suitable for the CHE231F context. For Andrew the key aspect of a conceptual approach was being able to picture real situations, and he contrasted this to focusing merely on the calculations. The data suggest that the chief impediment to his adoption of a conceptual approach was his unwillingness to expend effort on his studies. However, after the second test, he reported making some fairly radical changes to his work habits, and this did seem to coincide with more use of a conceptual approach. In the seventh journal task he wrote about his change of approach.

If anything thus far I have hopefully learnt to visualise problems before just jumping into the Mathematics of it. This sought [sic] of approach has mainly been accomplished through diagrams. I also think it is important for me as an engineer to be able to visualise industrial processes.  (Journal task 7, lines 22-26)

Despite an increased valuing and use of a conceptual approach Andrew continued to show evidence of using an algorithmic approach. For example, in preparing for the rewrite examination he mentioned that he was working on recognising familiar problems.

You should practise enough. You will just look at the question, and I bet, maybe [the top student in the class] or someone, she's just got a list of questions, and says 'I've done this already'. Or it's similar to another question. With the numbers a bit different. 'Cos all the problems are basically the same, there's not actually that much different.  (Interview 5, lines 383-388)

7.2.8. Eddy

Eddy used strategies indicating a conceptual approach right throughout CHE231F, and described having adopted this approach some time back.
Was it when I first came to university, or was it while I was still at school there? - somebody told me that once you understand something then you'll know how to do it. So my aim was to understand. (Interview 5, lines 228-231)

This intention was strengthened by his experience of Physics I, where he found that whatever he did not understand he ‘always got hopelessly wrong’ (Interview 5, lines 239 – 242). He felt that knowing only how to do the calculations would not be of any use in CHE231F.

He commented early on that he had a retentive memory, and described using the textbook as follows:

You hear something new and you think, ‘OK like what is it?’, and then, you go to your textbook and say, ‘Oh it’s this and that and that’, and it’s like ‘OK, now I know, for next time’. (Interview 4, lines 523-526)

This may seem to suggest that he was also using an information-based approach, but on closer inspection it seems clear that his consulting the textbook and remembering things was always done with the underlying intention to understand. This conclusion was supported by other comments such as the following.

I think sometimes I grasp stuff quite easily and once it’s in there it stays. Once you understand something [you won’t forget it]. (Interview 5, lines 223-225)

Eddy was able to articulate in some detail what a conceptual approach implied for him. He felt strongly that you needed to develop your own problem solving methods, and that one should use these until you got ‘stuck’. Then you needed to find out in what way you needed to add to or modify your understanding, and make the changes. He said that once he had been through this process he never forgot new things that he had learnt.

7.2.9. Mike

From the very start of the course Mike asserted the importance of focusing on understanding (a conceptual approach). In every single interview he made unprompted statements along these lines, for example, when discussing how he was approaching doing mass balances, he said:
Ja, you’ve got to understand what’s going on before you can do anything about it. (Interview 1, lines 311-312)

Early on in the course he found that he understood mass balances with very little effort, and it appeared that most of his earlier learning experiences had been similarly effortless. However in the energy balance section he found that he had to work a lot harder to gain the necessary understanding.

Frequently he talked about this approach in terms of putting things in your own words and formulating your own methods. In the fifth interview I asked him to tell me more about what he meant by ‘getting it right in my head before anything else’ and he gave an interesting illustration of what this meant for him.

That would be like understanding, giving a definition of say steady state and not actually you know having a thing here and then saying, ‘Oh, what’s steady state?’, and go and look there [in the notes/textbook]. But actually saying, ‘Oh, you know, nothing’s changing, it’s steady state’. Just sort of having a picture of it in mind of what’s happening. (Interview 5, lines 518-523)

This quote introduces another aspect of Mike’s conceptual approach, which was being able to visualise a concept, ‘having a picture of it in my mind’. Later on in the same discussion he talked about ‘putting it into your own language’. The above quote also introduces Mike’s disdain and dislike for an information-gathering approach when he asserts that it’s not a question of ‘go and look there’, where ‘there’ is presumably referring to the notes or the textbook. Throughout the course he had spent little time consulting either of these sources of information, which I had taken to be largely due to the effort it would require, and in the fifth interview he asserted in a couple of places that this approach had been justified.

As mentioned above, another aspect of Mike’s conceptual approach was working out your own problem-solving methods. In his first journal hand-in he repeatedly asserted that there was no one set way to solve mass balance problems, and that one should not try and learn solutions to different problems, but rather make sure you could understand the problem and the associated concepts. This comment was also echoed in many of his interview responses. This can be seen as a recognition of the shortcomings of an algorithmic approach, although Mike also made use of such an
approach when he did not feel like expending effort and knew he could get away with it. This was both in the Mathematics course where he felt not much understanding was required, and in CHE231F in instances where he had seen a problem before and happened to remember how to do it.

7.2.10. Maria

Maria approached CHE231F by concentrating on learning definitions and formulae, and remembering theoretical derivations, what has been termed here an information-based approach. However, she was strongly critical of this approach, and made statements from early on in the course that could be interpreted as recognising the importance of a conceptual approach. For example, she spoke about the importance of thinking about ‘the words in the practical sense’ and explained that this meant thinking of the real world context of the problem, she recognised that there was no set formula for solving CHE231F problems, and she talked about linking different concepts.

Somehow she did not seem to be able to act on her convictions, and she continued to approach learning in the same way that had worked for her in her science courses. She was aware that she needed to actually try doing problems on her own, and after the first test she said:

For the test, I think I should have done more problems, rather than trying to theorise it.  (Interview 2, lines 81-82)

She continued to say that she should be doing more problems after the second test, and also in three separate journal tasks, but she only actually started doing this when the course had nearly ended.

7.2.11. Shakira

In her previous Science courses Shakira had used what has been termed in this study an information-based approach, and this had worked well for her. The approach involved focusing on what she termed ‘theory’ and then being able to do any calculations without extra effort, as these were simple applications of the theory. This focus is illustrated in the following comment.
I have to go over my notes again. I go over them sometimes, not like after each lecture and stuff, so it's very important because I seem to forget the small definitions and stuff, and the way they all apply. And I sometimes just forget the whole thing. (Interview 4, lines 85 – 89)

Shakira showed a growing awareness during CHE231F that this approach was not working, but continued to rely on an information-based approach. After the final examination she admitted that she had known that there was a great deal she did not understand, but had been too nervous to face up to this. During the fifth interview she articulated the problems with her approach as follows:

‘Cos all the other courses I’ve studied for, I could do the theory, and then know how to apply it in a problem and it would work. But here you know the theory but the problem doesn’t directly relate to that. And so you have to use other ways, and you have to know techniques. (Interview 5, lines 399-403)

When I asked later on in the same interview if she had changed at all in how she approached her studies she indicated that she had changed in her awareness, but had not applied what she learnt. That she was still using an information-based approach also was suggested by her comment in the sixth interview that she was making sure she read each chapter as they covered the work in her new courses.

7.2.12. Summary of findings

From the above descriptions it will be clear that each student's motivation for and implementation of approach to learning was highly idiosyncratic. However, definite similarities between the experiences of subsets of these students are evident, and these will be briefly summarised.

Students who spoke of using a conceptual approach right throughout the course were Thabo, John, Eddy and Mike. Each of these was able to articulate clearly that they used such an approach in whatever they did, focusing primarily on conceptual understanding. Each of these students could remember prior experiences where they had used algorithmic and/or information-based approaches, but this was not their preference. They recognised quickly in CHE231F that a conceptual approach was essential, and were able to implement this directly. All of these students focused on working through examples on their own, although they stressed that
they used this to build conceptual understanding and felt that they were developing their own problem-solving methods.

Geoff, Lindiwe, Thembi and Andrew were all using an algorithmic approach at the start of the course, focusing on remembering set solutions to apply to problems in the assessment context, rather than aiming for conceptual understanding. From early on in the course they each individually voiced an awareness of the deficiencies of this algorithmic approach, but it was at different stages that they each actually managed to implement such a conceptual approach. This latter development can be seen as representing the control aspect of metacognition. Lindiwe managed a substantial shift to a conceptual approach after the second test, while Andrew showed some partial shift in this direction at that stage. Geoff and Thembi totally changed to focusing on their understanding when preparing for the rewrite examination.

Nomsa used both algorithmic and information-based approaches in the course, and although at the end of the course she did voice some awareness of the problems with these approaches, from these data it is difficult to say to what extent this represented a genuine metacognitive shift. She had used an information-based approach since school, and in CHE231F added a focus on problem-solving, which she approached in an algorithmic manner.

Both Shakira and Maria exhibited an exclusive preference for an information-gathering approach, having not even really picked up on the need to work through problems on their own in CHE231F. An interesting background fact is that these two students are the only two in the sample who had changed to chemical engineering from doing science degrees. They both commented that the information-gathering approach had worked for them in the science context, and it caused them considerable frustration that this previously successful approach was no longer working.

If the metacognitive development of the seven students who did not use a conceptual approach from the start of the course is now considered, there appears to be a distinct difference between those using only an algorithmic approach and those
using an information-based approach (in Nomsa’s case, in addition to an algorithmic approach). Lindiwe, Thembi, Geoff and Andrew all explicitly displayed increased awareness of the importance of a conceptual approach (and the limitations of the algorithmic approach), although they were differed in the extent to which they were able to convert this awareness into control of how they approached their learning in CHE231F. Shakira made almost no statements in this regard, Nomsa’s apparent awareness of a conceptual approach was questionable, while Maria made some comments which could be interpreted as an increased awareness of the need to consider the physical situation behind the numerical problems. What these three had in common was no coherent scheme of how to achieve a conceptual approach in practice, and unlike the former group of students did not at any stage experiment with this approach.

Table 7.1 provides a summary of the above discussion.

Table 7.1
Summary of individual approaches to learning as seen in self-reflective data

<table>
<thead>
<tr>
<th>Information-based</th>
<th>Algorithmic</th>
<th>Conceptual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thabo</td>
<td></td>
<td>Geoff</td>
</tr>
<tr>
<td>John</td>
<td></td>
<td>Lindiwe</td>
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<tr>
<td>Eddy</td>
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<td>Thembi</td>
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<tr>
<td>Mike</td>
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<td>Andrew</td>
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<tr>
<td>Nomsa</td>
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<td>Nomsa</td>
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<tr>
<td>Maria</td>
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<td>Shakira</td>
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</tbody>
</table>

Note. → indicates metacognitive development during CHE231F

From the analysis thus far it is also clear that context plays an important role in influencing students’ approach to learning. Even the students who were using a conceptual approach in CHE231F could cite other courses, particularly the Mathematics and Chemistry courses running concurrently in second year, where
they felt forced by the context to use algorithmic or information-based approaches. Furthermore, nearly all students recognised at some stage that CHE231F was requiring from them a conceptual approach, even if they did not manage to implement this.

The rest of this chapter provides an analysis of the conceptual data for additional evidence on the approaches to learning that were used by the interviewees.

7.3. Analysis of conceptual interview data

The conceptual discussion questions used in the interviews were described in detail in section 6.5.1. In this section the analysis of student responses to these questions will be presented. These data provide evidence of approaches to learning in action, compared to the previous section which discussed students’ self-reflective accounts of the approaches they were using.

The questions were designed to assess conceptual understanding, and in most cases it will be seen that a correct answer required a conceptual approach, although there are a few occasions where students gave a correct answer using what appeared to be an algorithmic or information-based approach. There are also a few instances where a conceptual approach was used, but the response was not sufficient to be scored as correct. The emphasis in this analysis, compared to section 6.5, is on the approach used, rather than on whether the item was correctly answered or not.

On a number of occasions students initially showed a focus on calculations or information remembered, but then followed this up by demonstrating a conceptual approach. In these cases the responses have been coded as conceptual, as the focus on understanding was demonstrated, even though part of the response might seem to be indicating a lower order approach.

In these discussions I first posed the question, then let students respond, sometimes asking for clarification of what they had said. In instances where the response was incomplete or unsatisfactory I often asked further questions to lead them to reconsider their initial response. I have termed this latter intervention ‘prompting’, and in the analysis that follows have used only unprompted responses for the
purposes of categorisation. Responses following prompting have sometimes been used to aid in the description of approaches, and in these few cases are labelled accordingly.

The findings of this analysis will be presented in two parts. The conceptual data from the first two interviews which dealt with mass balances will first be presented, followed by the energy balance data which was gathered in the next two interviews. This allows for comparisons to be made between approaches that students were seen to be using in the first and second halves of the course, and for any shifts in approach to be identified.

7.3.1. Mass balances

The analysis in this section is presented in two parts. Firstly, the data relating to the mass balance target concepts will be presented, and these findings summarised, and secondly, an analysis of students’ responses to the question on the purpose of the recycle problems follows.

Target concept 1: What is represented in the ‘orange juice’ demonstration?

Conceptual approach (Thabo, Geoff, Thembi, John, Eddy, Mike)

Students considered to have used a conceptual approach recognised both that the orange juice and the bolts were representing the solution and grounds respectively, and that the pouring off of orange juice was representing the action of the separator. These students were then also able to identify the key concept in the tutorial problem, namely that the concentration of the solution did not change when part of it was poured out, as illustrated in Eddy’s response.

Ja, what was it, orange juice with nuts and bolts in it, I think. Oh, what was that, a separator, separating solids and insolubles, or something. It was useful, I mean it gave you the picture of what was actually going on, that you’re not changing concentrations and stuff like that.

(Eddy, Interview 1, lines 292-296)

Algorithmic approach (Lindiwe, Nomsa, Andrew, Maria, Shakira)

In the responses classified as representing an algorithmic approach, students could identify what the orange juice and the bolts were representing, and/or identify that
the action of the separator was being demonstrated, but they were unable to identify any further conceptual purpose to the demonstration. I have taken these responses to indicate an algorithmic approach as the students are focusing on the mechanics of the problem but missing the key concepts. It is also worth noting that at the time of the first interview, when the question about the purpose of the demonstration was posed to students, they had all either successfully completed the problem or had discussed the solution with a tutor or other group members.

Information-based approach
This approach was not evident in these data. This not surprising as the question could not be answered by recalling information from either the lecture notes or textbook.

Target concept 2: Explain the difference between overall and per pass conversion.
At first glance one would think that this question would merely require an information-based approach for an adequate answer, in that it could be described as a recall of definitions. However, an analysis of the responses revealed the existence of both algorithmic and conceptual approaches to dealing with this question, and suggests that a conceptual approach was needed in order to be able to use these definitions appropriately in the context of a given system.

Conceptual approach (Thabo, Geoff, Lindiwe, Thembi, Nomsa, John, Eddy, Mike, Maria)
In differentiating between overall and per pass conversion, students needed to identify a particular location in the system where conversion would be measured, namely the whole system for overall conversion, and only the reactor for per pass conversion. This approach is illustrated by Thembi’s response, in which she stresses the purpose of the reactor.

Per pass [conversion] is mostly concerned with the reactor, so what it converts, that’s per pass. But overall [conversion] is, well including recycle ... so how much of everything that’s coming in and that’s coming back, that is being converted.

(Thembi, Interview 2, lines 257-261)

In a number of responses coded in this category students first gave the relevant formula or discussed the calculation method, but then followed this up with a
conceptual approach. With Eddy I had to ask him in each case to explain what he meant, but I have not considered this prompting as I was not adding any information or suggesting a line of thinking. His explanation for overall conversion is reproduced below.

Eddy: OK, overall conversion, that's the easiest one. Just say that you close this part off, draw a black box, and then your overall conversion would be the amount of moles of this in, minus that out, divided by that out [pointing to the relevant parts of the diagram].

Interviewer: So what does the overall conversion tell you, say we had a 50% overall conversion, what would it tell you?

Eddy: That 50% of your reactants in your fresh feed [stream] is being used up in your process, and then the rest is coming out.  (Eddy, Interview 2, lines 341-349)

Geoff's response is also interesting to consider at this point in that, although he later demonstrated a conceptual approach, his initial terminology of 'conversion...across the reactor' (lines 352-353) is very likely conceptually weaker than students who referred to conversion taking place in the reactor. The possibility that this indicates an underlying conceptual gap is further strengthened by Geoff's comment earlier in the interview that:

You see I'm not sure – you see maybe my definition of a reactor is incorrect. I'm looking at a reactor as something that does something to your mixed feed [stream], so that you can get something out.  

(Geoff, Interview 2, lines 288-290)

Algorithmic approach (Andrew)

In his response to this question Andrew firstly suggested that conversion per pass would refer to the reactor product stream as it goes through the splitter, indicating that he had not grasped that conversion had to do with a chemical reaction that takes place in the reactor. Later on he suggested that how you calculate conversion depends on where you take a basis\(^8\) (lines 288-292). Here he has confused a concept

\(^8\) Taking a basis is a calculation procedure whereby a numerical value is assigned to the flowrate of a particular stream, or species in a stream. Further calculations then proceed from this point. It is a particularly useful technique for a system where all specifications are in terms of ratios and proportions, but can also be used where a flowrate is given but temporarily ignored for ease of calculation. In the latter instance the final answer is then scaled up or down in order to match the initial quantities.
that is always defined in the same way (conversion), with a calculation method that depends on the given information in a particular problem (taking a basis). Further on in his response Andrew made repeated reference to the method that had been used to solve the problem in class (lines 384-386).

Information-based approach (Shakira)

In her response Shakira seemed to be clutching at statements remembered from lectures, which she was unable to explain in a conceptually or algorithmically sensible way. This indicates an information-based approach.

Conversion per pass is, I think, overall conversion was I know in the reactor we say 75% is converted over there, and then it comes out... So that would be the overall conversion. (Shakira, Interview 2, lines 268-269)

**Target concept 3: Which is greater: overall or per pass conversion?**

Owing to changes made to the interview protocol as the series of interviews progressed, this question was not used with four of the interviewees: Lindiwe, Nomsa, Andrew and Maria. The responses from the remaining students were analysed.

Conceptual approach (Thabo, Geoff, Thembi, John, Mike)

Students who were able to correctly reason out that overall would always be greater than per pass conversion in all cases used a conceptual approach, for example:

For me, in real life, with a recycle stream you continually have unreacted feed coming back into the product. Therefore increasing the amount of product you’re getting. (Thabo, Interview 2, lines 471-473)

John and Thembi each took this discussion one step further when, unprompted, they considered the limiting case where there was no recycle stream, in which case overall would be equal to per pass conversion.

Algorithmic approach

There was no evidence of an algorithmic approach in response to this question, a finding which is not surprising, as this question does not easily lend itself to a purely calculation-based approach. Such an approach would require a fairly
complex algebraic derivation, which would in any event most probably depend on a reasonable conceptual understanding.

Information-based approach (Eddy, Shakira)

These students recalled from the examples done in lectures that overall and per pass conversion were usually different, but they did not reason conceptually in order to be sure of this, or to be able to say if one was greater than the other. For example, Eddy said that ‘you can have 100% overall conversion, and then maybe say a 50% per pass conversion or something like that’ (lines 363-364), but he was not able to proceed much further in responding to the question.

**Target concept 4: What could you do to increase per pass conversion?**

Conceptual approach (Thembi, John)

This question required students to use their conceptual understanding of the nature of the actual process in order to realise that per pass conversion had to do with the chemical reaction happening in the reactor. Therefore, in order to change the per pass conversion the conditions in the reactor (for example, temperature or pressure) needed to be changed. Up to this stage the mass balance calculations in class had involved only the streams surrounding the reactor, and so this question required students to think beyond the possibilities presented in class. Only Thembi and John managed this conceptual approach without prompting.

Three different categories of responses which could all be described as illustrating an algorithmic approach were identified, and these will be discussed in turn.

Algorithmic approach 1 (Lindiwe, Nomsa, Maria, Shakira)

These interviewees suggested changing the composition of the mixed feed stream. Although this answer in certain instances could be considered technically correct, I would argue that it is conceptually weaker, as it is not referring to the primary issue (the reaction conditions). Students who gave this response were not able to explain why they would make such a change, and I would therefore suggest that this response is related to the usual themes of the mass balance calculations in class, which tend to be generally concerned with stream compositions. In other words, these students were suggesting something along the lines of common calculations.
After Lindiwe gave such a response she was then prompted to think of other ways of changing the per pass conversion. This prompted response is worth considering as it provides an interesting illustration of a ‘scaffolded’ (Bruner, 1976; Vygotsky, 1962) shift to a more conceptual approach.

Interviewer: OK. Any other things you think you could do to increase the conversion per pass?
Lindiwe: In the reactor?
Interviewer: Yes, conversion per pass.
Lindiwe: Does conversion depend on how easily the reaction takes place?
Interviewer: Yeah, what do you think? How can you make it happen more easily?

(Lindiwe, Interview 2, lines 243-251)

Algorithmic approach 2 (Eddy)

Eddy attempted to use the formula for calculating per pass conversion, but this did not lead to a conceptually satisfactory answer.

Per pass conversion. It’s the moles of that [mixed feed] minus that [reactor product] divided by what’s coming [in], right? So if you make what comes in here smaller, then that would increase your per pass conversion.

(Eddy, Interview 2, lines 395-398)

Instead of realising that the conversion per pass depends on the chemical reaction that happens in the reactor, Eddy grasped at the formula that was given in class for calculating per pass conversion, and assumed that this formula could be used to reason out how to increase pass conversion. This formula is given as follows:

\[
\text{Percentage conversion per pass} = \left( \frac{\text{reactant in MF} - \text{reactant in RP}}{\text{reactant in MF}} \right) \times 100
\]

It is initially difficult to figure out why this thinking leads to an incorrect answer, as this sort of reasoning is often used in scientific calculations. The problem is that he has assumed that all the variables are independent (as they are for example in the formula \(F=ma\)). In this instance however, changing the denominator will cause changes in both terms in the numerator, and it therefore cannot be used to determine changes to the conversion per pass. The problem here is that Eddy is
using an algorithmic approach which lacks the underlying conceptual understanding.

Algorithmic approach 3 (Thabo, Andrew, Mike)

An analysis of Andrew's response to this question illustrates yet another manifestation of an algorithmic approach in response to this question.

Andrew: You'd make this stream [reactor product] bigger.

... Interviewer: How would you increase that stream?
Andrew: I don't know. The question was stated 50% [conversion per pass], so if they said it's 60 you'd just have changed the numbers accordingly.

(Andrew, Interview 2, lines 499, 508-510, 515-516, emphasis added)

From the above it can be seen that Andrew has failed to even engage with the question as he does not see the point of the question. For him it does not matter how one would increase conversion per pass, what matters is how to do the calculations when given a certain value for conversion per pass. Evidence of this same approach can be seen in the initial responses from Thabo and Mike, both of whom expressed surprise that I could ask such a question, and indicated that it was not something they were inclined to think about.

No actually I’ve no clue as to why the conversion is 50% per pass, but it seems to work out for me. (Thabo, Interview 2, lines 408-409)

These responses have been considered different to the 'no attempt' category to be described below. It was not only that they could not answer the question, but they did not even see the point of such a question, as they did not consider this knowledge necessary for doing calculations in CHE231F.

Information-based approach

It would be expected that there would be no evidence of an information-based approach in the responses to this question, since it was not content that had been covered in class and could therefore not be recalled.
No attempt (Geoff)

When presented with this question Geoff merely said: ‘I’m not actually quite sure’ (Interview 2, line 78), after which he was provided with some prompts.

Target concept 5: What could you do to increase overall conversion?

Conceptual approach (Thabo, Geoff, Thembi)

This approach involved students using a fundamental understanding of the purpose of recycle systems (to increase overall conversion), for example:

I would think that the more unreacted product you have in the recycle ratio, the more feed you’d actually have coming into the reactor, and the more the reactor would be able to convert.

(Thabo, Interview 2, lines 448-450)

In some responses coded in this category students initially recalled the conclusion from class, but then backed this up with an explanation indicating the use of a conceptual approach, as illustrated in Thembi’s response:

Thembi: You recycled - wait, wait - recycled more or recycled less? [laughter]
Interviewer: OK, think about it.
Thembi: I think you’d have to recycle more.
Interviewer: To get a higher...?
Thembi: A higher overall conversion.
Interviewer: Why do you say that?
Thembi: Because then you would be putting in more reactants, and whatever went in, more of it is getting converted, cos you’re recycling more of it.

(Thembi, Interview 2, lines 361-370)

Algorithmic approach (Andrew)

Andrew’s response to this question again illustrates an extreme form of an algorithmic approach whereby he fails to engage with a question that is not focused on doing the calculation (similar to his response to the previous question). He is able to explain how to do the calculations if a 90% overall conversion is given, and refers often to the way he did that particular calculation, but is unable to explain what difference was made to the system in order to achieve that conversion.
Interviewer: If you want a bigger overall conversion what were you doing?
Andrew: Just change the amounts here.
Interviewer: Change the amounts in the product stream?
Andrew: Ja.
Interviewer: How did you do that?
Andrew: It's 90%. 'Cos the basis was here [in FF], overall conversion 90%, ... and it's a ratio of 2 to 2, 1 to 1.
Interviewer: You're telling me how you solve the problem if you've got a bigger conversion... What I'm saying is what did that actually do to the system?

(Andrew, Interview 2, lines 615-623)

Information-based approach (Lindiwe, Eddy, Maria)

These students recalled the conclusion from class but did not explain why this might be so, prior to further prompting.

Unclassifiable (John)

John responded immediately with 'more recycle' after which the discussion moved on. This response was possibly due to a conceptual approach, but there was no evidence to directly confirm this conclusion.

No attempt (Nomsa, Mike, Shakira)

These students did not give a response to this question until prompted further. Nomsa' response when prompted to have a look at the recycle ratio is worth considering, as it seems to indicate an algorithmic approach coupled with a serious conceptual misunderstanding.

Interviewer: Now tell me, for bigger overall conversion, what do you think you must do to the recycle ratio?
Nomsa: You must increase it. No you must decrease it, 'cos you want to have more coming over here [P], so therefore the RC ratio has to be smaller, because more of the ... [voice trails away].

(Nomsa, Interview 2, lines 435-439)

She is taking a larger overall conversion to imply a larger total product (P) stream, whereas it means only an increase in one component of the product stream (EO) and the decrease in the volume of reactants in this stream (E and EO) could in fact imply a lower overall flow rate.
Target concept 6: What is the overall conversion in worked example one?

Due to changes made to the interview schedule, this question was not used with Thabo and Geoff. The rest of the responses were analysed and are presented below.

Conceptual approach (Eddy, Mike, Shakira)

A conceptual approach to this question involved reasoning out that the conversion was 100% on the basis of there being no leftover reactants in the product stream, as illustrated in Mike's response when I asked him explain why he said 100%.

‘Cos what goes in must come out. And there are no purges, and only here, it's coming out here. And none of the reactants were coming out anywhere else. All the reactants coming in are forming all the products going out. (Mike, Interview 2, lines 511-513)

Algorithmic approach (Nomsa, John, Andrew)

Students who used an algorithmic approach did stoichiometric calculations on the worked example in order to calculate that the overall conversion was 100%. When students had arrived at the answer using an algorithmic approach, the interviewer prompted them to consider other ways of arriving at the answer by looking at the composition of the streams. Andrew's comment following this interchange was indicative of his apparent negative attitude to thinking things out for himself.

Interviewer: What else do you notice about this? Look at the product stream. Compare it to say this product stream in the previous system. What's different?
Andrew: Ja there's still reactants left.
Interviewer: So there's another way of knowing.
Andrew: Of checking.
Interviewer: Overall conversion.
[Andrew laughs]
Interviewer: If you've got no reactants here what can you always say?
Andrew: 100% [overall] conversion.
Interviewer: So, think about that. What? You weren't sure of that?
Andrew: Somebody should have told me that.
(Andrew, Interview 2, lines 425-438, emphasis added)

Information-based approach (Maria)

Maria recalled from class that the overall conversion in worked example one was 100%, but could not explain why this was so.
No attempt (Lindiwe, Thembi)
These students did not make any substantial attempt before receiving further prompting.

**Target concept 7: Is there a build-up of nitrogen in the system in worked example three?**

Conceptual approach (Thabo, Lindiwe, Thembi, Nomza, John, Andrew, Eddy, Mike, Maria)
Students demonstrating a conceptual approach were able to explain that because the input of nitrogen equalled the output of nitrogen, this meant that the system was in steady state, and that therefore there was no buildup, even though a (constant) high concentration of nitrogen existed in the parts of the recycle loop. Some students did not actually use the term ‘steady state’ but their responses nonetheless indicated that they understood the concept, for example Eddy:

> It’s just that you’ve got stuff coming, you got that same stuff going out, and then, obviously that inside you still got mixed, those are just going for a ride! (Eddy, Interview 2, lines 558-560)

Two of the students in this category initially responded that there was buildup in the system, but then were able unprompted to work out, using their understanding of steady state, that this answer was incorrect.

Algorithmic approach (Geoff, Shakira)
In these responses students were able to do the calculations but were missing the underlying conceptual understanding regarding steady state systems. When I asked Geoff why he said there was buildup he replied:

> Well it’s more nitrogen than you put in. (Geoff, Interview 2, line 563)

On the other hand he was not quite happy with this answer, and later on when he still could not resolve his confusion he said:

> It just seems to be going round and round. (Geoff, Interview 2, line 585)

Information-based approach
There was no evidence of an information-based approach in responses to this question.
Summary of mass balance questions (target concepts 1-7)

Table 7.2 presents a summary of the approaches exhibited by individual students in their responses to these questions.

Table 7.2
Summary of individual approaches to learning used in response to mass balance conceptual questions

<table>
<thead>
<tr>
<th>Target concept</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<tr>
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<td>C</td>
<td>C</td>
<td>A</td>
<td>C</td>
<td>—</td>
<td>C</td>
</tr>
<tr>
<td>Geoff</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>NA</td>
<td>C</td>
<td>—</td>
<td>A</td>
</tr>
<tr>
<td>Lindiwe</td>
<td>A</td>
<td>C</td>
<td>—</td>
<td>A</td>
<td>I</td>
<td>NA</td>
<td>C</td>
</tr>
<tr>
<td>Thembi</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>NA</td>
<td>C</td>
</tr>
<tr>
<td>Nomsa</td>
<td>A</td>
<td>C</td>
<td>—</td>
<td>A</td>
<td>NA</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>John</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>?</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>Andrew</td>
<td>A</td>
<td>A</td>
<td>—</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>Eddy</td>
<td>C</td>
<td>C</td>
<td>I</td>
<td>A</td>
<td>I</td>
<td>C</td>
<td>C</td>
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<tr>
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<td>C</td>
<td>C</td>
<td>A</td>
<td>NA</td>
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<td>C</td>
</tr>
<tr>
<td>Maria</td>
<td>A</td>
<td>C</td>
<td>—</td>
<td>A</td>
<td>I</td>
<td>I</td>
<td>C</td>
</tr>
<tr>
<td>Shakira</td>
<td>A</td>
<td>I</td>
<td>I</td>
<td>A</td>
<td>NA</td>
<td>C</td>
<td>A</td>
</tr>
</tbody>
</table>

Note. I = Information-based approach; A = Algorithmic approach; C = Conceptual approach; — = No data for this question; NA = No attempt; ? = Unclassifiable.

These qualitative findings do not permit any fine-grained quantitative conclusions. Nonetheless, if one takes a broad measure and examines to what extent conceptual approaches were used by each student across the different questions, one can make some reasonably defensible rough conclusions. The following students used conceptual approaches in the majority of the questions: Thabo, Geoff, Thembi, John, Eddy and Mike. The remaining students used conceptual approaches for a third or less of the questions. Of these students Nomsa and Andrew used mainly algorithmic approaches, while Lindiwe, Maria and Shakira used either algorithmic or information-based approaches in those questions which they did not answer conceptually.

When these results are compared to the conclusions of the self-reflective data, there is general agreement for all students in terms of dominant approaches except Geoff.
and Thembi. From the self-reflective data Geoff and Thembi were described as generally using an algorithmic approach due to course constraints, although they recognised the deficiencies of this approach and from early on valued a conceptual approach. It is seen here that in the interview situation they mainly used a conceptual approach. At this stage one could tentatively suggest that the less pressured context of the interview enabled them to use the approach which they inherently preferred (a conceptual approach), an approach which they struggled to use in the course environment.

What is also apparent in these findings is the diversity of approaches used by most students. This is to be expected for those students who were shifting metacognitively and experimenting with different approaches, but it is somewhat surprising in the cases of those students who claimed to be using exclusively a conceptual approach. All of these show at least one instance of using an algorithmic approach, while Eddy also demonstrated the use of an information-based approach.

Another way of looking at these findings is to compare the sets of responses for different questions. Two points emerge in relation to the nature of the questions. Firstly, the questions were explicitly designed to engage students in conceptual reasoning. It is therefore interesting to note the range of approaches that they elicited, and that in some instances algorithmic or information-based approaches were associated with correct answers. It would also appear from the findings that certain tasks (for example, target concepts 2 and 7) were particularly successful in ‘triggering’ the desired response (conceptual approach). Secondly, it has been seen that some tasks did not seem to allow for either algorithmic or information-based approaches. The former refers to a task that could not in any way be numerically calculated (target concept 3), and the latter are those where the relevant material had not been covered in class and could therefore not be recalled from memory (target concepts 1, 4 and 7). The limited opportunities for demonstration of an information-based approach (in only four tasks) raises the significance of the finding for students who used information-based approaches in a large proportion of these remaining tasks (Maria and Shakira).
Additional question on purpose of recycle examples

Students were asked both before and after the series of interview questions what they thought had been the purpose behind the presentation of these worked examples in class. These responses were analysed and grouped into three categories, the first two of which appeared to indicate conceptual and algorithmic approaches respectively, while the third category did not seem to indicate the use of any particular approach.

Conceptual approach

Responses in this group focused on the development of conceptual understanding of recycle systems. These students referred to the comparisons that could be drawn between these various systems once the calculations had been completed, and how these comparisons illustrated various concepts. Here is a representative response of this category.

Eddy: So I’d say that probably that if you compare all of them all together, you probably end up that you know your compositions of your streams would be same, ignoring inerts, and even if you add inerts, or something like that.

Interviewer: What do you think is the point of doing those kind of comparisons?

Eddy: So that you don’t get confused in the real world! [laughter]  (Eddy, Interview2, lines 638-644)

Algorithmic approach

In these responses students said that these problems were given in order to show how to do the calculations involved with solving recycle problems, with particular emphasis on choosing a basis and using input-output tables. Some responses in this category indicated that once you knew how to do these problems you’d then be able to tackle similar problems, for example:

Where you choose your basis would be very important, like taking in the mixed feed [stream] or in the fresh feed [stream]. And then the recycle affects whatever’s happening, and where you take your basis.

(Shakira, Interview 2, lines 247-250)
No particular purpose

Students who responded in this category said that these were just introductory problems that would usually be presented at this stage in the course. In these responses no particular purpose could be identified for the presentation of these problems, for example:

Interviewer: These problems, do you have a sense of...? Are these just four randomly picked recycle problems? Or is there any sort of specific reason she picked these four?
Andrew: I don't have a clue. (Andrew, Interview 2, lines 247-251)

Given the purpose and format of the discussion questions it was expected that a comparison of the before- and after- responses would show a shift towards a conceptual approach. The results are given in Table 7.3.

Table 7.3
Comparison of students’ perceptions of the purpose of the examples before and after engaging with the conceptual discussion questions

<table>
<thead>
<tr>
<th>Student</th>
<th>Before discussion</th>
<th>After discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thabo</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>Geoff</td>
<td>no purpose</td>
<td>C</td>
</tr>
<tr>
<td>Lindiwe</td>
<td>no purpose</td>
<td>no purpose</td>
</tr>
<tr>
<td>Thembi</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Nomsa</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>John</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Andrew</td>
<td>no purpose</td>
<td>C</td>
</tr>
<tr>
<td>Eddy</td>
<td>no purpose</td>
<td>C</td>
</tr>
<tr>
<td>Mike</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>Maria</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Shakira</td>
<td>A</td>
<td>A</td>
</tr>
</tbody>
</table>

Note. C = Conceptual approach; A = Algorithmic approach.

It is interesting to note that while only John stated the ‘conceptual’ purpose before the discussion, the students who shifted to this purpose after the discussion were largely those who have been shown earlier to use a conceptual approach (Eddy, Mike, Thabo) and others who had shown increased awareness of the need for a conceptual approach (Geoff and Andrew). The students who had been shown
earlier to favour an information-based approach and had more limited metacognitive development, were less amenable to this change (Nomsa, Maria and Shakira).

Thembi and Lindiwe are exceptions to this general pattern. In Thembi’s case this is particularly intriguing given her strong conceptual approach in the rest of the mass balance questions. Part of the reason for this response might lie in the nature of this question, which focused on the purpose of the problems as presented in class. In the previous analysis it has already been suggested that Thembi was able to demonstrate the use of a conceptual approach in the non-pressured atmosphere of the interview, something which she was not managing in the class context. On both occasions Lindiwe did not engage with the question at all (‘I don’t know’), which is most probably attributable to her general lack of engagement and apparent moodiness in the second interview, which was noted at the time.

7.3.2. Energy balances

The format of the conceptual discussion in the third interview differed from the recycle questions in the second interview in that it was mostly an extended discussion around a set of artefacts rather than a series of specific questions (except for the last question directed at target concept 12). Although it was possible in section 6.3 to isolate ‘target concepts’ from this discussion for the purposes of calculating a ‘conceptual score’, focusing only on responses around these concepts did not work for the analysis of approaches to learning as it had in section 7.3.1 above. Student responses around target concepts 8-11 were often quite brief and did not give any indication of approach used. This outcome is possibly related to the nature of the concepts and the particular questions, which generally did not lend themselves to extended reasoning. However, the interview structure resulted in considerable discussion between these particular responses. In this wider discussion there was frequently evidence of approach to learning, and the data on target concepts 8-11 is therefore presented as one section. The data on target concepts 12 and 13 was analysed per concept as in the previous section.
Energy balance data discussion (Target concepts 8-11)

In this section an analysis of the discussions around target concepts 8-11 is presented. All instances of explicit approaches to learning are categorised and discussed. It must be borne in mind however that this analysis differs to that in section 7.3.1 above. In the previous section every response was classified according to a particular approach, or noted down as undeclassifiable or described as ‘no attempt’. In this section discrete responses are not being used, and therefore not every part of the discussion is accounted for, only those where an approach could be identified. This is therefore a very different type of analysis, with the advantage of providing greater description of the nature of these approaches, and the disadvantage of not being able to give a definitive single classification for each student.

Illustrations of the different approaches identified in these data are outlined below.

Conceptual approach

Making links between data forms (Thabo, Geoff, Lindiwe, Nomsa, John, Andrew, Eddy)

The opening point to the conceptual discussion in the third interview was to ask students if they could see links between the different forms of data that were presented. The ability to make such links can be seen as evidence of a conceptual approach, although it could be said that in this case the approach was prompted by the format of the question. Mike’s response is reproduced here as illustration.

Ja there are links. They’re all basically trying to find out a value of your enthalpy change.  

(Mike, Interview 3, lines 718-719)

This particular formulation of the question was only developed after the first three interviews had taken place with Geoff, Thabo and Lindiwe, and Geoff had in fact spontaneously made links between the different data forms. Of the remaining students, all of them managed at least at some later stage of the discussion to make such links. For the purposes of identifying approach I have discounted these later responses, as they were directly prompted by my questions.

If the data from the rest of the discussion is now considered it can be seen that all the instances where students were explicitly using a conceptual approach deal with
students spontaneously making links of one kind or another. These different link-making activities are outlined below with illustrative examples.

Making links to the real world (Lindiwe, John, Eddy)

Students who engaged in this form of link-making related what was happening in the given data to what they knew of practical applications. This also frequently involved invoking a sense of scale of the different quantities, for example in Eddy’s discussion of the different parts of the H-T graph.

Because to take the enthalpy change say from that point to that point [demonstrating a sensible heat change], that’s small, because here you have that much [gesturing the enthalpy (y-axis) change], and here you will have a huge one [showing enthalpy of phase change]. If you’re designing you must try to get most of that enthalpy is going into your system. (Eddy, Interview 3, lines 391-395)

Making links to prior knowledge (Thabo, Geoff, Nomsa, John, Andrew, Eddy)

In these responses students used concepts or experiences from other courses or from earlier on in CHE231F to assist them in making sense of the current data. For example, Geoff made use of a discussion they had had in the chemical engineering design course (CHE232F) to explain what he understood by the term ‘flow work’.

But I saw it as work done by whatever the fluid or whatever on the sides of the pipe. Prof X was showing us a diagram, and he was showing fluids, and there’s all sorts of turbulent flow rubbing against sides of pipes. (Geoff, Interview 3, lines 343-347)

Criticisms of non-conceptual approaches (Thabo, Geoff, Thembi, Andrew)

At times in this discussion some students expressed their dissatisfaction with an algorithmic approach or an information-based approach, which could be seen as indicating metacognitive development towards a conceptual approach.

For solving energy balances students had been taught by the lecturer to first write down the standard inclusive energy balance equation, to cross off terms which were equal to zero, and then to find values for the remaining terms. Thembi and Andrew criticised this focus on equations, and indicated that they preferred to approach a problem using their conceptual understanding.
Thabo and Geoff both indicated during the discussion a frustration with knowing definitions but not understanding the meaning of terms or knowing how they linked together, for example the following comment from Thabo.

And there’s also - not understanding what some things mean because, I mean Dr Barnes talks about specific enthalpy and enthalpy. But what is specific enthalpy, what is enthalpy? (Thabo, Interview 3, lines 315-317)

Algorithmic approach (Thabo, Geoff, Eddy, Mike, Shakira)

Two manifestations of an algorithmic approach were evident in the data from this discussion. In one instance students were seen to be grasping at any formula that came to mind when trying to answer a conceptual question. This was particularly evident when I asked students to consider how the values in the steam table could be calculated, and they tended to come up with the formula $H=U+PV$, as illustrated in the following comment.

Interviewer: Well how would you get them [these enthalpy values] if you didn’t have the [steam] tables...
Geoff: OK there are some very nice equations [laughter]. Ja I’d probably use the equations.
Interviewer: What sort of equations?
Geoff: I know there’s that one, it’s not this one, it’s that famous chemistry one. Ja H- oh flip!
Interviewer: $H=U+PV$?
Geoff: Ja and we’ve got both H and U in it.

(Geoff, Interview 3, lines 449–457)

The whole purpose of this series of lectures and tutorials in CHE231F had been to develop methods for finding and calculating enthalpy values, which in practical chemical engineering problems are hardly ever calculated using $H=U+PV$. However, it seems to be the most common formula that students grasped at in the context of this discussion, most probably due to its prominence in first year Physics and Chemistry. Students who displayed this ‘grasping at formulae’ during the discussion were Thabo, Geoff, Eddy, Mike and Shakira.

Another manifestation of an algorithmic approach arose in the context of a particular lecture, where the lecturer had divided up the class into four teams. She had presented a scenario where a quantity of air underwent a temperature change, and given each team a different set of heat capacity data to use to calculate the
appropriate enthalpy change. During the third interview I was interested that four interviewees spontaneously made reference to this exercise, which clearly made some sort of impression on them. (It was unusual in any of the interviews for more than one student to spontaneously refer to the same class or tutorial exercise.) Yet it was just as interesting to note that two of them (Thabo and Shakira) could not explain what the purpose of the heat capacity calculation was. (It was to calculate enthalpy.) The discussion with Shakira reproduced below is illustrative of this response.

Shakira: This is mean molar, I remember doing this in the problem.
Interviewer: Maybe - what would you use this data for?
Shakira: On Monday when each group had that problem, then our group had, you had to find the mean molar of air at, what was it? 100 degrees. And then 300, and then we found the difference between those mean molar heat capacities. So you added each one, and then you divided.
Interviewer: Your group was doing when you got just molar heat capacity. ... This is different data. What was the ultimate point of that exercise, what were you getting out of it?
Shakira: The exercise?
Interviewer: Ja, how does heat capacity link to anything else here?
Shakira: Heat capacity is, let me think, we have an equation for heat capacity, heat capacity is equal to, I can’t remember.
Interviewer: When you were doing that exercise in your group you had to average out heat capacity and then what did you finally calculate? Do you remember what you were calculating?
Shakira: We calculated, heat capacity is equal to the integral of T, no, ja, the integral of temperatures related to enthalpy. The integral from $T_1$ to $T_2$ of $\Delta H$ equals heat capacity.

(Shakira, Interview 3, lines 374-400)

Interestingly, when asked generally Geoff was unable to explain what heat capacity data had been used for, but in the context of discussing this class exercise he was able to do so.

Information-based approach (Geoff, Nomsa, Shakira)

An information-based approach was displayed on the occasions that students made recourse to statements they remembered from class and from their notes, as
illustrated in the following response from Shakira, when asked to point out sensible heat changes on the H-T graph.

I think in my workbook I’ve got it [getting it out]. Remember we have those definitions. Where’s it? [paging] [reading out loud] ‘The change in enthalpy that takes place within a single phase’.

(Shakira, Interview 3, lines 530 – 533)

**What is enthalpy? (Target concept 12)**

Conceptual approach (Lindiwe, John, Maria)

These students were able to explain in their own words what was meant by enthalpy, as illustrated in Lindiwe’s response.

I suppose enthalpy would be the total energy of the system, after heat has been added, work has been done, and all that. It’s just the total, the energy.

(Lindiwe, Interview 3, lines 340-342)

Algorithmic approach (Thabo, Geoff, Thembi, Nomsa, Andrew, Eddy, Mike)

In these responses although students’ answers were not technically correct as they did not refer to enthalpy as the total amount of energy possessed by a flow system, they all referred to how enthalpy was used in common calculations that they had done in the course. These students all defined enthalpy in terms of changes in the system, and sometimes specified these changes as involving either heat or work. On first glance it was assumed that the students defining enthalpy as heat were deducing this response from the abbreviation for enthalpy, ‘H’. However, if the group of these responses is considered, they all have in common that they refer to the ways enthalpy had been used in chemical engineering calculations in class. These class calculations almost all referred to enthalpy changes, and often had heat or work being converted to enthalpy of the system or vice versa.

Information-based approach (Shakira)

Although Shakira’s answer was technically correct, and scored as such in section 6.5.2, a closer inspection of her response seems to indicate an information-based approach. She started reciting a few words, then said that she had forgotten the definition, but then found the appropriate place in the workbook and was reminded of the definition, which she recited verbatim.
How do energy balances change when chemical reaction takes place? (Target concept 13)

Conceptual approach (Thabo, Geoff, Lindiwe)

Responses in this category referred directly to what was actually happening in the system – that the chemical reaction generated or consumed heat, and that this had to be accounted for in the energy balance by using heats of formation, as illustrated in Thabo’s response.

Instead of just having a system where the energy is provided maybe by the flow coming in or the work done, or the enthalpy changes, you now have a reaction takes place, which may consume heat, which may give off heat, and as such affect your energy balance accordingly.

(Thabo, Interview 4, lines 471-475)

Algorithmic approach (Thembi, Nomsa, John, Eddy, Mike)

These students described the methods used to solve energy balances with reaction, without making reference to what was happening differently in the real system. In Eddy’s response he seems to be describing the calculation method (where you consider the heats of formation for each species) in terms of something that actually would be done to the system, as shown in the emphasised part in his response below.

Interviewer: What has changed in how you solve an energy balance problem?
Eddy: To be honest, you have a general energy balance, energy equation, right. From there you just added a few heat of formations and then your datum line dropped to something else, and then there was nothing new, I mean, the stuff reacted, you do a energy balance and you do a normal mass balance.

Interviewer: So the only new thing is heats of formation. Why have you now added heats of formation into your energy balance?
Eddy: Well according to that Himmelblau [the textbook], you first have to form the species before you react it, before it goes to higher temperatures.

(Eddy, Interview 4, lines 410-422, emphasis added)
Incomplete algorithmic approach (Andrew, Maria, Shakira)

This category was created for responses which referred to aspects of the calculation methods, but which did not single out specifically what was different in the calculations where reaction took place. Shakira’s response is representative.

I guess with reaction there’s a lot of, we use correlation a lot, ja. In solving the problems and specially finding final temperatures and stuff so, it’s like you have to find a lot of the data for yourself. (Shakira, Interview 4, lines 23-28)

Summary of energy balance data

The results from the analysis presented above are summarised in the following table.

Table 7.4
Summary of individual approaches to learning used in response to energy balance conceptual questions

<table>
<thead>
<tr>
<th>Target concept</th>
<th>8-11: Approaches explicit in extended discussion</th>
<th>12</th>
<th>13</th>
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<td>Thabo</td>
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<td>Thembi</td>
<td>C</td>
<td>Crit of A/I</td>
<td>A</td>
</tr>
<tr>
<td>Nomsa</td>
<td>C</td>
<td>I</td>
<td>A</td>
</tr>
<tr>
<td>John</td>
<td>C</td>
<td></td>
<td>C</td>
</tr>
<tr>
<td>Andrew</td>
<td>C</td>
<td>Crit of A/I</td>
<td>A</td>
</tr>
<tr>
<td>Eddy</td>
<td>C</td>
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<td>A</td>
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<tr>
<td>Mike</td>
<td>A</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Maria</td>
<td>C</td>
<td></td>
<td>inc A</td>
</tr>
<tr>
<td>Shakira</td>
<td>A</td>
<td>I</td>
<td>I</td>
</tr>
</tbody>
</table>

Note: I = Information-based approach; A = Algorithmic approach; C = Conceptual approach; Crit of A/I = Criticism of A or I approach; inc A = Incomplete A approach

Even more caution needs to be attached to interpretations of these findings than was suggested with the mass balance questions, the main reason being the form of analysis used for the discussion around target concepts 8-11. As was mentioned earlier, all that this analysis is showing is which approaches were evident from the data, and there were many responses where no approaches could be determined.
Nonetheless it is possible to derive some tentative support for, and in cases expansion on, earlier findings.

Of the group described in the analysis of self-reflective data as using a predominantly conceptual approach, Thabo, John and Eddy used both algorithmic and conceptual approaches in these discussions, which could be considered similar to their performance in the mass balance discussions. In this analysis it is not possible to determine which approaches were dominant. Mike shows an exclusive use of an algorithmic approach, which is surprising given his stated preferences, although this could be linked to his general lack of effort throughout the course.

Of all the interviewees only Lindiwe demonstrates an exclusive use of a conceptual approach in this discussion. This contrasts sharply with her responses in the mass balance discussions, and supports the earlier conclusion that she managed to put this approach firmly in place in the second half of the course.

The criticism of non-conceptual approaches by Geoff, Andrew and Thembi lends support to the earlier conclusion that they were undergoing significant metacognitive development during the course. In these discussions Thembi only exhibited algorithmic approaches, which contrasts with her consistent use of conceptual approaches in the mass balance discussions. Geoff and Andrew use a combination of approaches that can be considered similar to Thabo, John and Eddy discussed above, although Geoff also displayed evidence of an information-based approach during the extended discussion.

Nomsa and Shakira were seen to be using an information-based approach during the third interview, which supports the earlier findings. Both of them also displayed use of an algorithmic approach, while Nomsa also demonstrated a conceptual approach. This seems to suggest in both cases some development towards more sophisticated approaches. In the data from the extended discussion it was not possible to identify any particular approaches used by Maria, and this is more than likely due to her brief responses (in turn related to her lower level of confidence in English). In the other two questions she showed use of both a
conceptual and algorithmic approach, which would in her case also seem to suggest that some metacognitive development was taking place.

7.4. Additional evidence from conceptual journal data

Data from the self-reflective journal tasks were used in the analysis presented in section 7.2. The conceptual journal tasks were also scrutinised for evidence of approach to learning. These were of limited usefulness in this regard, partly because of the voluntary nature of the tasks, and mainly because of the directedness of the instructions which usually prompted a conceptual approach. For example, in the fourth journal task students were given clear instructions on how to construct a concept map and which terms to use. In the tasks which required students to consult the textbook they were told to make it clear in their submission how this had helped sort out specific concepts with which they were struggling. There were differences in the quality of responses to these tasks from the various interviewees, but this appeared to be related often to their general level of conscientiousness and care taken in reading the instructions. Two tasks however did permit useful analysis, and these are presented below.

7.4.1. Drawing your own concept map

As mentioned above, most of the conceptual tasks gave fairly explicit instructions to students. However, in journal task 9, students were given free rein to construct their own concept map or any other form of summarising the important concepts in energy balances. Most students who submitted this journal task produced some form of a concept map. This provided a useful opportunity to analyse the different ways in which students had approached this task.

At the time of marking these tasks, it had struck me that there was a qualitative difference between submissions where students had taken time and effort to produce a really useful concept map, and others where they appeared to have just thrown together a list of headings from the lecture notes. When I later analysed the submissions from the interviewees these distinctly different groups were again evident.
Students who submitted ‘good’ concept maps, where there was an original reworking of concepts and how they link together, and a clear input of effort and original thought were Geoff, Lindiwe, Thembi, and Andrew. ‘Poor’ concept maps, which showed a rushed off copying down of the lecture topics, with no real original thought or useful links drawn between concepts, were produced by Thabo, Nomsa, John, Shakira and Maria. Eddy and Mike did not hand-in this set of journal tasks. These journal task responses are reproduced in Appendix F.

It is interesting to note that those who benefited most and took most effort with this task were the ‘middle group’ of algorithmic thinkers undergoing metacognitive development (Geoff, Lindiwe, Thembi and Andrew). In the fourth interview Geoff, Thembi and Andrew each spontaneously mentioned this journal task as having been particularly helpful for them. The students who were firmly set in a conceptual approach either did not bother to hand in at all, or else did shoddy work. And finally, the students who made use of an information-based approach also produced poor concept maps.

It seems then that this exercise of getting students to overtly practice a conceptual approach was most useful for those students who were in the process of shifting towards and experimenting with such an approach. The students who were firmly settled in a conceptual approach did not make much use of this exercise, and those who had not been using a conceptual approach much at all also did not engage with the task.

7.4.2. Using the textbook – the concept of bypass

The concept of bypass provided an opportunity for a rather different sort of analysis. This concept had not been covered in class, but had been in the section of the textbook that students had been required to consult in journal tasks 2 and 6. It then appeared in a question in the second class test. This provided the opportunity to see how students were able to use in another context the concepts that they had read in the textbook and written about in the journal task.

Because of the voluntary and idiosyncratic nature of the journal tasks, one of the interviewees (John) had not mentioned bypass at all in his journal, and was
therefore omitted from this analysis. Other students also had to be omitted due to
the non-availability of their test scripts (Maria) and their prior exposure to this
concept (Mike). The test scripts of the remaining interviewees were scrutinised and
the results were intriguing. The only students to give the correct diagram for a
bypass system were Shakira and Nomsa, students who overall obtained some of the
poorest marks on the course. What this seems to indicate is that this question was
rewarding an information-based approach (atypical for this course) in that it
required students to recall information that they had read in the textbook and
reproduced in their journal task. Students who have been shown elsewhere in the
analyses in this chapter to make common use of an information-based approach
were therefore those who were most successful in this question. In short, Shakira
and Nomsa had taken the effort to remember the information that they had
gathered in the textbook, while the other students were not doing this, at least not to
the same extent. The assessment item considered here contrasted strongly to the
majority of the rest of the assessment items in this course, which required a
conceptual approach, and in which these two students generally scored poorly.

This analysis can therefore be seen to have provided further evidence for an
information-based approach, and its use by Shakira and Nomsa. (The data for
Maria was not available in this analysis.) An explanation of the bypass concept, a
description of the journal tasks and the test items, and more details of the analysis
are all given in Appendix G.

7.5. Conclusion

This section draws together the conclusions from the extensive analyses reported in
this chapter. These include the characteristics of the different approaches that were
identified, a summary of the use of approaches by individual students, a
consideration of the influence of context on the choice of approach, and finally,
specific conclusions regarding metacognitive development.
7.5.1. Characteristics of each approach to learning

In the introduction to this chapter the three approaches identified in this study were briefly described. The subsequent analyses have provided considerable elaboration on the nature of these approaches. The self-reflective data have provided students’ descriptions of what they were doing, and the conceptual data have given a picture of these approaches in action in the context of students’ responses to conceptual questions both in the interviews and in the journals. The characteristics of these approaches, as seen in both forms of data, will be summarised below.

The focus on understanding which is the hallmark of the conceptual approach was strongly evident in the self-reflective data coded under such an approach. There was a noticeable affective dimension to this approach, in which students expressed frustration when they didn’t understand, and an enjoyment and positive feeling when understanding. Many students linked the use of this approach to the real world situation of the chemical engineer, both in terms of the skills required, and the nature of the systems with which one would work. Another aspect of the conceptual approach was developing your own methods to solving problems, based on having constructed your own understanding. All of these students placed a high priority on working through problems on their own, but recognised that quality was more important than quantity.

In the conceptual data, students using a conceptual approach were shown reasoning out situations from first principles, or using a visualisation of the real world situation. They displayed a fundamental understanding of the purpose of the concepts that were dealt with in class, for example, the purpose of a recycle system. Many showed evidence of having puzzled over difficult concepts, and often made links with prior knowledge, and with other subjects that were being taken concurrently. They used their own words to explain concepts. They displayed a sense of confidence and security with their understanding.

The description of an algorithmic approach as being primarily concerned with the learning of solution methods was manifested in the self-reflective data coded under this approach. Students displayed a focus on remembering solutions, in order to be able to apply these when similar problems were given in a test or examination. The
emphasis lay on working through as many problems as possible, and remembering the solution methods given in the memoranda. Some of these students were aiming at finding one ideal method for solving a particular set of problems. Solving problems was seen as involving a search for the appropriate equation, and a substitution of values. The focus was on method rather than understanding. Students felt that understanding might come later, after one had worked through many problems, but this was not something they chiefly focused on. From an affective perspective, students using an algorithmic approach often expressed dissatisfaction with this approach.

The conceptual data provided ample illustration of students using an algorithmic approach. The key issue was a focus on calculations at the expense of understanding. This manifested in grasping at formulae without an underlying conceptual understanding, which in many cases led to conceptually illogical answers. This approach also involved not seeing the conceptual purpose of activities done in class, and in some cases, struggling to see the validity of the conceptual interview questions. The key focus was on the calculations that were covered in the course, and there was often an unwillingness to think outside the narrow scope of these calculations. These students were often also very unsure of their answers, and frequently didn’t have any ways of assessing the correctness of these.

Finally, the key feature of the information-based approach, a focus on gathering and remembering information, was well represented in the self-reflective data coded under this approach. Learning in this approach involved collecting information pertinent to the topic, copying down notes, and then memorising formulae, definitions and derivations, for reproduction in tests and examinations. The focus here was on what students termed ‘theory’. This approach involved considerable effort in cramming and trying to retain information that was not necessarily understood. Similarly to the algorithmic approach, students using this approach were generally aware that it was not working in the CHE231F context.

In response to the conceptual interview questions, students using an information-based approach often recalled definitions from the textbook, or conclusions that
were reached in class, without being able to explain what was meant by these statements. These students were frequently unsure of their answers, and unable to evaluate whether these were correct or not. A particularly interesting manifestation of the information-based approach arose from the analysis of students’ responses to a test question focusing on a system that had been covered in the textbook, and referred to in a journal task, but not in class. In general, students using an information-based approach were far more successful in reproducing the details of this system in the test question.

The summary now shifts to a consideration of which students were using particular approaches and when.

7.5.2. Uses of approaches by individual students

In terms of the approaches used by individual students, the analysis of conceptual data, from both interviews and journal tasks, has largely supported the initial findings from the analysis of the self-reflective data, given in section 7.2.12. For this reason Table 7.1 which summarised the findings from the self-reflective data is repeated below as Table 7.5, as it can now be considered to represent the combined findings of the self-reflective and conceptual data. The analysis of both forms of data allowed for considerable elaboration of detail on the use of approaches by individual students, and at this stage it seems reasonable to conclude the following points.

Thabo, John, Eddy and Mike all made predominant use of a conceptual approach throughout the course. Geoff, Lindiwe, Thembi and Andrew all started out using mainly an algorithmic approach although increasingly aware of the problems with this approach and the need for a conceptual approach. At different stages in the course they each managed some sort of a shift to a conceptual approach, Lindiwe considerably earlier, and to a greater extent, than the other three. Nomsa used predominantly algorithmic and information-based approaches, while Maria and Shakira had a strong tendency towards only an information-based approach. These latter three showed a small degree of metacognitive development in the course but did not manage to actually change their approaches in any notable way.
Table 7.5
Summary of individual approaches to learning

<table>
<thead>
<tr>
<th>Information-based</th>
<th>Algorithmic</th>
<th>Conceptual</th>
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</thead>
<tbody>
<tr>
<td>Thabo</td>
<td></td>
<td></td>
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<tr>
<td>John</td>
<td></td>
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<tr>
<td>Eddy</td>
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<tr>
<td>Mike</td>
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<tr>
<td>Geoff</td>
<td></td>
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<tr>
<td>Lindiwe</td>
<td></td>
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<tr>
<td>Thembi</td>
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<tr>
<td>Andrew</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nomsa</td>
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<td></td>
</tr>
<tr>
<td>Maria</td>
<td></td>
<td></td>
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<tr>
<td>Shakira</td>
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</tr>
</tbody>
</table>

Note. ————> indicates metacognitive development during CHE231F

7.5.3. The influence of context

In a number of different ways these analyses have illustrated the influence of context on students’ utilisation of approaches to learning. These can be divided into course effects and task effects.

On a course level, the self-reflective data showed a number of students talking about adopting different approaches in different courses. Some of them spoke about having felt forced to use a non-conceptual approach in some of their first year courses, and some of them talked about using algorithmic and information-based approaches in the context of the Mathematics II and Chemistry II courses respectively. All students showed some awareness that CHE231F was requiring of them a conceptual approach.

On the level of task, the conceptual data showed the use of a diversity of approaches, even for those students who stated that they were exclusively using a conceptual approach. The use of an algorithmic approach in this context seemed frequently linked to a lack of effort, as shown most dramatically in Mike’s responses to the energy balance questions. Conversely, students who stated that they were
not using a conceptual approach in general did show use of this approach in some of their responses. This was most notable in Mike and Thembi’s responses to the mass balance questions.

The issue of the influence context will be taken up in greater detail in the next chapter, which examines students’ perceptions of the CHE231F context and its influence on their metacognitive development.

7.5.4. Further comments on metacognitive development

In terms of the theoretical framework of the present study, where metacognitive development is conceptualised as a shift in approach to learning, the students who used a conceptual approach throughout the course did not by definition experience metacognitive development. In a broader sense, it is clear that the consolidation of this approach that they demonstrated did constitute some sort of metacognitive development. They all displayed increasingly sophisticated notions of this approach as they applied it in the demanding context of CHE231F. Nonetheless, the focus of the study is on those students who were not using a conceptual approach at the start of the course, and whether and to what extent they managed a shift to this approach.

As stated above, there was a significant variation in the metacognitive development demonstrated by students who were initially not using a conceptual approach. This variation can be described in terms of the aspects of knowledge, awareness and control. All of these students seemed to have some knowledge of the need for a conceptual approach, and awareness that the approach they were using was problematic. Lindiwe, Geoff, Thembi and Andrew were generally more articulate and detailed in expressing this knowledge and awareness. However, where these students differed most was in the control that they managed to exert in shifting to a new approach.

The control can be characterised by two aspects: extent and timing. Extent refers to whether students shifted completely to a new approach, or experimented partly with a new approach, or did not try a new approach at all. Lindiwe, Geoff and Thembi all showed a substantial shift to a conceptual approach. Andrew showed a
partial shift, where he was using a conceptual approach but it seemed in conjunction with an algorithmic approach. Nomsa, Shakira and Maria did not manage any actual shift. In terms of timing, Lindiwe displayed a substantial shift after the second test, the same time at which Andrew managed a partial shift. Geoff and Thembi both only managed a substantial shift during the preparation for the rewrite examination, although this was preceded by a long period of partial experimentation with the new approach.

It would appear that a substantial early shift to a conceptual approach, as managed by Lindiwe, was necessary for success on the course. All other metacognitive development displayed by students was in one way or another limited. The partial nature of Andrew’s metacognitive development seemed to be due to his general unwillingness to expend effort and time on his studies. This however was not the case for Geoff and Thembi, who were both extremely hardworking and dedicated. They showed a sophisticated awareness of the deficiencies of algorithmic approach from early on in the course, seemed to be experimenting on occasions with a conceptual approach, and when they did manage to exert control this encompassed a total shift to this new approach. The question that remains is why they only managed this control once the actual course had ended. Another question relates to Nomsa, Shakira and Maria, and why they managed virtually no metacognitive development, also despite serious hard work and engagement with the course activities. The next chapter will seek to address these questions.
Chapter 8
Perceptions of time

8.1. Introduction

In the analysis reported in the previous chapter it was established that students differed in their use of approaches to learning in the course. Some students used a conceptual approach throughout the course, and these students were all successful in the final assessment. Another group of students started out using mainly an algorithmic approach, and during the course became increasingly aware of the need for a conceptual approach. At different stages, mostly quite late, these students managed to shift towards using a conceptual approach. Only one of these students was successful in the course, and this was the only one who had managed this shift early on in the course. A final group of students used an information-based approach either on its own or in combination with an algorithmic approach for the entire duration of the course, with very little shift at all, particularly in implementation of a conceptual approach. The present analysis is intended to explore why it was that so few students had experienced successful metacognitive development towards a conceptual approach in this course. This was despite the need for a conceptual approach having been an explicit message throughout the course, reflected in teaching, curriculum and assessment. Furthermore, many of these students seemed to some extent to recognise this message, some of them from early on in the course; the difficulty came in implementing the approach which was done either partially, late, or not at all.

The theoretical framework for this study has as a key component the assumption that students’ perceptions of the course context influence their choice of approach to learning (and presumably any shifts in approach, designated as metacognitive development). These constructs were used in the formulation of the last two research questions outlined in Chapter 1. These questions concern the relationship between students’ perceptions of the context and their approaches to learning, and specifically which aspects of context were related to limited metacognitive development. The present chapter seeks to address these questions.
In the analysis to be reported here I therefore focused on students' perceptions of the course. For the group who were not using a conceptual approach, it seemed possible that something other than the need for such an approach was dominating their perceptions. During the data collection process, I had already become aware of the dominance of time issues for many of the interviewees, and this provided a starting point for the investigation. Firstly a very crude analysis was conducted to give a rough idea of whether this observation was justified. Counting up uses of the word ‘time’ by interviewees gave a total of 265 instances over 60 interviews, which averages out at 4.4 uses of ‘time’ per interview. In order to give a reference point for interpreting what is on its own a fairly meaningless statistic, I did a similar analysis for the words ‘understand’ and ‘understanding’, which together were used 320 times. Considering that understanding was a key theme both in the course (used frequently by the lecturer) and the interviews, one would expect that students would use these words quite frequently in their interview responses. Time issues were not part of the formal interview protocol, with one exception where (in the fourth interview) students were asked to comment on a perception that the lectures were fast. I would therefore assert that given that this theme of time was mentioned by the students almost as much as the one of understanding that was explicitly central to both the course and interview agendas, it was an important aspect of students’ perceptions. Although in this rough analysis there were distinctions noted between different students in their frequency of using the word ‘time’, it was decided not to make anything of this distinction, as it was likely to be due as much to conversational style and length of responses as anything else. A more substantial analysis of this issue was called for.

In this chapter such an analysis of students’ perceptions of time is presented, and this is used to explain the limited metacognitive development that was earlier observed.

\[9\] In this analysis I excluded figurative expressions like ‘time and again’, and ‘on time’ to leave only references to time in the literal sense, as intended in this analysis.
8.2. Common perceptions of time

8.2.1. ‘Time is money’ metaphor

In an analysis of students’ comments around time, what was immediately evident was the predominance of the ‘time is money’ metaphor. This has been identified by Lakoff and Johnson (1980) as a common Western way of conceptualising time, arising at about the period of the Industrial Revolution, when people started being paid by the amount of time worked (Lakoff, 1993). The presence of the metaphor is indicated by expressions such as ‘spending time’, ‘saving time’, ‘wasting time’ and ‘time management’, as illustrated in the following quotes.

I thought I could prepare differently, ‘cos I spent lots of time just on mass balances, and then I like, not totally skipped, but I only did a little examples with the equilibrium stuff. (Eddy, Interview 3, lines 78-80)

Ja, because it does definitely help if you remember a certain problem like that and say ‘OK well this was the shortest method I did it’. If it works here then I’ll definitely save time. (Nomsa, Interview 5, lines 251-253)

But I rather want to do a lot more work on my energy balances, because I still don’t have that in the bag. I’m still not quite sure. ‘Cos I wasted time during mass balances for that week. (Geoff, Interview 6, lines 99-101)

Ja I’d say [I’ve] develop[ed] quite a lot. For one thing I’ve had to be more responsible, like, really manage my time well. (Lindiwe, Interview 4, lines 298-299)

Lakoff and Johnson argue that this kind of metaphor is not merely a linguistic device, but indicative of how something is conceptualised, and hugely powerful in its influence on broader thinking. In this particular metaphor, time is seen as a resource of which one has a limited amount to be rationally apportioned to different tasks. From students’ comments it is clear that what matters most in this regard is to allocate time according to the importance of the task (defined by students’ views of the reward to be obtained). A significant implication of this metaphor is the belief that time is something that one can control.

All students other than Maria showed evidence on a number of occasions of using this metaphor. This occurred particularly in reference to the contexts of working
outside class, and doing a test or examination paper. The ‘time as money metaphor’
appears to shape student planning (how am I going to spend my time?), valuing of
different activities (will this be a ‘waste of time?’) and interpretation of results (I
should have spent more time on a certain topic).

There was a fair degree of consensus amongst all these students that paying
attention to time management was the most important thing in order to ensure
success in the course.

   And I think it's all a matter of time management.
       (Nomsa, Interview 4, line 231)

   It's just a matter of, it's just time management. That's what this course
also teaches you: can you manage your time. Ja.
       (Thabo, Interview 3, lines 568 – 570)

8.2.2. Criteria for decisions on time allocation

Working within this metaphor, students had to decide how to allocate the limited
amount of time that they had outside class. It was noted that all students ‘found
time’ for some activities, and said that they did not have enough time for others.
The following two quotes illustrate these common decisions.

   But you know if there was a test then obviously I’d get ... even if I had
hand-ins I would find free time.       (Mike, Interview 2, lines 308-309)

   I simply didn’t have the time to do a decent journal.
       (Thabo, Interview 4, lines 292-293)

The basis that students appeared to use for deciding whether they had time for
something rested first and foremost on its perceived value. Value was commonly
equated with assessment marks, and usually this meant that activities which were to
be assessed for marks (‘hand-ins’ and tests) were at the top of the priority scale.
Apart from the journal there were no assignments that had to be handed in for
CHE231F, and so in between tests many students did not spend much time out of
class on this subject, as explained by Thembi.

   The thing was it just never gave you time to actually spend any time on
231, ’cos then you never had to hand-in anything for 231. So you got
hand-ins [for the other subjects] and these were important. So you just
never got down to doing anything you didn’t have to hand in for.
(Thembi, Interview 6, lines 341-349)

However, when students explained why it was that they had not done certain low value activities, the reason was not usually given in terms of their value, but rather because ‘there wasn’t enough time’. It therefore seems that when deciding whether something can be fitted in to the schedule, the time available is not a fixed amount. Rather it depends on the value of the activity. This is a commonsense justification that most people use in their everyday life. As evident in Mike’s quote earlier on, time would always be found for an activity such as studying for a test.

A second measure that students used for deciding whether to do something or not was based on how much time the activity was likely to take. The journals, which held a low value in terms of marks to be obtained, were seen by some students as being very time-consuming (and therefore not worth doing) and by others as not taking up too much time (so they might as well be done).

8.2.3. Decisions about whether to invest time in understanding

It was widely recognised by students that ‘thinking’ was a very time-consuming activity. Their approach to learning determined the value that they placed on understanding, and because of the value criterion described above, students responded in different ways to this issue.

Students using information-based and algorithmic approaches tried to avoid activities involving thinking as they were perceived as likely to take up too much time. They preferred to choose activities that were not time-intensive and that were perceived as likely to directly yield marks. This viewpoint extended both to the context of deciding what to do in one’s out of class time, and also to the context of deciding which questions to do in an assessment situation. The justification given for avoiding activities involving ‘thinking’ was similar to that given for avoiding low value activities: simply that there was not enough time. This view on ‘thinking’ is illustrated with the following three quotes.

Commenting on a set of journal tasks that had been handed out that week, Geoff said the following:
And I don’t think I have the time. I don’t know – one thing looks like an exercise - I might do that, as practice. But to sit and think, at the moment I don’t have time to do that. (Geoff, Interview 4, lines 380-382)

Shakira commented at the end of the course that she had been too scared to delve into things that she did not understand, as she realised that this would be time-consuming:

I knew last semester that material balances was like, it was the first section that we did. That was my major downfall. And I was just too scared to actually go into it, because I felt I didn’t have time and if I actually start and I realise how much I did know, that would just make it all the more worse. (Shakira, Interview 5, lines 13-18)

Nomsa described a common examination strategy where students chose to start with the ‘easy’ questions that did not require too much thinking (and consequently time).

OK. I first looked at this question 1, and I said ‘It’s going to take too much time and need a lot of thinking’. So I thought, ‘Let me first build my confidence by doing those easy ones first’.

(Nomsa, Interview 3, lines 50-52)

Students using a conceptual approach differed radically in the choices they made in this regard. They valued understanding above all else, and were willing to invest time in ‘thinking’. Despite the large investment of time with little immediate visible gain, they were prepared to do this due to the long-term reward that they knew they would obtain. Eddy described this clearly when he compared what he had done in first year with what he was doing in CHE231F.

OK, the laziness part of me [in first year] was usually not going to the text. I would take my notes, I would do enough, but then, you know, you look at the textbooks and [snaps fingers], when you write a test I’ll take the time, but with this it’s like, you get stuff, and then even if you don’t write a test, if you don’t understand it then you must go to your textbook. (Eddy, Interview 4, lines 489-494, emphasis added)

8.3. Problems with time

As has been seen in the above analysis, virtually all students displayed a strong belief in the ‘time as money’ metaphor, and it influenced most of their learning decisions in the course. An important feature of this metaphor is the implication
that one can control time, and that all this involves are rational decisions, to be made on the basis of simple judgements of value and time available. However, in their actual experience many students, particularly those not using a conceptual approach to learning, found that it was not possible to stay in control of time. Despite their best efforts at time management and huge investments of time, they could not keep up with the time demands of the course, and were not succeeding in the class tests. I have termed this phenomenon the ‘breakdown’ of the metaphor, in that the beliefs which structured students’ thinking did not work out in practice.

The breakdown of the ‘time is money’ metaphor was reflected in other ways of talking about time, in which time seemed more like a runaway roller coaster or a nightmarish monster than an impassive resource which was firmly under control. Students used expressions such as ‘time caught up with me’, ‘time’s not on your side’. Other language more directly challenged the effectiveness of their time management, as they started to feel that there was never enough time, no matter how well they apportioned it: ‘running out of time’, ‘time-consuming tasks’. All the same, the experience of not being able to control time did not seem to change students’ beliefs related to the original metaphor, and they merely became more committed to time management, believing that they just had to work harder and faster.

It can be seen how approach to learning and perceptions of time had the potential to become linked in a vicious cycle. Students not using a conceptual approach were more likely to experience problems with time, and because they were experiencing problems with time they were less likely to use a conceptual approach, believing that there was not enough time for the time-consuming activity of ‘thinking’.

This experience of not coping with time was noted in a number of contexts, two of which will be dealt with here by way of illustration of the phenomenon. These analyses will also confirm that although in some respects all students had this experience at one time or another, it was the students using non-conceptual approaches for whom this became a central feature of their perception of the course.
8.3.1. Not coping with time in lectures

In this analysis I identified which students said that they were struggling with the pace in lectures. At this stage I left aside students’ responses to my question in the fourth interview which asked whether they thought the pace was fast, and focused only on unprompted mentions of this issue. In the second interview the following students mentioned spontaneously that they found the pace of Dr Barnes’ lectures too fast: Geoff, Lindiwe, Thembi, Nomsa and Andrew. Nomsa and Lindiwe each repeated this opinion in a later interview. Notably this group comprises all of those using an algorithmic approach at the start of the course. In contrast, Shakira had commented in the first interview that she found Dr Stevens’ lectures too fast, and in the second interview said that she found Dr Barnes’ pace fine. Maria did not raise this issue at all.

None of the students using a conceptual approach from the start of the course noted problems with the pace of the lectures, with some of them actually commenting that there was more time in the CHE231F lectures, specifically in terms of time allocated to work through problems for yourself. John was one student who voiced this opinion.

Well we get more time to actually solve them [the problems] now, like there’s more effort put on solving, us actually trying to solve the problems, whereas other lecturers they’d give us a little bit of time, if you didn’t get it, then they’d either just give you the answers, or tell you to find it out at home. (John, Interview 1, lines 37-41)

The differing experiences of the ‘conceptual’ and ‘algorithmic’ groups can be readily explained in that while the former were concentrating on understanding (which was what the lectures were designed for), the latter were focusing on getting down every step in the solution of examples, and these were often quickly covered or incomplete because of the conceptual objectives. It is somewhat surprising that Maria and Shakira did not find the lecture pace a problem. This could well be because their expectations were so much lower than the algorithmic group (they only wanted to get down the definitions and formulae).

This interpretation is supported by another interesting observation in the context of lecture pace. Nomsa commented that she found the pace of the Chemistry class
much slower and more manageable than CHE231F. By contrast, John found Chemistry 'very fast' and commented that:

It’s just so much in, I don’t know. I know [the lecturer] just goes very fast, but all the stuff, it’s just too much, it’s deriving of equations, and tons and tons of equations, like in a section there’s like fifty [equations].

(John, Interview 3, lines 155–158)

I sat in on one of the Chemistry classes and noted the passive transmissive teaching style used by the lecturer. At some stages of the lecture he silently wrote on the board while students copied down, and at other stages he dictated notes to them. This was interspersed with some explanation and a few jokes, but at no stage did the lecture attempt to gauge the class’s understanding or to elicit questions. It seems likely that Nomsa and John’s different experiences of the pace of this class relate to their different approaches (and intentions). Nomsa seemed to be happy with the steady stream of definitions and with the established routine of students copying down what was written on the board, while John was frustrated with the lack of conceptual engagement in this class.

In response to my question in the fourth interview on whether they agreed that the lectures were fast, most students conceded that they were fast (even those who had not spontaneously mentioned this issue). However, some of the students followed up this concession immediately with the observation that the lectures would seem fast if you weren’t keeping up to date at home (John, Thabo, Mike, Eddy and Andrew). Geoff, Lindiwe and Shakira were not asked this particular question. Thus drawing any conclusions here is tenuous, except to say that of those who were asked the question, only Thembi, Nomsa and Maria did not make this link. What is interesting is that the students who were struggling with the pace in class were in fact putting in long hours at home, but, because of the approach they used, this did not help in their experience of the lectures.

8.3.2. Not coping with time outside class

This issue has already been partly covered in section 6.2, where the issue of ‘working hard’ was considered. It was shown there that a majority of the interviewees (all except John, Andrew, Mike and Maria) were working outside class
to an extent that was impinging on their general energy levels and psychological state. These students spoke of working every evening after class till around midnight, working through most of the weekend taking maybe an evening off, and then working throughout the vacation week. For many of them with this level of work they were barely managing to submit the required hand-ins and prepare for tests. It was only Eddy, Thabo and Lindiwe (some of those using a conceptual approach) who said they found time outside class to puzzle over homework problems from the CHE231F class or to sort out misunderstandings.

At this stage it is important to remember that not all of this out of class work concerned CHE231F. In fact, the hand-ins and projects were mainly from other courses. Following information from a number of the interviewees I compiled a schedule of all their hand-in and test dates over the semester, to gain some sense of the ‘out of class’ workload. This schedule is given in Appendix H. From the perspective of a typical engineering programme, at a first glance this schedule does not look too onerous: on average about three assignments or tests per week. A number of things need to be borne in mind. Firstly, these assignments are on top of the normal load of contact time, which involves four lectures every morning, and practicals or tutorials on four out of five afternoons. More importantly though, one needs to look at the nature of the assignments, and from the perspective of the students. I asked Geoff to provide an assessment of how long he spent on the average assignment in each course: three hours for a CHE232F tutorial; three hours for a CHE233W group practical but nine hours for the one individual practical; three to four hours on a CEM203W practical if he did it himself but two hours if he copied the solution. The CEM203W writing project took a lot of time as it required much attention to detail; he estimated that in total he spent 12 hours on this project. It appeared that most of the assignments were required to be typed, and those students who were less experienced in word processing and spreadsheeting spent many hours working on these aspects. This is not to suggest that these are not important skills to master, but just to note that this added considerably to the time pressure for many students. It is interesting to note that the CHE231F journals were not required to be typed, and as a result only a handful of students (presumably those with computers at home) handed in typed submissions. I asked Thembi to
describe the various hand-ins for me, and her comments essentially confirmed Geoff’s assessments. Her closing comment is an apt summary of the situation.

The thing was it just never gave you time to actually spend any time on 231, cos then you never had to hand-in anything for 231. So you had hand-ins and those were important. And it’s not as if you just sit down and you do it. You have to ... most of the things you never know so you have to go ask someone else, and if they’re not around you just have to keep [going back to find them]. It takes you a lot longer than you think it’s going to take you. So you just never got down to... doing anything you didn’t have to hand in for.  

(Thembi, Interview 6, lines 341-349)

8.3.3. Not coping with time in tests

If the assessment context is considered, all students (even John) indicated at some stage in the course that they struggled with the time pressure in tests and the final examination. By applying time management strategies to their approach to the paper (as advocated by the lecturer) the more successful students were able to manage this aspect of the assessment, but for some interviewees this became an insurmountable battle, and ultimately dominated their experience of the course. This latter group included Geoff, Thembi, Nomsa and Shakira, and to some extent Andrew and Maria as well.

These students started to focus exclusively on ‘working faster’, often at the expense of making sure of conceptual understanding. For example, many of them tried to remember standard problem solutions so that they could save time in the examination. Furthermore, the more stressed they became about the time limits in the examination, the less able they were to think sensibly while writing the paper. Once again a vicious cycle was noted, where the more they worried about time, the less inclined they were to use a conceptual approach, and therefore the greater the problems they had with completing the tests and examinations.

The following extract from the interview with Shakira held after the June examination gives a palpable sense of the panic resulting from the time pressure, and the resultant avoidance of time-consuming thinking.

And then I started with it, and then, I did part 1, and then I realised no I’m probably doing the wrong thing. So then I doubted myself, so I
scratched, and I did the whole thing again, and then I realised, no, time was running out, so then I went on to this [question 4] and I then. It was just like there was no time for the paper. It wasn't where you just read it and just do what you know, it was like you had to sit and think about it and that took so much of time. And then this question as well. At first I thought it was OK but then after reading it, I just confused myself with the whole thing. Just going around in circles, and then I wasn't sure whether what I was writing was right or wrong. And then I felt it was wrong so I kept scratching it.

(Shakira, Interview 5, lines 39-51, emphasis added)

From early on in the course Nomsa voiced her concerns about not being able to think fast enough, an issue which had her doubting her ability to be an engineer. This is illustrated in the following quote, which was said in a noticeably emotional tone of voice.

I've discovered something about me, which made me think quite a lot. Am I really fit to become a chemical engineer, like the way I think, and the way I take things you know. Like when working in groups in tuts, and my group mates usually work so fast, and you know they think so fast, ideas just come. And I have to sit, try to figure out really what's happening, until eventually I get the idea. So I want to do more problems, like training to get used to thinking fast and stuff. (Nomsa, Interview 1, lines 376-384)

In the last sentence of this quote her focus on ‘thinking fast’ is stated, and this dominated her examination preparation as well.

The student who had the most chronic problems in this regard was Thembii, who mentioned this issue in almost every interview, and in a number of her journal responses. She said she had never managed to finish an exam paper since school, and that this was something that she had just resigned herself to by now. The problem was that in CHE231F it was causing her to fail the assessments. Viewing her examination scripts gives the sense of someone who became almost paralysed, as there was very little even written down in her script after a three hour examination (especially compared to other students who filled reams).

8.3.4. Conclusion

Students who tended most to experience the breakdown of the ‘time is money’ metaphor, and the consequent experience of not coping with time pressure, were
those identified in the previous chapter as using non-conceptual approaches to learning. These two factors interacted in a vicious cycle, with the experience of time pressure (often exacerbated by a non-conceptual approach) also inhibiting any metacognitive development towards a conceptual approach.

It would appear that the dominance of time issues in these students’ experience of the course tended to overshadow their focus on a conceptual approach, and limited their metacognitive development. Nonetheless, the metacognitive development that was demonstrated by students such as Geoff and Thembi was not insignificant, and it is hardly surprising to note that this was strongly interlinked with developments in their perceptions of time, as will be seen in the next section.

8.4. Relationship between perceptions of time and metacognitive development

8.4.1. Development of new perceptions of time congruent with conceptual focus

It has been shown throughout this analysis that although students using a conceptual approach had a similar framework for perceiving time to others, and experienced similar problems, their approach to learning meant that their perceptions differed in subtle respects. Most importantly they placed a premium on understanding. This meant that they were willing to invest substantial time in understanding without receiving immediate reward. It also meant that when they experienced time pressure, they still concentrated on getting their understanding right, rather than focusing on working faster.

It would therefore be expected that students demonstrating metacognitive development towards a conceptual approach would exhibit accompanying changes in their perceptions of time, and this indeed was most evident in statements from Geoff and Thembi towards the end of the course. An awareness of this new ‘valuing’ of understanding and its implication for perceptions of time is illustrated in the following comment from Geoff. When asked what advice he would give to a new student, he said he wouldn’t give the advice he was given, which was to do
loads of problems. He would rather suggest they focus on understanding, and when he was asked to explain what he meant by that, he replied:

Whew! I’d say do a difficult problem and spend some time on it and try and get out of it as much as you can. Like understand the percentage conversion, understand where you took your reference points from and why, and how did you get that answer.

(Geoff, Interview 5, lines 603-607)

The unexpected endpoint of this seeming counter-intuitive approach to time management (wasting time on a very time-consuming activity with no immediate gains) is that students find that other activities and the course in general become much more manageable in terms of time. This was recognised by students who had started to engage with a conceptual approach.

It saves a lot of time, and I just find if I’m doing my own things, then it’s logical to me, so, it comes a lot easier when I do do something. So I can rationalise things rather than memorise them.

(Thembi, Interview 4, lines 418-421)

These shifts in perception of time were not so clearly evident in the data from the two other students who demonstrated significant metacognitive development from an algorithmic to a conceptual approach. In the case of Andrew, time pressure was never a dominant focus like it was for most other interviewees, as he generally was not working hard enough to experience this pressure. In his case it seems that lack of effort was a more significant factor inhibiting metacognitive development than perceptions of time. As far as Lindiwe is concerned, it seems likely that these shifts in perceptions of time did in fact take place, as she managed not to let time pressure, which she certainly experienced, interfere with her use of a conceptual approach. That this shift was not vocalised is possibly partly due to her general reticence in the interview situation, as well as the fact that her metacognitive shift took place during the course at a time when the interviews were not so strongly focused on reflection.

8.4.2. Unlimited time test and possibilities for metacognitive development

In the pilot study I had noted the potential of the unlimited time test for helping students to engage in reflection on their conceptual understanding and ultimately in the perception they had of understanding (Case et al., 1999). This finding was
strengthened in the 1999 data, where students were far more likely to show this reflection after the unlimited test than the other two class tests. Thembi explained why this was so in the following comment.

Well I suppose it really actually shows you what you really, well not what you really know, but into how much depth you actually understand. ‘Cos I mean when you have a normal test, and you have time pressures or whatever, you’ll do what you know, and maybe you might pass or whatever, and that’s fine, but you never got to the other stuff that you actually did really know. I mean you can go through the solutions afterwards. It’s not really the same.

(Thembi, Interview 5, lines 483-490)

Other students who specifically commented that the unlimited time test had shown the problems in their understanding were Nomsa and Andrew. Shakira commented on being able to have time to actually think about the questions, which contrasts to her usual experience as illustrated in the quote in section 8.3.3. John and Lindiwe said that this experience had boosted their confidence in their understanding. Many students mentioned the feeling of relaxedness, which was for them a rather strange but very pleasant feeling in a test situation.

Some students struggled however with the new situation of no time constraint, and ended up tired before they had finished the paper. Even if they had experienced conceptual benefits, their ultimate feeling was sheer exhaustion. Because of this, both Thabo and Geoff had mixed feelings about the unlimited time test. Thabo thought it was good that he had worked through every single question, but did not like the experience of feeling tired at the end. Despite his earlier experiences of test panic, Geoff now said that he had struggled to concentrate in this test without the usual time pressure. Maria, who had had her paper removed from her nearly six hours after the start of the test, just said that she was ‘out of it’.

The lecturer’s purpose behind the unlimited time test was to show students that it was not time, but understanding, that mattered. And indeed it seems that this purpose was obtained for many students but only for this particular test. In the assessment that followed, the usual time pressure pertained, and students reverted to their existing priorities.
8.5. Conclusion

The analysis in this chapter has shown important similarities and differences in the students' perceptions of time. All students, those using conceptual and non-conceptual approaches, subscribed to what has been termed the 'time is money' metaphor. They viewed time as a finite resource that one could rationally allocate to different activities, and believed time management was of utmost importance. Within this general belief a subtle difference was identified between those using conceptual and non-conceptual approaches. The former group were willing to invest considerable amounts of time in developing understanding, even though it did not directly account for marks in the short term. The latter group avoided expending time on conceptual activities and concentrated instead on the large workload of hand-in assignments.

All students experienced to some extent what has been termed the 'breakdown' of the time is money metaphor, when they found in practice that it was difficult to be in control of time. For students using non-conceptual approaches, however, this led to a vicious cycle which came to dominate their experience of the course. The more they felt time pressured, the less inclined they were to use a conceptual approach, and consequently the more they struggled to reach the course outcomes within the time constraints.

Students' perceptions of time were therefore in general linked to limited metacognitive development. Unfortunately the CHE231F context served in many ways to support these perceptions. In particular, the assessment contexts reinforced the importance of being able to work under time pressure. This message was at odds with the other messages of the importance of conceptual understanding. This was especially so for students who held the value systems described earlier, which were related to the belief that there was not enough time to think. In the one assessment context where the time pressure was removed, students were able to focus on conceptual understanding. This however was an isolated experience.

It has been shown that those students who did experience metacognitive development also showed a change in their perceptions of time, particularly in regard to the value of the time-consuming activity of developing understanding. It
seems that the extent of this development was limited by the mixed messages in the course context with respect to time, which only provided an isolated experience (the unlimited time test) with the potential to help develop these new perceptions.
Chapter 9
Conclusion

In this final chapter the findings of the study are drawn together and implications are considered, both for theory and for practice.

9.1. Summary of findings

The context for this study was a second year chemical engineering course, ‘Material and Energy Balances’, generally referred to by the course code CHE231F. In 1998 significant changes, focused mainly on improving students’ conceptual understanding, had been implemented to the teaching of this course. These changes included a reduction in course content, more interactive methods of lecturing, and different forms of assessment questions. The course coordinator had also given serious consideration to the importance of metacognitive development in supporting conceptual learning and had implemented a series of journal tasks to this end.

This study has centred on eleven students in the CHE231F course in 1999. As a researcher I followed the ups and downs of their experiences of this course through a series of interviews, as well as reading their journal entries, observing them in class, and scrutinising their test and examination scripts. Of the eleven, only five passed the course. These were not the five most hardworking or apparently most organised students. They did however show a more consistent use of a conceptual approach to learning, and a consequently general higher level of understanding of key CHE231F concepts (as measured in an initial assessment of their responses to conceptual interview questions). This set the background for the major focus of the analysis of the data, as I sought to uncover how and why only certain students had developed the requisite conceptual understanding.

Approaches to learning are a useful way of describing different ways in which students’ engage with educational contexts, and are identified primarily by the student’s underlying intentions when undertaking learning activities. They are not
stable characteristics that students bring to any context but occur in response to particular contexts. An analysis of both self-reflective and conceptual data suggested the existence of three different approaches to learning in this context: a conceptual approach, in which the underlying intention is to understand concepts; an algorithmic approach, in which students focus on learning solution methods; and an information-based approach, where there is an emphasis on gathering and remembering pieces of information.

In the analyses of data the influence of context was evident. Many students described using a different approach in the second year Mathematics and Chemistry courses compared to what they were using in CHE231F. In response to the conceptual interview questions students also deployed a range of approaches. However, when reflecting on the CHE231F context most students described a dominant approach, or attempts to shift from one approach to another. Four students made predominant use of a conceptual approach from the start of the CHE231F course. Together with another student who shifted to this approach very early on (and who seemed to have considerable previous experience of such an approach), these were the five students who were successful in the course. It therefore appeared that the course was in fact assessing conceptual understanding, as had been planned. However, the lecturers had also hoped to support metacognitive development, and it seemed that this aim was not met. Of the seven students using non-conceptual approaches at the start of the course, there was only one who managed a clear shift to a conceptual approach during the course. The remaining six students displayed partial, late, or no metacognitive development, and this experience was collectively referred to as ‘limited metacognitive development’.

The focus of this study shifted towards those six students who had not managed to substantially use a conceptual approach at any stage in the course. What was of particular concern was that the three students using predominantly an algorithmic approach had shown significant awareness of the deficiencies in this approach, and at times did make genuine attempts to change their approach, but they were unsuccessful in these attempts over the duration of the course. Two of these
students did manage to seriously engage with a conceptual approach during their preparation for the rewrite examination, but this was too late to build sufficient conceptual understanding. At this stage of the study it was necessary to explore why it was that this metacognitive development had been so limited. This was done through an exploration of key aspects of students’ perceptions of the CHE231F course context.

A dominant aspect of students’ perceptions of this course concerned time pressure. This time pressure was noted both in the workload outside class, and in tests and examinations. Students’ ways of talking about time suggested the use of a ‘time is money’ metaphor, where time is seen as a resource that one can rationally apportion to different activities. All students shared this general perception, yet there were significant subtle differences between those using conceptual and those using non-conceptual approaches. The former group recognised that although using a conceptual approach was costly in terms of time, it was essential for success in the course, and actually in the long run would therefore save time. The latter group avoided this approach as it was felt that there was not enough time available. This led to a vicious cycle when, after failing to develop conceptual understanding, they experienced even more time pressure, and were even more inclined to feel that there was not time for the use of a conceptual approach.

In the remainder of this chapter these research findings are discussed from two different perspectives. Firstly, there is an assessment of the utility and validity of the theoretical framework that was developed for this study, and this is followed by a discussion of the implications that this study has for practice.

### 9.2 Assessment of the theoretical framework

In Chapter 2 the theoretical framework for this study was developed, building on a critical examination of key constructs in the student learning literature. This framework guided and shaped the data collection and analysis processes. It is appropriate to consider a two-way reflection on the theoretical framework and the study, both in terms of the appropriateness of the theory for the study, and in terms of the implications of the study for the theory. This discussion is organised around
the three main constructs of the theoretical framework: approach to learning, perception of context and metacognitive development, and is followed by an assessment of the relational perspective on learning.

9.2.1. Approach to learning

In the theoretical framework for this study I assumed the validity of the construct ‘approach to learning’, as derived from the work by Marton and Säljö (1976a, 1976b) and developed by later researchers. Biggs’ (1986) description of approaches to learning as ‘congruent motive-strategy packages’ was considered useful in that this emphasises the focus on students’ underlying intentions. I kept to Marton and Säljö’s original conceptualisation of the approaches that students use being determined by context, rather than stable characteristics held by students. However, I decided to let the specific forms of approaches emerge from the data, rather than presupposing the existence of deep and surface approaches, similar to the research approach used by Booth (1992).

In reflecting on the findings of the study it is first of all clear that the notion of approach to learning was highly productive, not only in describing differences in students’ experiences of this course, but also in providing an explanation for different learning outcomes. It also seems clear that the assumption that approaches used are determined by context, rather than being stable entities, was appropriate for the purposes of this study. Finally, the research approach of identifying specific student approaches in the data proved to be useful, particularly with regard to the manifestations of a ‘surface approach’. Had I used the deep/surface model it is unlikely that the distinction would have been made between algorithmic and information-based approaches, a distinction which has been of crucial importance in this study.

9.2.2. Perception of context

Although issues of student perception appear in much early student learning research, it is Ramsden’s work (for example, 1984, 1988b, 1992) that enunciated the link between perceptions of context and approach to learning. This link was a key
feature of the theoretical framework. Ramsden suggests that perception is analysed at the four levels of assessment, teaching, curriculum and student characteristics. Further elaboration on the nature of perception itself was obtained from a phenomenographic view on learning which emphasises a non-dualistic nature of perception (Gurwitsch, 1964; Marton & Booth, 1997). Another perspective on the nature of perception was drawn from the work of Lakoff and Johnson (1980) who argue that the metaphors people use are a reflection of the way they perceive the world.

The link between perception and approach to learning is the key issue on which the present thesis is based. However, this study does more than support the validity of this link; it also provides a detailed example of this link in practice. The use of a non-dualistic view of perception in the analysis may be not as explicit as other aspects of the theoretical framework; that is, from the analysis of students’ perceptions as presented in Chapter 8 it is not possible to tell whether a dualistic or non-dualistic perspective is engaged. However, the main contribution of this viewpoint comes in the discussion of the research implications, particularly in the latter part of this chapter. The non-dualistic view makes it logically impossible to ascribe the situation exclusively to student characteristics, and forces an examination of the course context. Finally, it is clear from the analysis that the theory of metaphor provided a most productive research tool for identifying student perceptions, by highlighting the ‘time is money’ metaphor.

9.2.3. Metacognitive development

Baird’s (1990) formulation of metacognitive development as ‘knowledge, awareness and control’ was used as a starting point for describing this construct. However, in the theoretical framework of the present study metacognitive development was conceptualised as a shift in approach to learning (as suggested by Biggs & Moore, 1993 and others). One of the major benefits of this conceptualisation is that it completes the links between all three key constructs used in this framework. The construct itself is also useful in that it encapsulates ways in which students might develop in their learning, and focuses research attention on the role of teaching in supporting this development.
Once again there is a two-way relationship between the theoretical construct and the present study. Reflecting on the utility of the construct in this particular study, it is clear that the construct was a productive one for describing changes in approach to learning, and particularly for focusing attention on the limited extent of this development that was observed. A reflection on the theoretical implications of the study suggests two conclusions. Firstly, the present study supports the conceptualisation of metacognitive development as a shift in approach to learning. Secondly, this study provides further elaboration of the difficulties of establishing contexts that provide integrated support for metacognitive development.

9.2.4. Relational perspective on learning

It is worthwhile to reflect on the appropriateness of the relational perspective on learning that was adopted for the present study. This perspective had two chief benefits. It allowed an eclectic use of theory, specifically with regard to the use of both constructivist and phenomenographic views on learning. It also supported a strong focus on the practical relevance of the research. It therefore provided a most useful broad framing perspective for this study.

9.3. Implications for practice

The origins of this study were very much with practical concerns, and so it is fitting that the thesis ends with a consideration of the research findings as they apply to practice. These implications can be divided into general issues for higher education teaching contexts and specific implications for the CHE231F course (and other course contexts which might be judged similar).

9.3.1. General implications

The first general implication for practice arises from a consideration of the course objectives which centred on the development of conceptual understanding and metacognitive skills. From this study it has been seen that conceptual understanding (obtained through use of a conceptual approach) was indeed necessary and sufficient for success in CHE231F. This achievement in terms of the nature of the assessment should not be underestimated, as it appears both from the
literature and from experience that many university courses do not assess for understanding. It would therefore appear that the use of conceptual non-numerical questions as designed in this course does indeed facilitate testing for conceptual understanding.

With regard to the course objective to promote metacognitive development, the study has shown that the only students to have made successful use of a conceptual approach were those who were already using such an approach from the start of the course. Furthermore, many of these students appeared to have significant prior experience of such an approach. Other students became aware of the need for a conceptual approach, and made attempts to shift to this approach, but it would appear that the course context did not fully support this development. There are two conclusions to be drawn from this finding. Firstly, requiring a conceptual approach and supporting metacognitive development towards such an approach are two entirely different things. The CHE231F course as it ran in 1999 seems to have been more successful at the former than the latter.

The second implication for practice builds on the above conclusions about the course objective to promote metacognitive development. This implication is basically an illustration of Ramsden's (1984) premise: that the way a lecturer perceives a course is not necessarily the same as the way students perceive it, and that this has a significant influence on the quality of student learning. CHE231F was explicitly designed to foster metacognitive development, with frequent overt mention of learning processes in class, significant use of peer discussion in lectures and tutorials, and a series of journal tasks aimed towards conceptual understanding and metacognitive development. What many students perceived as the salient features of the course were the time pressure and the need for time management. Even though they engaged in journal tasks and discussions, the focus of these students was on learning to work fast. The outcome of these ‘mixed messages’ was that students focused overwhelming on the message given out by the time-pressured context, rather than the formal message about the importance of developing a conceptual approach given in the course outline and in lectures.
Biggs (1999) suggests that a key aspect of good teaching is ‘constructive alignment’, where curriculum, teaching and learning activities are all structured around the same objectives. What this study shows is that this is not a simple matter of design, due to the compounding influence of student perceptions. The CHE231F was in both design and execution ‘constructively aligned’, as was evident in the detailed description of curriculum, teaching and assessment given in section 4.4.3. However, one aspect of the course (time pressured assessments) combined with another aspect of the broader programme environment (high workload outside class), were overwhelming factors that led to a lack of necessary metacognitive development for a large proportion of the students. These aspects played out in ways that were not anticipated by the lecturers when they designed and taught the course.

9.3.2. Specific implications for CHE231F

This study has highlighted aspects of the course that were supportive of conceptual understanding and metacognitive development, and other aspects which distinctly were not so. The first set of ‘supportive’ aspects will be briefly discussed, followed by an assessment of aspects detrimental to metacognitive development.

In discussing aspects of the CHE231F course that were highly effective, it is useful to make a distinction between aspects of the course that supported and rewarded conceptual understanding for those students who were already familiar with a conceptual approach, and aspects of the course that supported metacognitive development for those who were attempting to shift to such an approach. From the comments of the students using a conceptual approach it is clear that they found the teaching and assessment of CHE231F supportive of this approach. For example, these students commented on the amount of time in class available for discussing and doing problems. The nature of the assessment also clearly reinforced this approach, as they achieved success in at least some of the tests, and also in the final examination.

Notable aspects of the course which supported metacognitive development for those students who were attempting to shift from an algorithmic to a conceptual approach were the unlimited time test and the journal tasks. Many, although not
all, of these students found that the unlimited time test forced them to consider their conceptual understanding. This message differed strongly from the other test experiences which led them to believe that they needed to work faster. It is possible that the ambivalent feelings of some students like Geoff about the unlimited time test arose from it being an isolated experience, and therefore not relevant to the general assessment demands of CHE231F. As for the journal tasks, the analysis of journal task 9 (the unstructured concept map task) showed that the students who gained most from this sort of task were those actively engaged in exploring a conceptual approach (metacognitive development).

It can therefore be concluded that certain innovative aspects of the CHE231F were indeed highly effective in promoting conceptual understanding and metacognitive development. Should there be a plan to continue with these course objectives for CHE231F it is clear that the interactive teaching methods, the journal tasks, the unlimited time test, and the form of assessment questions should be retained.

The important implications for possible change of the CHE231F course arise from a consideration of those aspects of the contexts that seemed most detrimental to supporting metacognitive development. The two most significant aspects here are the heavy workload out of class, and the time pressure in assessments.

The out of class workload was largely due to the other courses that were taken in parallel with CHE231F, and that had a large number of hand-in assignments throughout the semester. Except for the journal assignments, the tasks that the CHE231F lecturers required students to do outside class were not for marks. These therefore took a lower priority to the hand-in assignments, and many students did not undertake the conceptual problems that the lecturers were hoping they would do outside class. One solution would be to convert these CHE231F tasks into hand-in assignments, but it is possible that this would only exacerbate the situation highlighted in the present study. A more productive approach would arise from a coordinated approach to teaching and learning amongst these various courses. Not only is it arguable that the hand-in load should be reduced, but more importantly, a joint vision of the approaches to learning required and supported by all of these courses would be highly beneficial. From students’ descriptions of their approaches
to learning, particularly in Mathematics II and Chemistry II, it seems that these courses were likely respectively promoting algorithmic and information-based approaches to learning. Students would be more likely to adopt a conceptual approach if this is the message received from all of the courses in their programme. This approach has been shown to be effective in secondary school contexts, for example in the PEEL project (Baird & Northfield, 1992).

The other implication, relating to time pressure in assessments, bears specifically on the CHE231F course itself. It is clear that the considerable time pressure in the tests and examinations limited students’ development towards a conceptual approach, as they focused on other ways of managing to work fast. Students’ experiences of the unlimited time test support this conclusion, as this was the assessment experience which caused the most reflection by students about their conceptual understanding. It may not be practical or even desirable to have all assessments untimed as such, but it seems that a considerable reduction in time pressure is necessary to support those students who are experimenting with a conceptual approach.

Time-pressured assessments are frequently defended with the view that students will need to work fast one day in real life situations, and that this should therefore be assessed. It may be argued that final year assessments should to some extent simulate real world pressures, but it is debatable whether such time-pressured assessment should be taking place during developmental stages of the programme. The research findings of this study suggest that time pressure is manageable only if one is already comfortable with a conceptual approach. For students using a non-conceptual approach time pressure is first of all unmanageable, but more importantly inhibits experimentation with a new approach. Time-pressured assessments are not conducive to the risk-taking that is a necessary part of metacognitive development. This thesis suggests that it is more important to support development towards a conceptual approach, and that students will consequently be able to work fast, possibly with some practice in this area. Focusing on working fast without a conceptual approach is clearly disastrous, yet for a significant group of students this was their perception of the situation in CHE231F.
9.3.3. An aside regarding comparisons of 1998 and 1999

Recalling the outcomes of the pilot study, and the discussion of the significantly different final course outcomes in 1998 and 1999, the reader may be left wondering about reasons for this change. This study did not set out to compare the course from one year to another, and the data collected do not permit this question to be properly addressed. One point relating to the findings of the 1999 study is however worth mentioning. The workload in some of the parallel courses taken in the first semester alongside CHE231F did increase considerably in 1999; for example, in the CHE232F design course weekly hand-in tutorial problems were introduced, together with a fairly challenging major design project. This may have exacerbated the time pressure situation which seemed to limit students' metacognitive development. The change could also be partly due to students' complacency following the excellent course outcomes in the previous year, which therefore led to them being less amenable to the message that they needed to alter their approach to learning. Another factor which might be relevant is the introduction of a second lecturer in 1999, with Dr Stevens' approach to teaching differing slightly to Dr Barnes', as was mentioned briefly in section 4.4.4. However, all of this is merely speculation, and as stated earlier, this study did not set out to answer this question, nor did it collect appropriate data to do so. The study focused primarily on the course at one point in time (1999), and sought to understand as fully as possible all aspects of the context and how they related to students' learning.

9.4. Conclusion

In this chapter the outcomes of this study have been considered from both theoretical and practical perspectives. The theoretical framework adopted in this study, with its particular conceptualisation and interweaving of the constructs of approach to learning, perception of context and metacognitive development, all within a relational perspective, has been shown to be highly productive. More importantly however, the study has generated an understanding of student learning which has strong implications for practice. These implications are fundamentally directed at the context in which the study took place. It is for the reader to consider the transferability of particular findings to other comparable contexts, although it is
suggested that these might well have applicability in other tertiary science and engineering contexts where time pressure has been a traditional component of the learning environment. This study suggests that such environments are not conducive to developing learning approaches focused towards conceptual understanding.

This thesis began with a well-known quote from Newman, who painted a picture of poor quality learning all too prevalent both in his time and ours. The description of students ‘who have too much on their hands to indulge themselves in thinking or investigation’ could have been written to characterise the time-pressured environment and the algorithmic and information-based approaches it fostered, as identified in the present study. The study has also shown that some students did use a conceptual approach, and that this was necessary for success in the course. It is therefore fitting to end with a vision from Newman for a type of learning he terms ‘enlargement’, which in this study would be termed a conceptual approach:

The enlargement consists, not merely in the passive reception into the mind of a number of ideas hitherto unknown to it, but in the mind’s energetic and simultaneous action upon and towards and among those new ideas, which are rushing in upon it. It is the action of a formative power, reducing to order and meaning the matter of our acquirements; it is a making the objects of our knowledge subjectively our own, or, to use a familiar word, it is a digestion of what we receive, into the substance of our previous state of thought; and without this no enlargement is said to follow. There is no enlargement, unless there be a comparison of ideas one with another, as they come before the mind, and a systematizing of them. We feel our minds to be growing and expanding then, when we not only learn, but refer what we learn to what we know already. (Newman, 1852/1964, p. 101, emphasis in original)
Appendix A.
CHE231F course handout

Expected outcomes
Course outline
Course organisation
Course calendar
MATERIAL AND ENERGY BALANCES - CHE231F

EXPECTED OUTCOMES - 1999

At the **beginning** of this course, each student should have a thorough knowledge of the content of MAM103W or MAM105F, CEM100W and CHE104W or CHE100Z. These courses are prerequisites for ChE231F.

By the **end** of this course, each student should:

**CONTENT**

1. Be able to carry out a **material balance** over a typical chemical process system involving:

- mixing
- reaction
- separation
- recycle streams
- purge streams

   *law of mass conservation*
   *reaction stoichiometry, including limiting and excess reactants*
   *tie substances*
   *ideal gas laws*
   *equilibrium relationships*

2. Be able to carry out an **energy balance** over typical chemical process systems including:

- adiabatic reactors
- isothermal reactors

   *heat capacity integration, mean heat capacities*
   *phase change data*
   *steam tables*
   *heats of formation and combustion to calculate heats of reaction*

3. Be able to carry out **simultaneous material and energy balance** calculations over typical chemical processes involving all of the skills outlined above.

**SKILLS**

- To have developed a systematic approach to the solution of material and energy balances
- To be adept at the use of computers in the solution of chemical engineering problems. This will involve competence in MATLAB programming and/or spreadsheet manipulation.
- To develop a more self-directed and reflective approach to learning and to therefore be able to build a good understanding of the concepts presented in the course.
MATERIAL AND ENERGY BALANCES - CHE231F

COURSE OUTLINE - 1999

Material balances without reaction (conservation of mass, systematic approach to solving prediction problems)

1. Material balances involving chemical reactions (conventions, limiting and excess reactants, tie substances, element balances)

2. Material balances involving recycle

3. Material and energy balances involving chemical equilibrium

4. Energy balances involving heat and work (review of basic thermodynamics, development of energy equation, concept of enthalpy, heat capacity, heats of transition, steam tables)

5. Energy balances involving chemical reactions (total enthalpy, standard heats of formation, standard heats of combustion, heats of reaction, isothermal and adiabatic reactors)

6. Simultaneous material and energy balances
MATERIAL AND ENERGY BALANCES - CHE231F

COURSE ORGANISATION - 1999

1. LECTURERS: Dr Barnes (Course Co-ordinator)
               Dr Stevens
LEARNING COUNSELLOR: Ms Jenni Case
SENIOR TUTOR: Ms Fox
TEACHING ASSISTANTS: xxxxxx
                     xxxxxx
                     xxxxxx
                     xxxxxx
                     xxxxxx
                     xxxxxx

2. D.P. REQUIREMENTS:
   a. Attendance at and satisfactory participation in 7 out of 9 of
      tutorials. Any non-attendance must be justified in writing to the
      senior tutor.
   b. A minimum class test average of 30%.
   c. Submission of all specified journal hand-ins.

3. COURSE ASSESSMENT:
   Class tests (3 @ 10% each) 30%
   Examination (June) 70%
   100%

   Note 1: You may take one pre-prepared A4 sheet into each test.
   Note 2: A sub-minimum of 50% is required in the examination to
           pass the course.

4. BOOKS REQUIRED:
                   Basic Principles and Calculations in Chemical Engineering, 6th ed.
                   Prentice-Hall.
   Additional reading (can be found in short loan in the Jagger library and in the
   Resource Centre)
   Introduction to Chemical Engineering.
   Reklaitis, G.V. (1983).
   Introduction to Material and Energy Balances.
   John Wiley & Sons
   Elementary principles of chemical processes (2nd edition)
   John Wiley & Sons
OTHER REQUIREMENTS:

Calculator with trig. and log. functions, preferably programmable.

5. TIMES AND VENUES:

Lectures: 2nd lecture, Monday to Friday PD Hahn 3
Tutorials: Wed 13h35 Chemical Engineering LT1, LT2 and Resource Centre

Please all meet in the Resource Centre on Wednesday 24th February

6. CLASS TEST DATES:

Wednesday 17 March, 14h00 ñ 16h00
Wednesday 21 April, 14h00 ñ 16h00
Wednesday 19 May, 12h30 ñ 17h00

In your tutorial venue

7. TUTORIALS

Tutorial solutions

• Tutorial solutions will be available behind the glass on the north wall of the resource centre.

Tutorial attendance:

• to get a dp, you must attend the tutorial. If you cannot attend, you must write an apology to the senior tutor and give it to her BEFORE the tut.
• the tut starts at 13h35
• please arrive with your Himmelblau, calculator, pencil, paper, logical inventive creative mind, etc

During the tut:

• you will work in co-operative learning groups of 3 students
• you will choose the groups yourselves during the first week of lectures

At the end of the tutorial:

You may leave
• when your whole group has finished the tut
• or at 16h30
• make sure that you have been checked off on the register

help

• If you need any help outside of the tutorial afternoons, you may approach the course co-ordinator, study counsellor, senior tutor or tutors. You will be notified of their consulting hours.
## Table: Material and Energy Balances

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### KEY:
- **Public Holidays**
- **Lectures given by Dr Stevens**
- **Lectures given by Dr Barnes**
Appendix B.

Journal tasks

Your 231 Journal: General instructions
Journal Task Week 1 Keys to Success & Concepts learnt in CHE104W
Journal Task Week 2 Mass balances: consult the textbooks
Journal Task Week 3 Planning your ‘crib sheet’ for the class test
Journal Task Week 4 Material balances with reaction – making sense of the terms using a concept map
Journal Task Week 5 Reflecting on the first class test
Journal Task Week 6 Recycle: consult the textbook
Journal Task Week 7 The halfway mark
Journal Task Week 8 Energy balances: concepts you don’t understand
Journal Task Week 9 What do you know so far about energy balances? – making a concept map or other summary
Journal Task Week 10 Reflecting on test #2
Journal Task Week 11 A bit of practice with energy balance concepts
Journal Task Week 12 What have you learnt in CHE231F?
Your 231 Journal

What is the point?

One of the important priorities of CHE231F is that you develop a more self-directed and reflective approach to learning. This is not only an end in itself, but will be critical if you hope to be successful in the course! Our research has shown that you will need to develop in your learning abilities in order to build a good understanding of the concepts presented in this course.

The knowledge, awareness and control of one’s learning is called **metacognition**. Engaging seriously with the journal tasks will help you to become more metacognitive, and will build a good foundation for further studies in chemical engineering. It is as important as learning how to do a mass balance!!

What will I have to do?

You will be issued with a folder to use for this purpose. Write your name on the front cover.

Each week you will be handed a task which you will be required to complete. In addition you are strongly encouraged to add any other reflections on your learning in this course. Each week you will need to fill at the very least 1 A4 page. Keep all previous week’s journal tasks in the folder as well.

How will it be assessed?

Journal hand-ins will take place on the following days:

- Monday 15 March (Weeks 1-3)
- Monday 12 April (Weeks 4-6)
- Monday 3 May (Weeks 7-9)
- Monday 24 May (Weeks 10-12)

(Hand in the CHE231F box in the Chem Eng Building)

It will be assessed and returned to you with comments by the Friday of the same week. A record will be kept as to whether your submission was satisfactory or not. (A satisfactory submission will contain all the weekly tasks completed with the necessary effort.) Each satisfactory hand-in will earn you 1% bonus marks on your cumulative class mark, while a hand-in that is particularly well done (in terms of effort and quality) will earn you 2% bonus marks.

**NB:** Satisfactory submission of the **first** journal hand-in is a DP requirement for CHE231F

Any queries?

See Ms Case or Dr Barnes.
Journal Task  

WEEK 1

A. The following "Keys to Success" (Ray Landis) were presented in Monday’s lecture:

1. get your life situation together
2. commitment and motivation
3. know why you want to be an engineer
4. learn how to be effective as a student

What do you think of this? Where do you stand on these points?

Reflect on
1. those aspects you think you need to work on, and
2. those you think you have got sorted out.
3. any other points not featured in these ‘Keys to Success’ which you think are just as important and which you need to work on.

B. Last year you were introduced to the concept of mass balances towards the end of the CHE104W course.

How does what you have learnt this week compare with what you learnt last year?

1. Are there are any concepts which seem contradictory ¿ make a note of these and see if you can resolve them.
2. Are there any aspects that confused you last year which you have now managed to resolve?
3. What are the most important new ideas that you have picked up this week?

Remember that you in doing this task you need to fill at least a page (at the very least) in your journal.
Journal Task

WEEK 2

Basic mass balances are discussed in the following sections in the recommended textbooks for this course (copies of all both in Jagger Library Short Loan Section and Chem Eng Resource Centre):

Himmelblau Section 3.1 p141-149 in the 6th Edition
Thompson & Cecklar p25-47
Felder & Rousseau Sections 4.1-4.4 p83-112 2nd Edition
Reklaitis Chapter 2 p33-85

Find at least TWO of these references to look at and read carefully through the recommended sections. It might be helpful to jot down a few notes as you go through this, but only pencil these in the text if it’s your own book!

1. Write down useful NEW ideas that you have picked up from these sections. Don’t just write down the name of a concept, but describe it for yourself as well.
2. Write down anything from these sections which has helped to clarify material presented in the CHE231F lectures. Specify what it is that confused you, and how you have cleared up this confusion.
3. If there are any ideas which you have picked up, which seem interesting, but at this stage don’t seem relevant to your work in CHE231F, note them down for future reference.
4. What do you think is the purpose of this task?

Journal Task

WEEK 3

Planning your “crib sheet” for the class test

1. In what ways do you think the crib sheet might be able to help you in the test? What sorts of things do you think you should include on your crib sheet and why?
2. Write down a long list of things that you want to include on your crib sheet. Structure this list into things that fit together so that it is organised into more than just a ‘shopping list’.
3. Compare your list with a classmate in CHE231F. Add on any new ideas (make it clear which ideas you have added at this stage)

(You can now use these ‘rough notes’ to produce a final version on your yellow sheet. Don’t hand this in with your journal - you’ll need it on Wednesday!)

Remember: On Monday 15 March (this coming Monday) you need to hand your journal in with all 3 tasks so far completed. Post it in the ChE231F box in the Chem Eng building by the end of the day.
NB: This first journal hand-in is a DP requirement for CHE231F.
Journal Task

MATERIAL BALANCES WITH REACTION – making sense of the terms using a concept map

Some of the ideas encountered this week are shown below. Link those terms you see as related with arrows and on each arrow write a statement about the nature of the link. The statement may be a phrase or an equation. Multiple links may exist between terms. Make as many links as possible but make sure you label all of them. To give you an idea, one possible link has already been made. What you are creating is called a concept map.

(Before you start make sure you know what each term means; look back at your notes; or look at the recommended textbooks¹). When you have made all the links you can think of, compare with a friend, and add any new ones you think are important in a different colour.

1 You could try Himmelblau 6th edition: Section 1.7 p63-73, 5th edition: Section 1.9 p64-75; or Thompson & Cecklar p113-124; or Felder & Rousseau Section 4.6 p118-140; or Reklaitis Chapter 3 p107 – 164).

What do you think is the purpose of making a concept map like this? Answer briefly.
Journal Task  
WEEK 5

Reflecting on the first class test
1. Give a general analysis of your performance in the test.
   • You may wish to calculate your % mark for each question.
   • Recall how you felt before and after the test.
   • Are you happy with your performance in this test?
   • Do you think your mark reflects your understanding of the material?
2. Identify your weak and strong points as displayed in this test performance
3. What are the most important lessons that you have learnt from this test?
   Is there anything that you need to do differently from now on?

Journal Task  
WEEK 6

Work carefully through section 3.2 'Recycle, Bypass and Purge Calculations' in Himmelblau (p206-224 in the 6th Edition). It might be helpful to jot down a few notes as you go through this, even if they are just pencilled into the margin.

There are six worked problems in this section ñ our suggestion is that you try them first without looking at the solutions, and then compare your work with what Himmelblau has done.

1. Write down anything from this section which has helped to clarify material presented in the CHE231F lectures. Clearly state what confused you, and how it was resolved by what you read in this section.
2. Write down useful NEW ideas that you have picked up from this section. Donít just write down the name of a concept, but describe it for yourself as well.
3. If there are any ideas which you have picked up which seem interesting, but at this stage donít seem relevant to your work in CHE231F, note them down.
4. What do you think of Himmelblau's problem-solving method? It is somewhat different to those which have been presented in lectures. In what ways do you think it is different, and which method do you prefer?

You may also wish to look at the other recommended textbooks for this journal task: useful sections might be Thompson & Cecklar p167-182; Felder & Rousseau section 4.5 p113-117; Reklaitis p69-75

REMEMBER: 2\textsuperscript{nd} Journal hand-in (optional) is on the first day back from the vac, Monday 12 April. Make sure your journal is in the CHE231 box by 12h00 noon if you wish to make use of this opportunity for feedback and bonus marks. Journal hand-ins particularly well done score an extra 2\% on the class mark, while each of those satisfactorily completed and in on time earn an extra 1\%.
Journal Task  
WEEK 7

The Halfway Mark

It’s now just over halfway through the CHE231F course. Take a bit of time to reflect on how things are going:

1. What have you learnt so far? Apart from the obvious content like mass balances, combustion, recycle and equilibria ñ what else have you learnt?

2. What aspects of the course (if any) are going particularly well for you? What things do you think you have really handled well?

3. What things (if any) do you think you are going to have to do differently in the 2nd half of the course? In what ways could you be making more of the resources available and opportunities to learn?

Journal Task  
WEEK 8

1. Go back through all your notes and problems so far on Energy Balances. Find **two concepts** (or definitions or equations) that you don’t understand OR are not too sure of OR would like to find out more about. Write them down.

2. Now go to the recommended texts for this course (Himmelblau, Thompson & Cecklar, Felder & Rousseau, Reklaitis), and look to see if there is anything there to help you with the two problems you have identified above (make use of the contents page, the index, and general browsing to locate a topic). If you haven’t found anything to clarify these problems, find a classmate or tutor or lecturer to help you.

3. Make some notes on how you have resolved your confusion. You must clearly state what you have discovered your problem to be, and how you have resolved it. Donít just write out a paragraph from the textbook!!

NOTE: This is not an easy task to do properly. You need to make time to seriously think about what you do understand and what you donít understand. If you take the time for this task you should be able to progress significantly in your understanding. Merely copying out notes on a topic will not be considered a satisfactory response to this task ñ the task requires you to think about your own learning of Energy Balances.
Journal Task  
WEEK 9

What do you know so far about energy balances?

1. Look back over your lecture notes, tuts and textbook, and pick out all the most important concepts that you have picked up so far about energy balances.

2. Now try and pull it all together in some kind of summary – how does it all fit together?
   To organise this you might like to use a concept map (encountered in week 4) or else some kind of tree to classify ideas, or a diagram, or a table, or even just a structured list of ideas.
   The most important thing to do is to work out how all these concepts relate to each other, and also how they relate to the other work you have previously done in CHE231F.

NB: Journal Hand-in #3 is this coming Monday 3 May Ń in CHE231 box
**OPTIONAL** Ń for extra bonus marks on your class mark
(1% if satisfactorily completed and in on time; 2% if particularly well done).

Journal Task  
WEEK 10

Reflecting on test #2

Make sure you have in front of you the Test 2 question paper, and your answer script.

1. Reflect on your performance in this test - you may wish to use questions like:
   How do you feel about it? What did you do well? Where did you go wrong?
   What would you do differently again? etc etc

2. Have a look at your journal entry for week 5, where you reflected on test #1. Did you take your own advice in preparing for test #2?

3. What lessons have you learnt from test #2 that you need to work on for the final class test?

NB: Before you pack this test away (or burn it!), locate all the questions that you didn’t get 100% for, and do corrections Ń especially for those problems you really messed up. Ask classmates or the tutors for help if you need it.
Journal Task  

WEEK 11

A bit of practice with energy balance concepts…

1. For each of the following energy balances, devise, describe and draw a chemical system for which the particular energy balance will apply. You will need to invent your own specs regarding which components are involved, what the temperatures are, etc etc.

1.1. 

\[ F_{in} \sum H_{in} + Q - F_{out} \sum H_{out} = 0 \]

1.2. 

\[ F_{in} (\sum H^0_{\text{reactants}}) - F_{out} (\sum H^0_{\text{products}} + \sum \int C_p dT_{products}) = 0 \]

(Obviously there is no one right answer for these problems!! Use the opportunity to be inventive; and to make sure you really understand the terms in an energy balance.)

2. Have a look at the attached question (overleaf).

2.1. Read the description of the system carefully and work hard on making sense of what is happening in it. Make your own notes on the flow diagram to help with this, or even make a new diagram for yourself.

2.2. Now read questions a and b, and try to work out a broad strategy for what you are going to have to do to solve these problems. Make a few notes on this ñ maybe even just on the question sheet.

2.3. Now solve the problem to the best of your ability. When you get to as far as you are able confer with a classmate who has also given it a bash. Pool your ideas and struggle through; don’t give up!! If necessary, find some more help from another classmate or a tutor (Include the full solution in your journal with comments on how you solved it)

2.4. What did you learn from your approach to this problem? ñ try and extract any useful strategies or principles that you used in solving this problem.
Attached question for Journal Task Week 11
Journal Task WEEK 12

What have you learnt in CHE231F?

In this task, you need to reflect back over the course. Have a look back over all your journal tasks to help you do this.

1. What have you learnt in CHE231F? This could include content, learning skills, personal development

2. What did you think was the most useful journal task to you? Why?

3. What things do you still need to fix up before the final exam?

The last journal hand-in is on Monday 24 May.
This is your last opportunity to score bonus marks on your class mark.
Appendix C.

Sample interview transcript

Notes on transcription conventions and abbreviations:
Italics script:  Interviewer (originally in capitals for analysis purposes, hence the shorter lines)
Plain script:  Interviewee
...  Short pause in speech, or trailing off at end of sentence
( )  Interjection person not talking
[ ]  Explanatory text

Where quotes have been used in the thesis text, expressions such as ‘um’, ‘I mean’, and repetitions have been edited out when this will aid reading clarity.
Tell me about it ... everything ... generally ...?

OK um it wasn’t a difficult test, I don’t think it was difficult. But I made a stupid mistake in one of the big questions (OK). I misread the question so I put something - I think you had to put a basis somewhere (yes ...) it was 40 and 60 in the fresh feed, and I put it inside the loop [question 3] so obviously... So was that your major problem in question 3?

So then all my calculations are incorrect from there onwards ... But everything else ...

Ja, I knew how to do the question ...

You didn’t have a problem with the question.

OK, that’s really unfortunate ...

What did you get for that question then?

4. OK cos you didn’t really get off the starting blocks. And question 4? You did quite nicely on question 4 ...

Ja. I just ... in the end - significant figures. (OK) I was kind of short for time, so I just saw 14%, and then I ...

Oh OK right so you lost a mark or so on that ...

And then [questions] 1 and 2?

OK question 2 was quite an easy question - but question 1, I ...

When I saw that question you know I thought ag you know ... but then actually uh ... what did I get for it? I can’t remember ... [doesn’t have test script with him]. I didn’t do too badly in that question after all ... I actually thought I did quite ...

But the last two questions I did badly in hey I remember that ja.

Dr Barnes was talking today about layout ...

What do you think about your layout ...?

No mine was fine.

I thought your layout was very good.

But this new method has got me ...

Tell me about that ...

I just sat in class and I ... the thing is, the method I use is quite ... it’s sufficient for me, and I tend to get the right answers ... but now, I can see where this method is a lot easier, and if I had like six - seven components in a stream ... It might be easy to use, but...

By ‘this method’ you mean input output tables?

Ja. And I’m not very confident, I mean I can follow what’s going on ... But, I don’t know, it’s ... It just seems like I have to unlearn everything I’ve just learnt now, and ... That’s ... I was actually quite confused, cos I went to her [the lecturer] afterwards and I asked you know, should I use my method, or should I use yours, and she said “Do your method, for those 3 questions, and then compare ... and then do it with my method as well “. And I have to weigh the ...

Are you likely to do that?

Ja it’s a lot of work. Ja but I’ll do it, I think I need to see for myself.

So at the moment actually input output tables sort of confuses you ... and you prefer to write things against each stream ...

Ja.

Cos I don’t - you see she um, for her method to work, from the outside in ... now I wasn’t ... immediately I had kind of a negative attitude, so I didn’t follow ... and so I got lost ... in today’s lecture when I should have paid attention. Cos usually I will just take a basis and work it around the stream, and then I’d get my answers. (ja) Which is ...

OK, rather than...? What was she doing?

She worked backwards, and then from here she kind of went round from where the purge stream was ... She worked backwards, all the way backwards.

OK whereas you would prefer to go from ...

The fresh feed ...

Or the mixed feed?
Or the mixed feed ja. And work out. She did start with the fresh feed? Ja. As the basis. But um she … You prefer to start from just before the reactor … Ja. OK so that also seems to be like it’s going backwards. So this has been quite confusing for you this week … (ja) … And I haven’t had time to actually um sit and absorb it, cos I’ve been very tired, so, when I get home, I just, I just go to sleep. Ja OK right, so you’ve got a lot of things up in the air at the moment from what’s happened this week … What are you planning to do about that? Well um I’ve got today free basically, so I get home and I’ll try and catch up on some sleep, and then I’ll do …, I’ll do this today, just work on this … The test? No not the test … The problems … Ja I’ll try and get 3,4,5 and 6 – both ways … OK the questions you’ve been doing in the lectures … Then I should be fine. Ja OK, I want to talk about those shortly as well … um but just to go back to the test, so your general feeling about the test is … It wasn’t, so it wasn’t that difficult … And are you happy with what you got for it? I mean I’m unhappy that I made a stupid mistake, but … it’s fine. It’s a good start. I remember how last year my first CHE [104W] test was 25%, 15% … I know I got one of the lowest marks in the class … OK right, what do you think enabled you to get one of the better marks in the class this time? Oh, consistent working I think. OK right … Cos I didn’t really study as such for this test … I mean I just, I was working so I had an understanding so I thought, instead of cramming the night before, you know I’ll just try a problem or two and then … OK so basically working consistently … The other thing we spoke … cos I spoke to you on Wednesday last week, the day you wrote the test – you were worried about … panicking and stuff. And I saw you after the test with a big grin on your face … you’d tackled that alright … Ja. What do you think was your secret of being OK in that one … I um … whew … the first question wasn’t the kind of question that I could get settled on, cos it’s so … it’s not vague, it’s just it’s kind of you’ve got to think in different … you know in different frames of mind or something. But the second question was what kind of settled me, because it’s straightforward, and it’s just a matter of … of going through the motions and you’ll have the answer. And then by then I was kind of … you know ready for the rest of the test … So you felt … you didn’t actually have any anxiety through that test at all? No. Just when I hit question 3 and it was getting messy Then I started … , because then I couldn’t, I couldn’t … I was thinking to myself … “I don’t know what’s going on here”, the chances are the markers are not going to try and find out either. So I had to do the question twice, and the second was the neat copy. OK, would you quite often do that? Do a question and then copy it over neat … or is that what you only do when it gets out of hand … Ja no 1 … thing is, it was a nice [test] … cos there were four.
questions and there were 2 hours, so I knew I had a half an hour
a question, which is very generous. So I finished the first two
questions in ... I had ample time left to tackle a question twice.
OK so question 3 you actually wrote over a
second time, question 4 you didn’t?
No I did it the first time.
No that was fine the first time around, and
that was the one you actually did quite OK
on ...
Umm, did you use your crib sheet at all?
Umm just for definitions, just for theoretical air. But other than
that, no I didn’t really use it.
OK right so it was just ... just that one
definition. What are you likely to do in
upcoming tests - use the crib sheet again?
Ja definitely ...
And your thing of using it for definitions
worked out alright ...
So you’re generally happy with things from
this test - you’re like on track - is that your
feeling?
Ja. But I’m kind of a bit concerned now, because the problems
are getting quite a lot more difficult, and the lectures ... there’s a
difference, I’ve got to adapt to this new style of lecturing (yes?)
which is isn’t as ... it’s not necessarily as relaxed. I mean we
also get a chance to do the problem. But an approach to a
problem doesn’t answer questions for me, you know. I don’t
like seeing OK you’ll do it like this like this like this ... Cos the
chances of me following it like that aren’t ...
So it feels to you like she’s saying there’s one
way you must do it, or something?
Ja, that’s the way I feel, ja. (OK ...) And I feel a bit uneasy,
because I don’t necessarily want to use that method ...
The method of thinking of an approach first?
Ja.
And the method of input output [tables]?
And the method itself ja. I don’t like to be restricted, that’s what
I feel like at the moment.
So at the moment it feels like you’re being
told you must do it this way... you must be
forced into this thing ...
So this week’s been for you quite uneasy in a
way.
Definitely.
So the basic, the basic differences are ... this
thing of having to have an approach, and the
input output tables. Are there any other differences in
the way things are running this week ...
Umm ... What I like is, um ... the question comes open and then
we all give suggestions. That’s quite nice ...
Is that more to [than] what you had with Dr
Stevens?
Not really, but I’m just saying ... (you still like that) .
That’s ... I’m looking for the upside. On the downside though, it’s ...
OK I’m confused, and that’s putting me off. I think the
speed is different as well, it isn’t as relaxed. I feel there’s a
sense of urgency ... in lectures. And then, you know you have a
book ... and in lecture 1, you have to complete 4 problems ... and
I thought “that’s impossible “, it’s not going to happen. So that’s
kind of ... the fact that I’ve got to know exactly what I’m doing
in a lecture kind of makes me ...
You don’t actually like that?
Ja.
I remember you saying overall you liked a
course outline ...
Yes I like an outline, but I don’t like a minute by minute kind of ...
So this is feeling a bit like pressured for you
(mmm) ... then ... so actually the lectures
feel like they’re going a bit faster ... and
stuff ...
Ja.
OK that’s going to be interesting to, you
know, follow you with that and so on. I mean
it’s completely natural to feel that, there’s nothing wrong with that ...
And you’re going to particularly try and sort out this confusion for yourself ... OK, I’m interested to talk with you when we next talk, about how you managed to sort out this confusion, if or not, and so on ...
Actually let’s ... what I want to look at ...
Have you got your workbook here ... I’ve got one if you haven’t ...
I want to look at the problems that we’ve done this week ...
Firstly, what do you think is the general, purpose of ... you’ve done ... 5, am I right 5 ... 5 different ... what she’s called ... or in fact 4, so far, 4 illustrative examples, or hypothetical examples. What do you think the point is of ... of what you’ve been doing in these 3 lectures ...
Um the point. Um I’m not ...
You know she’s got these different examples ... they’re all quite similar, but they’re sort of different ...
Ja I mean at the moment, I haven’t seen the difference at such. I don’t actually ... to me I tackle all problems in the same way as really ...
So it’s basically like you’re just doing lots of recycle problems, you haven’t got a sense of any bigger purpose with these 4 ...
No not at the moment no ...
OK, um, what I ... a couple of things I was wanting to ask about these ...
The one thing is: all of these problems I notice have got 50% per pass conversion – do you remember that? (ja) And they’ve also all got E and O in stoichiometric ratios ... Why do you think they’ve got the same per pass conversion in each problem. Is that ...? What determines per pass conversion ...?
What determines it? [laughs].
Why have they taken it the same - apart from that it’s nice to keep ...
We’re seeing the advantages ... we’re seeing what happens when you have a purge stream or when you have a waste stream or ...
OK so you’re seeing what happens if you change other conditions ... but you keep per pass [conversion] the same ...
Ja OK. What determines per pass conversion in the reactor?
What determines per pass conversion ...?
Umm ...
You know these ones are all 50%
What determines ... If you wanted to change the per pass conversion what would you change? That’s maybe how I should ask that question.
If I wanted to change per pass conversion I would ... whew ...
I’m not actually quite sure.
OK let’s take it back from this problem, because all you’ve been changing here is recycle ratios and ... if you change the recycle ratio can you change the per pass conversion ...
Um.. The recycle ratio is RC:W. (ja).
Can you change the per pass conversion by changing the streams that are around the reactor?
Mmm. You see I’m not sure - you see maybe my definition of a reactor is incorrect. I’m looking at a reactor as something that does something to your mixed feed, so that you can get something out ...
What happens in a reactor?
Umm a reaction I … [suppose]…
A chemical reaction?
Ja.
OK so it’s a chemical reaction happening
there which changes reactants to
products …
Ja.
And in this case only 50% gets changed …
Um, if you have a chemical reaction, what do
you do if you want more than 50% to be
changed to products? How do you change
what is the conversion in a reaction? If we
say there’s a reaction happening in the
reactor?
How would you change it …? You could change the feed I
suppose … You could um … change the stoichiometry …
Here? Would you get more conversion. Say
we said lets put in lots of O and a bit of E.
Would we get more than 50% conversion
necessarily. What would we do, what
happens if you want a reaction to give you a
bigger yield? If you think of your chemistry?
Umm. whew. If you want a bigger yield, and you’ve got the
same amount — a little E and a lot of O …
Or whatever amount of E and O And you want a bigger yield?
Maybe something like if … I really don’t know …
Do you remember Le Chatelier’s Principle?
Ja, I was going to say that, but that’s if it’s in … if it’s in
equilibrium …
OK ja but in general … if you want to
change …
Temperature or pressure …
And in fact you’re going to do equilibrium
next and a lot of these [problems] actually
there is an equilibrium situation in the
reactor.
So say you wanted, to go back to that, if I
asked you now what determines per pass
conversion, what would you say —
It would be um … Temperature or the pressure …
The conditions in the reactor, OK …
So does that now seem … what are we doing in
all these problems … we’re keeping the per
pass conversion the same, because we’re
keeping the reactor the same …
Ja.
Tell me about overall conversion and per
pass conversion. What’s the difference
between them. I’m a clueless 231 student,
say …
Sometimes I feel the same! [laughter] OK I know the overall
conversion is how much of your fresh feed actually becomes, how
much of it is actually processed or reacted or … whatever comes
out … Whereas reactors only …
Comes out where?
In your product, and also in your waste (ja) … And I suppose
your reactor conversion is just the amount that is converted …
across your reactor … But that, as opposed to total conversion,
you often, you’re losing things, and things are being recycled
again, so … your reactor conversion isn’t always the same as
your …
Are either of them …? Is one greater than the
other?
Well it depends on your system I suppose. If … ja I think it
would depend on …
So sometimes you reckon per pass could be
greater than overall, sometimes overall
could be greater than per pass?
Ja.
OK. That’s something to go and think about,
ja.
I didn't expect this! [laughter]
What, am I putting you under pressure?
Ja no I switched off my brain after fourth [period]! [more laughter]
Ja I don't mean to make pressure I'm just trying to...
No but it's good, cos often that's the problem, that's the thing
I'm finding in many lectures, I can do problems, but often I don't quite understand little things, and it's actually a good thing now... that things have been cleared up...
OK if I jog your mind positively - I'm also trying to see how these problems come across to students...
OK so we talked about overall conversion and per pass conversion...
If we look at these problems, if we look say from [problems] 1 to 2 - firstly 1 is your absolutely brilliant thing...
Ideal situation...
Ja you can't get better than that. All the products come out and all the reactants are recycled...
In [problem] 2, you've got 2 things here that you worked out... you worked out what you needed if you want 75% overall conversion, and then you worked out if you wanted 90% overall conversion what you needed. What did you have to change to get your higher overall conversion? What was it that you were changing...
Sorry I wasn't paying attention...
No no don't worry. Do you want to go to your page 2...
I wasn't listening to the question. I just had a thought when I was looking at...
What's that thought, ja?
Something in 232 today is that if there was 100% conversion of the reactants to products in a reactor the reaction would stop. So you'd have to be keeping, you keep on having to have the same fresh feed in all the time. So that's just something I was thinking about...
OK so what did they say - if you had 100% conversion And if you only did one pass...
Like a batch thing... then it would be finished...
It would be sensible not to have 100% so you can keep feeding...
In fact that was an interesting question...
from what we were talking about per pass conversion... What did you have to do to have say 100% conversion, quite often...
To have 100% overall conversion...
Ja if you think of Le Chatelier's Principle...
why would it be that you might not get 100% conversion as well?
Maybe not ideal...
What do you know about high temperatures and high pressures, practically... in industry...
Oh it's expensive.
It's very expensive, ja.
OK so I mean that might be one way of doing it, but to recycle...
It seems a lot cheaper...
It's going to be cheaper ja.
And of course you've got the cost of that piping and stuff. Ja that's a good point...
so when that happened in 232, did that get you thinking of this...
Yes ja...
OK good.
What I was wondering was, in the first problem [2a], what did you need to do here to get 75% overall [conversion] ... and then you did another problem where you got 90% overall ... What did you do differently ...? What did you have to change to get a greater overall conversion ...? Oh gosh I haven’t done this problem ... It doesn’t matter, well then let’s just think about it ... What do you think you’d have to do – you worked it out for 75% and you got all these things here [in the input output table] you got a recycle ratio of 2 ... What will you have to change if you now want a greater overall conversion.

A greater overall conversion ... You’d have to ... Um ... Whew um ... First of all, you wouldn’t want to lose any of your, I know here we’re losing EO, what ...

We’re losing stuff out in the purge stream ... Is that the purge stream, this one here? Ja well it’s the product and purge combined ... Oh oh I see OK. We shouldn’t lose any of this, all of it needs to be recycled, if you want to increase the overall ... That would be to get 100% conversion, to get 90% conversion, which is not ... quite as much as that ... what would you do ... you wouldn’t make sure that nothing comes out here ...

Besides the product ... OK what did you have to introduce to this system to make sure that you’re not getting reactants coming out in this purge stream ...

You’d have to have a separator. An ideal separator I suppose. And what have you got here ... at that point ...

Oh that’s just a splitter ... That’s just a splitter, OK ... So in this system, could you arrange this system such that you get no reactants out in the product ...

No I don’t think so, no ...

You’re always getting some out ...

but say you want a greater overall conversion ... you said to me ... what are you going to do ...

Having more of it sent through the recycle ...

What’s going to happen to the recycle ratio, if you put more through the recycle stream ...

It will increase ja. What’s the recycle ratio again ...

RC/W. In some of the questions it was different I remember ...

If you work this one out, you actually find you get a recycle ratio of 8 ...

Oh OK ...

So between these two you have increased your recycle ratio ...

Cos when I was looking at this question I couldn’t understand what was happening, I just see an arrow and then I see products ...

Oh I see – you were wondering if that was going like that [in opposite direction to recycle stream] Ja so I was ...

Ja you actually need something like that [an arrow after splitter] ...

OK so these two here are talking about what happens if you’ve got the same system and a bigger overall conversion ...

What happens if you compare 2 to 3? Question 2 to question 3?
Ja, if you look at them, what is the difference between 2 and 3? Oh you have inerts. What is the effect of the inerts – and you worked out the same problem for 75% conversion – adding the inerts – what did it do? Did it say for example change the recycle ratio, to get the same overall conversion ... No the recycle ratio is the same. what does that surprise you? No because nothing's happening to the N2 ... OK so it doesn't actually surprise you that ... these things [E, O, EO] are all the same ... and the recycle ratios are the same ... what does the N2 then do to the system ... what does change about your input output tables in your streams? Um ... What does happen is that ... You can even think of it practically, if this was an industrial plant, and you'd worked out something and you'd made a whole design based with no N2, and suddenly you went oops there's N2, what is going to have to be different about your design? You said your recycle ratio's the same ... What's different about these streams ... and the flow rates and stuff ... have a look at the mixed feed stream ... Oh the N2 remains constant throughout, so eventually I see there would definitely be some sort of a buildup because here you have the same amount of O and less O leaving ... Umm actually I'm not quite sure what would happen ... OK let's see is there a buildup in this problem, of N2? How would you tell, is there a buildup of N2? Which in any case wouldn't be steady state? What would you check here to see whether there's a buildup of N2? Um ... If no N2 were leaving ... OK so some is coming in and some is leaving ... how do we check there's no buildup ... what we look at? if we look at the N2 in it's 3.76 ... And there's 3.76 leaving ... OK what does that tell you ... There's no build up But look at the mixed feed stream – how much N2 is there ... 11.28. Is that a buildup of N2, then, or? Well it's more N2 than you put in, so ... Where's that N2 coming from? Well that's, that's one of the things that was bugging me, because ... This is a confusing one, ja ... Because I was looking at, also the question today – I was seeing stuff leaving, yet all of it was leaving, and we have ... We drew a big black box and we had N2 coming in, and all the N2 coming in, and we still had to do calculations on N2 inside the system ... So even though there's N2 here [fresh feed] and there's N2 there [waste], of 3.76, inside the system there's like II and 7 and so on ... It's going round and round, so I mean it's ... That is quite confusing ... If we look back, if we look at the mixed feed stream, what is the mixed feed stream mainly made up of? N2 it seems. But we already said because the same comes in and out – there's no buildup. But what would you say then about the N2, instead of saying there's a buildup of N2 inside the system ... It just seems to be going round and round ... OK there's a lot that goes round and round, and it's quite high quantities actually ... so if we took the same system without N2,
we’d have the same numbers except for that row \([N_2]\), everything else would be the same 
we put that row in, and suddenly you’ve got quite a lot of \(N_2\) in each stream. What’s that going to do to your practical design of your reactor. 
There’d be a lot more pressure I’d think … Or bigger pipe sizes and stuff …
Let’s look at the next one, the one that you did today. How did today’s problem compare with that one? 
Now we have a waste, or purge stream, separate from the products … So there is an extra stream now … And what happens from there [problem 3] to there [problem 4]? 
So firstly there’s an extra stream … Is it made of the same kind of things as that product or …
It’s basically the same, it’s just that they’ve been split up now. Now you have that leaving there, and … ja, you’ve got two separate streams, as opposed to just one product … Do you expect that all these other streams are going to be the same as there? Or different? 
Isn’t that almost like the same thing, because you … all the \(N_2\) in is all the \(N_2\) leaving … So all you have is this thing just going in a circle again … 
OK so you’re expecting \(N_2\) in a circle here … Ja it’s just going to go around again … The problem in general, the E and the O and the EO You said the only difference between this problem [problem 3] and this problem [problem 4] is that the product is now split up into 2 streams - Do you expect the recycle ratio and so on to be the same here …? Or different? 
No it will be different this time. Because um, it’s recycle over waste, in that case, you don’t have, one component’s missing from our product stream [waste] so, the recycle ratio would tend to be … The denominator would be made smaller, so a bigger recycle ratio … 
Ja that’s actually a very interesting point to raise … so this one [problem 4] you would think the recycle ratio’s going to be less … what do you know though about this recycle stream, look at the components in that recycle stream [problem 3] and the components in this recycle stream [problem 4] …
Oh it’s also …! This one you had, oh we don’t have any of the product in this stream … Ja this one there’s no product there and there’s no product there … OK same, they’ll be the same then. They might be! 
And in fact if you looked at this one, I don’t know if you finished the working out on this one today, I just wrote the numbers in … 
There’s RC, There’s W [on input output table], so what is the recycle ratio here [problem 4]? It’s about 2, ja. which is the same as here [problem 3]. Now is that odd, or is that OK … Would you expect that this [problem 4] is going to be a totally different system to this [problem 3] … I’m not really, well I don’t think so, because it’s almost the same thing is basically happening, it’s just that you now have an extra stream … And it’s ideal separation … OK so that’s something to go and mull over … I’m mulling over these things myself as I’m talking about them with you … And it’s a good thing that I’m being asked these questions … Cos I just tackle a problem with, can I get the same numbers
out ... Can I just get it right you know?

When I asked you at the start, I think I asked you what the purpose was, of doing these different idealised problems, from our discussion now, would you say there are any other purposes to these 4 problems, are there other things that you can get out of these four problems than you got earlier on ...

Umm... OK now I understand the process a bit better, but I don’t know ...

OK that’s fine. I mean that’s not a hassle. It’s something to go and think about ...

I was going to ask you as well – an easy question. What is a tie substance – how do you use a tie substance?

It’s almost like the N₂, it doesn’t actually take part in the reaction ... It’s very nice, cos you can often know something else, I mean know something about the product stream, you can know that is that amount, then the rest of it must be made up of the other percentage of it ... It was quite helpful in that tutorial we did - tut 2. It made it a little bit easier...

Where did you use tie substances ...

I think it was the N₂, no it was the ash – you know the ash just went straight through.

I can leave you to go back to sleep now. What do you think ... I mean, why do you think I’m busy asking you these questions, that would be the last thing I think that I want to know from you ... what am I trying ...

To make my life difficult! No, why are you asking me these questions? What do you think I’m trying to get at in these problems ...

To actually understand what I’m doing, or what’s going on. And the thing is, I probably didn’t understand, not totally, but often I didn’t quite have an understanding of the process, I just knew how to do the calculations...

So what we’ve been looking at here in our discussion is not the calculations ...

More the conceptual ...

You’re happy with getting the calculations, I mean that’s what the focus has been in class, using an approach and so on ... And we’ve kind of been looking at these problem differently here... Maybe that’s something to [think about] ...

You know in Chemistry, um we had also [CHE]232 again, we were doing something about K, you know the equilibrium constant, and we were talking about pressure and things like that... And I’m trying to relate what we’re doing in Chemistry...

Chemistry’s quite conceptual (yeah...). I’m trying to think why’s CEM2 in our curriculum. And now the questions you’ve been asking, kind of ... it’s kind of linking now...

So the questions I’m asking are different to what you’re used to in chem eng...

Ja. We usually just... if you put this in – what comes out, kind of thing...

But it’s a lot more difficult if you say - what do expect’s going to happen to get a bigger overall conversion... OK ja, those aren’t really questions you’ve encountered much before?

No...

You find them quite different and difficult?

Ja. I find it a lot more difficult...

OK well if your brain is exhausted, I’ll leave you to go on your way! Do you have anything else you want to add on this or the test or anything else we’ve been talking about?

No no. You’ve given me lots to think ...
Have I given you something to think about?
To chew on for a while ...
OK, thanks a lot for your time.
## Appendix D.

### Interview protocols

<table>
<thead>
<tr>
<th>Interview</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interview 1</td>
<td>262</td>
</tr>
<tr>
<td>Class material used in Interview 1: Tutorial 1</td>
<td></td>
</tr>
<tr>
<td>Interview 2</td>
<td>265</td>
</tr>
<tr>
<td>Class material used in Interview 2: Recycle problems</td>
<td></td>
</tr>
<tr>
<td>- Worked example 1</td>
<td></td>
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<td>- Worked example 2</td>
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<td>- Worked example 4</td>
<td></td>
</tr>
<tr>
<td>Interview 3</td>
<td>270</td>
</tr>
<tr>
<td>Class material used in Interview 3: Energy balance data</td>
<td></td>
</tr>
<tr>
<td>- Enthalpy – temperature (H-T) graph</td>
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<td>- Table of heat capacity (C_p) data</td>
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<tr>
<td>- Extract from steam tables</td>
<td></td>
</tr>
<tr>
<td>- Energy balance equation in terms of U and H</td>
<td></td>
</tr>
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<td>Interview 4</td>
<td>275</td>
</tr>
<tr>
<td>Interview 5</td>
<td>276</td>
</tr>
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<td>Interview 6</td>
<td>277</td>
</tr>
</tbody>
</table>

**Note:** The interview protocols are reproduced here (without correction) in the form that they were used in the actual interviews.
Interview 1

Notes to myself:

- don’t talk too much; don’t butt in!
- use “that’s interesting” rather than “that’s good”
- use “tell me more about that”, “could you give me a specific example”

1. Thanks for agreeing to give up this time.
   - Explain briefly what it’s all about:
     - purpose: researching students’ experience of this course & impact on learning & metacognition
     - 4 sessions over the semester. Free to withdraw at any stage.
     - tape recording – so that I don’t have to frantically write notes – can switch off; can review. Can switch off/delete later.
     - confidentiality – no-one except me knows who said what incl. lecturers; if quotes used pseudonyms are given such that impossible to identify will be welcome to look at the products of my research
     - No ‘correct answers’ – I’m interested to find out your experience
     - Any questions?

2. How are things going for you so far in 231?
   - General discussion. (Difficult? Easy? Enjoyable? Specific confusions? - added: don’t mention these – but follow up on whatever student chooses to discuss)
     - What did you expect in 231? What had you heard about the course? Where did you hear this
     - Links to 104. Discuss.

3. In this I want to pick up on different aspects of the course – lecture, tut, self-study – and on what students think is important to do in each, what is the purpose etc. Use specific examples to facilitate shared starting point:
   - Dr Stevens said in class that students shouldn’t write down details of problems; rather concentrate on the problem. What did you think of this? worked well
   - Dr Stevens said today that those who understand all of this don’t need to attend this weeks’ lectures and a couple of people left. What did you think of this? Did you think of leaving? If not, why did you stay. worked well
   - Tut 1 Coffee problem (copy overleaf). Demonstration with orange juice and bolts – why did they do this?
   - Dr Stevens’ ‘formal analysis’ handout – what did you think of this; what did you think when he went through it, question about perception of teacher’s purpose for this, eg why do you think he did this? Why did he get you to give your own ideas before handing out this list?

4. Mention the thing in lectures so far which has made the most impression on you.

5. What is the purpose of mass balancing?

6. Do you have any questions for me?
Interview 2

Q: How are things going.... and let this lead into 1 and 2 (likely that both of these topics will be raised spontaneously based on first two interviews conducted in the Interview 2 cycle)

1. The test
   - general discussion – follow whatever comes up – this could be quite fruitful
   - likely that specific questions will be discussed (only 4 in the test)
   - what did you concentrate on in preparing for this test – with hindsight was that wise?
   - what was unexpected in the test? and try to get them to comment in these terms on both “content” and “style”
   - use of crib sheet including “would you prepare it, use it differently next time?”
   - what did you think before getting it back/ after getting it back?
   - Dr Barnes photocopied a few samples of people’s responses to one of the questions and showed these in class on Friday. What did you think of this?
   - in general - what would you do differently next time

NB: Would you mind if I made a photocopy of your script for when I am looking back at this conversation? (DON’T FORGET)

2. Comparison from Dr Stevens to Dr Barnes’s lectures
   (if this comes up spontaneously – highly likely)
   Differences – and what you are making of them. How you are coping/ adjusting.
   Why do you think she is doing what she is doing?

3. Dr Barnes’s Recycle Lectures
   (Note –my purpose in this section not to teach – mention this to students – although they are welcome to insist on explanation if desired.)
   Hypothetical / Illustrative examples of recycle (currently being done in lectures)
   All five problems – flow diagram and completed I/ O table - photocopied on separate loose sheets (copies overleaf)
   What do you think is the point/ purpose of these? (note: often different to lecturer’s intentions).
   - per pass conversion is fixed in these problems (1-3) – why – what determines per pass conversion? OR what would you do to a system if you wanted to increase per pass conversion
   - what is difference between per pass and overall conversion – which (if any) is greater - can per pass be greater than overall?
   - what is the overall conversion in problem 1?
   - look at problems 2a and b; what can you make out from these (the effect of recycle ratio on overall conversion)
   - compare problem 2 and 3 – what can you make out from these (the effect of inerts on overall conversion)
   - compare problem 3 and 4 – how do they differ - what effect does this have?
   - maybe - what is a tie substance

NB: don’t want to get stuck in the numbers of these problems – rather the big picture; conceptual ideas. Will have actual answers available.

4. Any questions?
<table>
<thead>
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<th>Class material used in Interview 2: Recycle problems</th>
</tr>
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<tbody>
<tr>
<td>Worked example 2</td>
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</tbody>
</table>
Class material used in Interview 2: Recycle problems
Worked example 4 (CHE231F workbook 1999, Lecture 22, page 1)
Interview 3

1. Howzit?

2. Vac week
   • How was the planned vac week catch-up? Anything come together then?

3. 2nd Test
   Follow same loose discussion as in previous interview, incl
   • particular questions
   • how do you think you'll do? (if they'll be brave enough to answer this – but most probably will give at least a general sense)
   • are you happy with your prep
   • was it what you expected
   • crib sheet

4. Peer marking exercise (Thur 15 April)
   • What did you think of this?
   • Did you learn anything from the exercise?
   • What do you think was the purpose

5. 2nd year lectures
   • Compare lectures in MAM280, CHE231 and CEM203....

6. Energy balances
   • How do you find energy balances so far?

Given
• energy balance equations
• H-T graph
• 8C steam table
• mean molar Cp data sheet
(copies overleaf)
How do these things link together?

Specific questions to follow with....
• What's the difference between U and H equations? Why is the H equation more frequently used?
• How could you calculate \( \Delta H \) between two points
• Explain the jagged block area, what happens when crossing line, why such a jump in values.
  How could you calculate info in steam table if you didn’t have the table?
• Gen: What is enthalpy? (gut feel)
Class material used in Interview 3: Energy balance data

Enthalpy – temperature (H-T) graph

(CHE231F workbook 1999, Lecture 30, page 3)
Class material used in Interview 3: Energy balance data
Table of heat capacity ($C_p$) data (CHE231F workbook 1999, Appendix B)
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<th>(CHE231F workbook 1999, Appendix A)</th>
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</table>
Class material used in Interview 3: Energy balance data
Energy balance equation in terms of U and H

(CHE231F workbook 1999, Lecture 30, page 1)
Interview 4
(Bring along journal!!)
Ask – possibility of 1 meeting next semester

1. howzit

2. getting back test 2 – different to what expected?....

3. journals – just talk generally about....
   • why did you/ didn’t you do optional hand-ins. Influence of extra marks?
   • which most useful tasks....
   • on particular tasks – what did you get out of this; why was it asked....
   • check ever experienced this before in a course
   • what do you think is the purpose of the journal?
   • what is your overall general feeling on it

4. Some students have said that the pace of 231 is very fast and that the details don’t get covered in class. What do you think about this? Lead into: Tasks to be done out of class – to what extent aware of these; for what reasons do you end up doing them/ not doing them. To what extent is this different to other courses you have experienced.

5. how do energy balances change if a reaction is happening? Follow up on issues raised – explain, why etc (usually ΔHₐ, ref points etc. Esp latter v. interesting – maybe lead to why ref points needed in energy balances).

6. looking back over course in general – development? metacognitive (i.e. learning about your learning...)  

7. plans for rest of semester, how do you feel about untimed test?
Interview 5
(Please bring along test 3 script if you still have it)

1. How did the exam go? ...
   - talk through the experience
   - what do you think of your mark (e.g. is it a reflection of your understanding)

2. How did test 3 go? ..... 
   - talk through the experience 
   - talk through particular questions if possible 
   - what was the impact of the untimedness, 
   - did this influence your exam prep?

3. In looking back over the discussions from last semester, I am interested in what students have said about the mistakes they made in the tests – sometimes these are called “silly mistakes” and sometimes they are called “conceptual errors”. What do you think is the difference between the two, and what type of mistakes do you think you have made more of in the exam?

4. Reflect back over the course. In what ways, if any do you think you changed, in terms of 
   - How you learn 
   - How you see yourself 
   - How you see chem eng

5. Do you think the 231 experience has any impact on how you will be approaching Transport and Thermos this semester?

6. What advice would you give to a student starting this course?

7. If you had the sole responsibility for running this course, what things would you change, and what would you keep the same?

Questions for particular students:
Looking back over the discussions we've had it seems to me that X has been a big issue for you in limiting your learning in 231 (or: has been a problem for you) / in helping your learning in 231. Do you think that’s an accurate assessment? / Could you comment on that?

Additional individual things to follow up: 
Nomsa: meaning of “information” as used in her discussions; doing calculations elsewhere (why? Does she think it’s a good thing?); feelings on becoming an engineer.
Geoff: (Remember to ask for test 1 script)
John: Use of textbook in 231 / opinion on the value of using textbooks?
Interview 6
Establish what they would like to get out of this meeting – and maybe get their burning curriculum queries out of the way.

1. Tell me about the re-write exam.... (have script in front of you). Plus preparation for this.

2. What are your final feelings on the mark (on having failed 231)?

3. What do you think you could have done differently in order to have passed?
Appendix E.
Interview scheduling
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<thead>
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<th>Week</th>
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**CHE231F June examination: 14 June 1999**

**MID-YEAR VACATION**

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<td>5</td>
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<td>Nomsa 6, Thembi 6, Andrew 6, Shakira 6 &amp; Geoff 6 during this week</td>
<td></td>
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</table>

**Notes:**

a. Geoff and Thabo elected to come for an interview during the lunch break preceding the first test; they said this would help to calm their nerves.

b. The sixth interviews all took place during this week; records of exact days when they were conducted were not kept.
Appendix F. Concept maps from journal task 9

Concept maps judged good:
Geoff
Lindiwe
Thembi
Andrew

Concept maps judged poor:
Thabo
Nomsa
John
Shakira
Maria

No submission:
Eddy
Mike

Note: Some tutor responses and queries are visible on the photocopied pages.
Geoff
Lindiwe
Lindiwe (cont.)
Thembi
Thabo
Nomsa
John
Maria
Appendix G.

Using the textbook - the concept of bypass
Introduction
In the second, sixth and eighth journal tasks students had been directed to parts of
the prescribed and recommended textbooks, and required to read through and find
information that they thought was useful, and then jot this down in their
submission. It was difficult to assess the impact of this task on students’ further
learning, as so much of this material was also covered in class. The concept of
bypass was an exception to this, in that it appeared in most journal submissions of
task 6, but was not covered in class, and was included in a question in the second
test. This provided an opportunity to see how students made use of the information
from a textbook, and the results provided a really interesting form of indirect
evidence of approach to learning.

The concept
A bypass stream is one which is split off before the reactor and later joins the reactor
product stream, thereby bypassing the reactor. This would be used in cases where
the given reactor processes a stream to a greater degree than ultimately required:
the idea therefore is to process only part of the feed and then combine processed
product with the unprocessed bypass stream to the required specifications.

A basic bypass system is represented in the following figure:

```
  bypass stream
     |
     |
feed ----> reactor ----> product

The concept of bypass was not formally covered in lectures.

The journal tasks
In the second journal task students were given a selection of recommended
textbooks and referred to the sections on basic mass balances. In some of these
textbooks bypass was mentioned in this section. In the sixth task students were
referred to a specific section in the prescribed textbook which dealt with recycle,
purge and bypass systems. It was therefore more likely that students would have
referred to bypass in the sixth task than in the second task.
All except two interviewees (John and Lindiwe) submitted the sixth task, and all of
these who submitted mentioned bypass in their responses (as could be expected).
Some of them put bypass under a section of “interesting ideas but not relevant to
the course”, and my response as marker in all cases was to write that these problems
could be encountered in the course even though they had not formally been dealt
with in class. All interviewees submitted the second task (the first journal
submission was compulsory), and of these three of them mentioned bypass in their
responses. One of these three was Lindiwe, which left John as the only student who
had not mentioned bypass in any of his journal submissions. John was therefore
omitted from the subsequent analysis.
In the journal responses, some students appeared to have copied definitions directly out of the textbook, while others appeared to have reformulated the ideas in their own words. Sometimes both of these approaches were combined, with a written definition followed by a comment, for example:

Bypass stream – a stream that skips one or more stages of the process and goes directly to another downstream stage. The calculations are quite simple – just like a stream being split and rejoining another.

(Nomsa, Journal 6, lines 27-30)

The comment that the bypass calculations were easy was given by quite a few students.

The test question
The following question appeared in the second test, which was written two weeks after journal task 2 had been marked and returned.

<table>
<thead>
<tr>
<th>Question 3</th>
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</thead>
<tbody>
<tr>
<td>A waste treatment plant operating under steady state conditions processes a waste liquor containing 500ppm of a noxious (poisonous) impurity. The impurity is removed with practically no loss of the carrier fluid. The treating process can remove the impurity down to a level of 10ppm. By local ordinance, a maximum of 100ppm is allowed in the discharge of the process effluent to a nearby river. This may be achieved by introducing a bypass stream.</td>
</tr>
<tr>
<td>a) Draw a clearly labelled diagram to represent the process. (3 marks)</td>
</tr>
<tr>
<td>b) What fraction of the waste liquor must be sent through the waste treatment unit, and what fraction may be bypassed? (4 marks)</td>
</tr>
<tr>
<td>c) What is the percentage impurity that is removed in the overall process? (1 mark)</td>
</tr>
</tbody>
</table>

The required answer for a) is similar to the diagram given earlier, with the bypass stream labelled as such, and the given concentrations allocated to the various streams: 500ppm for the feed, 10ppm for the reactor product, and 100ppm for the final combined product. An impurity stream leaving the reactor should also be drawn given that it was mentioned in the process description.
Analysis

The responses to question 3a) were analysed to get an indication of how many students were able to use the information that had been picked up in the journal task. I would assess this question as requiring not much more than reproducing the basic idea that had been represented in the textbook. The only additional complication was the impurity stream leaving the reactor.

Maria’s second test script was unfortunately never obtained despite repeated requests, and so she was also omitted from this analysis.

First of all I looked at the marker’s assessment of the responses to this question. Only two students, Mike and Shakira, obtained full marks for this question, and the remainder were awarded zero. In both the journal task and in the interview, Mike commented that he had formally been taught bypass in his first year course at another university. Shakira therefore remains as the only student who successfully managed to reproduce the information that she had read in the textbook.

In a further analysis students’ actual responses to the task were considered. For this analysis I ignored the labelling of the streams, and merely considered the construction of the flow diagram. Student responses could be grouped into the following four categories.

A. Correct diagram (Mike, Shakira, Nomso)

```
    +------------------+
    |                  |
    v                  v
   +------------------+
```

B. Bypass stream split off before the reactor but joined again in the wrong place (to the impurity stream rather than the reactor product) (Eddy, Lindiwe)

```
    +------------------+
    |                  |
    v                  v
   +------------------+
```

C. Bypass stream split off before the reactor but not joined again (Thembi, Thabo)

```
    +------------------+
    |                  |
    v                  v
   +------------------+
```

D. No attempt / Reproduction of completely unrelated system (Geoff, Andrew)
Conclusions
There appears to be a correlation between the responses and the prevalence of an information-based approach, as established in the analyses in 0. (For the various reasons discussed John, Mike and Maria are omitted from this particular analysis.) Shakira is the only student to have the question completely correct, and she represents the most extreme and exclusive information-gatherer in this sample. In terms of the flow diagram analysis, the other correct response comes from Nomsa, who also concentrates on information-gathering (combined with algorithmic approach). The rest of the students who made partially correct or completely incorrect responses were all those who did not espouse an information-based approach in the course.

It is also interesting to note that this test question seems to be quite different from most of the other assessment items used in the course: it rewards information-gathering, and the students who were most successful on this question were the least successful in the course overall.
Appendix H.

Hand-in and test schedule
<table>
<thead>
<tr>
<th>Week</th>
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<th>Monday</th>
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<td>CHE232 tut hand-in</td>
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**Vacation**

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**Study week** CHE232 project due
References


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