RELEVANCE IN CHEMICAL EDUCATION AND PRACTICE:

with particular reference to kinetics and equilibrium.

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SUMMARY.

This study concerns the general area of educational relevance. In particular, it addresses perceptions of the relevance of chemical education in respect of professional practice. Its scope has been confined to the conceptual areas of kinetics and equilibrium. The research has involved a total of 51 participants, representing educators, practitioners and students, in a programme of semi-structured interviews supported by a questionnaire.

The report begins with a consideration of the available research methodologies, and the reasons for selecting naturalistic case study. This is followed by a description of the particular procedures adopted. A method for interview analysis, and the results of its application to the initial phase interviews is discussed. A model of thinking strategies associated with chemical kinetics and equilibrium is introduced.

This is followed by the extension of the research sample and further interview analysis. From participants' statements about their experience of chemical education, a model of perceptual space is proposed, with suggestion of how this links with thinking strategies in forming an understanding of the concepts involved.

A discussion of relevance in an educational context is introduced next, and a distinction drawn between 'relevant education' and 'educational relevance'. The evaluative nature of the latter allows the formation of a triadic model of educational relevance for the concepts being considered. Evidence for a mismatch between expectations and eventual experience of chemical education is given. A mechanism is offered by which individuals' perceptions of educational relevance may be limited.
The formulation and application of a triangulatory questionnaire is then discussed, the further insights gained allowing the three models to be inter-related. Finally, a characterisation of educational relevance is proposed with a discussion of the implications this may have for student learning and staff development in chemical education.

There is no separate literature review as this is interwoven with each stage of the report.

* * *

* * *
TO ANN
WITH ALL MY LOVE
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PREFACE.

Any research inquiry is a journey, and a thesis an interlude during which one reviews and reports progress so that future journeying is authentically informed. The 'pure' science researcher is confronted with reporting an inquiry in which the prime factors are experimental design, high objectivity and close control of identified and isolated variables. A critic might thus question experimental design, and would no doubt look closely at inferences and conclusions, but only unusually would the experimenter be considered part of the experiment.

Reporting science education research using a naturalistic methodology introduces new factors. 'Hard' data are infrequently involved; the experimenter is deeply associated with the experiment, and objectivity is difficult to achieve, let alone maintain. It may be that objectivity is not even a high priority in research design. Provided credibility and authenticity are fostered in the inquiry, none of this invalidates naturalistic research. However, it does necessitate that the critic has some appreciation of the 'researcher-as-person' - a person with skills, knowledge, intelligence(hopefully!) and prejudices. Life-experiences can provide bias. Further, the naturalistic 'journey' can be very educative for both researcher and researched - an element of personal development is thus inevitable. The researcher is not as isolated from the 'experiment' compared with pure scientific research. No pots have been boiled, no electron microscopes energised; people have met and talked and interacted. In certain important respects, the researcher becomes part of the data, through personal contact with participants and a human, evaluative reaction of such interaction.

These aspects of the naturalistic paradigm have influenced the style of this research report. The author has deliberately
set out to report on a journey and a traveller, as well as to report on the reason for the journey - the questions defining the research problem and the search for answers. This has produced what, for some, may be considered a break with tradition. For example, literature survey is reported as and when it relates to a specific stage in the development of the inquiry. Critical evaluation of methodology also occurs 'in context' rather than as a final review. There is an attempt to provide a biography of the researcher, not in any formalised or rigorous way, but as an attempt to give the reader an insight of the 'researcher-contribution' in the inquiry. The intention is to present a 'map-reference' from which interpretation of naturalistic data has been attempted.

The problem tackled in this inquiry (that of attempting to understand the nature of educational relevance) involves an opaque yet powerful concept. Powerful, that is, in the sense that its use frequently introduces an element of unquestioned acceptance of justification. Rarely is such justification not just questioned, but unpacked to promote understanding. With so many professional, political and parental pressure groups currently demanding relevance in education, it is surprising that relatively little attention has been paid to what this may mean in operational terms. The author believes that a major strength of the naturalistic approach to research is its ability to progressively focus on significant aspects of such opaque, multi-faceted and multivariate situations, introducing an element of pattern and meaning. The style of this report reflects this progressive focusing technique.

The introductory chapters (1&2) review the experiences and commitments the author brings to the inquiry, and defines the research questions. Chapter 3 looks in depth at the reasons for adopting naturalistic methodology, and Chapter 4 reviews the detailed design of the inquiry. The next Chapter(5) considers in detail the major instrument selected for data
collection - the research interview - whilst Chapter 6 discusses sampling and the selection of research participants. Chapter 7 considers the analysis of the research data. The progress of the inquiry is then related to an analysis of the concept of relevance in education (Chapter 8), producing a basis for suggesting solutions to the research questions. By way of confirmatory triangulation, the data from a research questionnaire are next considered (Chapter 9) before a discussion of the full findings for Chemical Education is given. (Chapter 10).

As a result of this progressive focussing on particular aspects of the inquiry and the interpretation of data, it has been possible to suggest three models: thinking modes; perceptual dimensions for concept understanding; and educational relevance. In the opinion of the author, these models go a long way towards clarifying what we mean by educational relevance. Of practical necessity, the inquiry has been limited to specific conceptual areas in chemistry. It is hoped, however, that the in-depth case-study which forms the basis of this report will do more than be informative in a limited field of chemical education. If this case-study can also indicate new ways of evaluating educational relevance, and provide a positive influence on educational practice, the journey will have been well worthwhile.

* * *
Chapter One

Introduction: Roots.

1·1-1·10 In which personal perspectives and career background are discussed.
1. INTRODUCTION: ROOTS.

' "Where shall I begin, please your Majesty?" he asked.
"Begin at the beginning," the King said, gravely,
"and go on till you come to the end: then stop."'

Lewis Carroll
Alice in Wonderland (Ch. 10)

1·1 I have some idea where the beginning was; I am far less certain about the end, and where I shall be able to stop. The aptness of Lewis Carroll's words may seem obvious in telling everyday stories. However, inquiry seems to become increasingly open-ended as it progresses, the tendency for divergency competing efficiently with attempts to find natural conclusions. In the case of this inquiry, there is also the problem of a starting-point. No-one offered a research grant to work on an already defined problem; no supervisor said 'this is what I want you to look at'. This study developed from my own interest in science education resulting from career development, the form and direction being guided rather than dictated by supervision. Thus the story of this inquiry has roots in personal history and personal commitments of which the reader should be aware, for full understanding; roots which generated the research questions and which involved a re-orientation from scientist towards that of social scientist. I have a tale to tell, and I shall - as advised - begin where I think it all began.

1·2 I can still savour the surprise on learning that my school had awarded me the Blackburn Prize for Science, based on GCE 'O'level performance, a surprise the greater for two things.
I had hated physics, and loathed my biology teacher. Perhaps through some perverse, subconscious reaction, it was then that my ambition to teach science was born. There followed one or two years of internal conflict as I battled with an earlier and still not totally dormant, desire to enter the medical profession - and battled also to obtain 'a language other than English', for university entrance purposes. I cannot recollect learning much French in sitting 'O' level five times - but I learned perseverance. Chemistry was then my major interest and academic strength, with mathematics diametrically opposite.

1.3 After the surprise, confusion. My attempts to read chemistry for Honours came to nought. I was offered (and accepted) a General Sciences degree course in chemistry, physics and zoology. Having been told that my mathematical ability (a mediocre pass at 'O' level) was far too weak for chemistry, the next three years were partly spent battling with undergraduate physics and all its mathematical connotations. It seemed to me, during that time, that the judgement of academics was oddly left-handed in a right-handed world, and no university teacher seemed particularly interested in student progress. Perhaps this was my reason for over-indulgence in the more social aspects of undergraduate life, to the detriment of academic achievement. Nevertheless I managed to graduate, with my love of science somewhat diminished, but my determination to teach (oddly) strengthened. A year of postgraduate education introduced me to Plato and a well managed, happy community in a Grammar school in the middle of the New Forest. Those I think are the main impressions I have of that education year. During that time, the New Forest children taught me a great deal about teaching, giving me insights into the excitement of their 'discovery' that were the roots of my deep seated belief in teaching as a facilitation process. I became very sceptical of teaching as a knowledge transmission game.

1.4 My first teaching post, in Portsmouth, provided me with
the opportunity to really learn some chemistry, and to work
with probably the most remarkable teacher it has been my
fortune to meet. 'The Squire' was a bluff, taciturn
Yorkshireman of immense character and wit. He was revered by
the whole school with a mixture of fear and admiration. But
it was one phrase of his, presented after dressing me down
for failing to return pupils' work on time, that made the
most impression on me:- "Remember lad, exam results mean nowt
if the boys don't understand - they do the learning, and it's
your business to help them." How right he was; so many
teachers seem to expect students to know how to learn, once
provided with the knowledge.

1.5 It became clear to me that my weak first degree would be
a barrier to career progress. I moved to a school in Croydon,
and studied for a Masters Degree in Crystallography, part-time
four evenings a week. After a full day as a teacher, the
effect of role-reversal was dramatic. I was confronted with
the weaknesses of my own learning skills. For the first time
in higher education I experienced the benefit of tutors who
understood the demands being made, and who were seriously
concerned about students' progress. These were hard but
enjoyable and invigorating times. My perspective on scientific
knowledge changed, from 'accumulative fragmentalism' [a growing
collection of substantiated facts (Kelly, 1955); see 3.4.7] to
constructed understanding. The need to master Fourier
analysis (starting, as the reader will remember, from an '0'
level Mathematics baseline!) became a source of motivation,
which overcame earlier revulsion for mathematics. An object
lesson in relevance.

1.6 My 'Croydon period' saw two interesting trends developing.
As my depth of knowledge grew through higher degree studies,
and with it a perspective of integrated scientific understanding,
I became less satisfied with teaching young people. I have
often wondered why this should have been. A newly found
enthusiasm for understanding my subject ought to have augmented my keen interest in aiding young people's cognition, yet - perhaps paradoxically - I found school teaching was less satisfying. Rather than enriching my teaching, I grew restless with the relatively low level of understanding that could be obtained. At about this time I had several student teachers attached to me, and it was in their work that I found a new and satisfying role. We spent hours discussing what this thing 'science' was, and what chemistry was 'all about'. Translating this into designing learning situations became a deep fascination. I was struck by the relatively poor understanding of their subject these graduate student-teachers had, and the algorithmic nature of their undergraduate learning. The temptation for them to repeat those algorithms in their teaching was strong, particularly since they had seemingly always learned their science that way. They had accumulated many fragments or 'nuggets of truth' [Kelly (1955)]. Reconstructing those fragments on a framework of meaning seemed to open new avenues, both for me and those student teachers. An advertisement for a Lectureship in a College of Education, to develop new B.Ed. chemistry courses for secondary teachers, was too attractive an opportunity to ignore.

1.7 My move to undergraduate teaching was both fortunate and - at least in the short term - unfortunate. Fortunate because there was time to think, space to expand. I met, and learned from, many notable chemical educators. The chance was taken to teach in Jamaica for an all too brief period under British Council auspices. The differing perspectives on science, on chemistry and on teaching and learning which were encountered broadened my horizons, but did nothing to shake my belief in teaching as the facilitation of meaningful learning: rather, the opposite. The unfortunate part of this move was timing. In the early 1970's science recruitment diminished dramatically. A period of instability followed in which it became necessary
to collapse a physics and a chemistry department into a physical sciences department. Yet another degree course to design, and further curriculum innovation; this time a B.Ed. in physical science. On the strength of this experience, which was greatly aided by my earlier integration of scientific knowledge through reading crystallography, I ran a summer school in Singapore. At that time, Singapore's science teachers were being asked to change from separate sciences, to physical sciences. The experiences encountered there, in terms of somewhat entrenched 'subject traditionalism', and similar difficulties encountered in getting acceptance for the new B.Ed in physical science, raised questions in my mind about science education. What was this new game I was playing? What were its rules, and what did one do to score points? It seemed that at 'practitioner' level, my work to date had proved not only acceptable, but somewhat successful. However at institutional level, the only comment I seemed to get was "I hear you". To which my sotto voce reply was invariably, "Yes, you may hear me, but you're not listening!"

My further study for an M.Ed. in science education was thus no accident, though perhaps a side-step. More importantly, it catalysed a latent change from science to a form of social science. With a new 'acceptability', I took on the direction of professional teacher-development courses in my College, having to mould an existing harlequin provision in a wide range of curriculum subjects into a coherent philosophy and approach. This required the acquisition of management skills, new to me. This was a very instructive part of my career development, learning as I did a lot about other people and their visions and ambitions, and about personal interactions. It required achieving a greater understanding of the whole school curriculum, and the needs of the various age ranges. It seemed a long haul away from the teaching of chemistry, but has proved a very significant experience, breaking down the isolation of the subject purist, and
providing a sympathy with many viewpoints which, in earlier years, I might well have derided. I owe much of my present holistic view of education and learning, to my experiences during these several years. Thus, in the short term, an unfortunate move, but in the long term a very significant move.

1.9 But more change was in the air. Teacher education was drastically reduced in terms of student numbers, and to survive, my College entered into federation with three others. Now came the traumas of reorganisation, rationalisation and redundancy. Whilst part of an autonomous institution, my perspectives on education had found acceptance if not agreement. In the wider context of the federation, rather more traditional approaches existed, with an emphasis on Primary education. Since my expertise was mainly at Secondary level, it was natural that I should concentrate on Secondary Postgraduate Certificate work. With a change of Validating Body, contact was made with Surrey University Institute for Educational Development, and a latent research interest fanned into flame. The 'breeze' blowing on the embers consisted of an immediate sympathy and empathy with my own implicit attitudes and beliefs about teaching and learning, teachers and learners. Much of what is written in this introduction would have remained implicit, but for this interaction.

1.10 The importance of presenting the above details lies in the need to make clear my own position as an educator. In any evaluation, the baselines must be clearly drawn. What I hope the reader has gained from the previous paragraphs is not only how I view teaching and learning, but some indication of how those attitudes were derived. Also, I hope that, in outline, I have presented some of the skills brought to this inquiry, and how these have been gained. Summarising, therefore:-
a) I place the teacher in the role of a learning facilitator, being aware of the need to help the development of learning skills in the student, at the same time as aiding meaningful learning of content.
b) I expect the teacher to have a perspective of his/her subject which allows for a clear understanding of its 'conceptual infrastructure', and how that can be used in a meaningful and relevant manner.
c) In my view, the educational enterprise is not built of isolated, albeit interlocking, pieces. There is a 'wholeness' involved which demands more of both teacher and learner than successful specialisation, since learning is part of an integrated integrative human activity. This is not to decry the need for excellence in specialism, but to put such excellence in an holistic perspective.
d) Career progress has required and developed a range of skills peripheral to a teaching mode, including:
   - curriculum development
   - management
   - personal evaluation

   alongside an awareness of the problems and strategies associated with working in a rapidly changing situation.

I make no claims or judgements about my efficacy in those areas, since that is not my purpose.

* * *
Chapter Two

Introduction: Premises.

2.1-2.9 In which personal commitments and their implications for this study are discussed.
CHAPTER TWO.

2. INTRODUCTION: PREMISES.

'Education is the acquisition of the art of utilisation of knowledge.'

Whitehead 1932 p6.

2.1 The roots of this inquiry are embedded in the secondary school situation. Personal experience as teacher and teacher-educator gave rise to a string of questions concerning chemical education practice, the most significant of which became increasingly urgent - 'How do individuals construct chemical concepts?' An implication of this question is that knowledge is not independent of the processes individuals use in learning (an epistemological issue which will be discussed in Chapter 10). If - as seemed to be the evidence of practice - the learner is simply given a 'knowledge template', there would appear to be little room for conceptual creativity with understanding. If - as has recently increasingly become the practice - the learner is expected to interpret written materials, then there might be some room for conceptual creativity, but the extent and nature of understanding generated would seem to be highly debatable.

2.2 The decision to inquire further into this question led to the need for a better understanding of two related issues. On the one hand, the psychology of learning and of the learner was clearly of importance; on the other, there was the need to understand what was meant by 'knowledge'. The first of these factors led to an in-depth review of current approaches to the psychology of learning [Horscroft (1982a)]. As a result of this comprehensive review it became clear that I
felt most comfortable with a framework embracing the 'cognitive' school (e.g. Ausbel), and that of personal constructivism (e.g. Kelly). Many aspects of the currently strongly dominant Piagetian approach seemed inappropriate, particularly in that the stage theory contains little offering a satisfactory explanation of adolescent learning [Nagy and Griffiths (1982)]. Further, the apparently rigid stage structure of mental development seemed too hierarchical to match personal and recorded experience. One feature at least of the Piagetian view does have an important significance for me, however. To generalise, Piaget's insistence that thought, language and learning are inextricably mixed, implies that the learner must think and talk, to learn. This not only illuminates our understanding of the learning process, but has important methodological consequences for the investigation of such processes.

2.3 The two consequences of this review (a personal sympathy with constructivism, and the idea that by listening to the learner one can gain clues as to the processes of knowledge construction) were significant influences on the choice of methodology for this inquiry. Psychometry seemed to have little to offer in investigating the processes of learning, since the main focus is not on the individual's thinking processes, but on the results of those processes. A naturalistic mode of inquiry thus seemed to be the most appropriate, with the one-to-one interview situation appearing to offer the best way forward. The Interview-about-Instances [IAI] [Gilbert and Osborne (1980)] approach was also highly attractive, but was not in the end adopted for reasons which will become clear. The methodology of this inquiry is fully discussed in Chapters 4 and 5.

2.4 My attempts to define an epistemological position suitable for my research has had implications from two different angles. The first, personal, angle was a rejection
of logical-positivism, and an unrationaled belief that 'academic knowledge' was a sub-set of a more general 'world-knowledge'. My naive impression was that by some (personally) ill-understood process, individuals pooled their knowledge through discourse, to generate or define specialist knowledge. A series of PCKG* seminars on philosophies of science produced a clear sympathy with a 'consensus' view of knowledge, and the implied weakening of the objective and realist nature of science [Horscroft (1982b)]. Whilst this might be taken as empathetic with constructivism, there is a problem in suggesting such a correlation. Individuals may well construct their own personal 'world knowledge' but this, it may be argued, is of a very different order from the 'academic knowledge' that is traditionally the stuff of education.

2.5 The other perspective relates to the perceptions of others. There is considerable evidence [see for example, Swift et al (1982); Head (1985)] to show that certain groups of people project distinct philosophies of scientific knowledge. School teachers, text books and syllabi seem to be imbued with a Baconian (inductive) view of science. Professional journals and other written sources show clear evidence of editorial policy designed to satisfy the epistemology of the target audience. What had initially appeared to be unproblematical (ie. my inquiry was to embrace chemistry), now posed some difficult questions. Whose chemistry was I intending to involve; teachers' chemistry, students' chemistry, academic chemistry, etc.? The decision was taken at this point to attempt to characterise the way different groups of scientists viewed chemical knowledge, to see just how important a factor this was. Was researchers' science so very different from teachers' science, or students' science? An initial phase of the study was clearly necessary.

*Personal Construction of Knowledge Group: a research group sharing a common sympathy with a constructivist philosophy and psychology, involved in a wide range of educational research areas. (Department of Educational Studies, University of Surrey).
2.6 Any field of inquiry requires boundaries if it is not to become so eclectic as to be ephemeral. To perform an initial phase required a limitation in the chemical concepts it would embrace. My decision to look at the concepts of chemical kinetics and chemical equilibrium rested on five main premises:

1. Personal teaching experience showed that these were not easy concepts to learn.
2. Evidence of learning difficulty existed in the literature [e.g. Johnstone et al (1977)].
3. The concepts are fundamental in chemistry.
4. The concepts are fundamental to chemical practice.
5. Little research appeared to be in progress in this aspect of chemistry.

My first task was to map out my own understanding of the concept relationships involved [Novak (1984)], an exercise which highlighted the wide range of conceptual complexity involved (e.g. from the apparently simple idea of 'rate of reaction' to such complexities as 'transition state compound'). Apart from underlining some large gaps in both my knowledge and understanding, a significant outcome from this activity was the clarification of my personal view of this area of chemistry. It became obvious to me that, in my own thinking, kinetics and equilibria were very closely related. Diagram 1 (p14) outlines the main conceptual relationships in that personal perspective. This was interesting, since it was clear that most authoritative sources (e.g. texts) did not treat kinetics and equilibria as closely related phenomena, but as two distinct studies [see for example Atkins (1986)]. A more detailed discussion of this area of chemistry is undertaken in Chapter 8.

2.7 The lack of congruity between my concept structure and that displayed in texts etc., pointed to the possibility that these differing perspectives were related to the use to which the concepts are put. My own understanding reflects my teaching approach (or vice-versa); the texts are mainly
DIAGRAM 1: Personal perspective on the focal concepts.
written by academic specialists whose purposes are somewhat different - the recording of precise, accurate and logically proven knowledge for use as reference material. The initial phase of the inquiry was to provide an opportunity to identify and characterise any such differential understanding, access being gained to the B.P. Research Centre at Sunbury to interview industrial chemical practitioners. A preliminary analysis of the initial phase interviews was undertaken, so that further phases of the inquiry could be focussed on important issues. This analysis proved significant; so significant in fact that it re-focussed the inquiry onto a different problem from that originally selected. Two very distinct viewpoints emerged concerning the conceptual areas under study, and a fuller treatment of this will be found in Chapter 6. These distinct viewpoints appeared to relate to the context in which the individual was involved with the concepts, a possible correlation with a learning/researching polarity (ie. acquisition versus utilisation). Several strong claims were made concerning the irrelevance of university chemical education vis-a-vis industrial practice, and this irrelevance also seemed associated with the polarity.

2.8 My notion of educational relevance thus began to develop a multi-faceted characteristic. From the interviews there was clear evidence of a mismatch between vocational expectation and educational experience. The concept of educational relevance is widely used and rarely defined. The importance of relevance in course design, teaching techniques and learning strategies in any education, let alone chemical education, is fundamental. Yet the concept is largely unmapped. 'Relevance' is, I suppose, generally taken to be either 'obvious' or 'commonsense', or far too general an idea to be worth analysing. Might it not be possible, however, to improve our understanding of relevance by taking a fairly specific area of knowledge which has both academic and practical utility, and trying to find out why those possessing that knowledge
DIAGRAM 2: Background to the inquiry.
thought it to be relevant - or otherwise? A new focus for the inquiry therefore emerged. The implications of an improved understanding of educational relevance could be highly significant, not just for courses in Higher Education, but for all levels of chemical education.

2.9 I hope the reader has gained from these first two chapters, an understanding of those strands which have led to an identification of research questions.* Through reading the biography of the teacher, and that of the researcher, certain key ideas, commitments, or - if you prefer - concepts should be discernable. It is these key features which have resulted in my interest in understanding educational relevance, and have guided my literature searches. It may be helpful at this point, therefore, to present in diagrammatic form my perception of these key points, and how they relate to the nature of this inquiry (Diagram 2, p16).

*RESEARCH QUESTIONS:

A. What makes concept learning to be of greatest practical/vocational value?

B. What is required to make chemical education courses of optimal relevance?

C. Is it possible to characterise educational relevance in chemical education?

* * *
Chapter Three

Justifications.

In which is discussed the choice of approach used in this study.

3·1 Research avenues.
3·2 Implications for Science education research.
3·3 Choice of paradigm.
3·4 Justifications.
CHAPTER THREE.

JUSTIFICATIONS:

'Education should begin in research and end in research... an education which does not begin by evoking initiative and end by encouraging it is wrong. For its whole aim is the production of active wisdom.'

Whitehead 1932 p58.

* * *

3.1 Research avenues.

3.1.1 Professor Whitehead's writings are full of significance for me; either he was a great prophet-philosopher, or we educationalists have learned little in the last half century—or of course, both! His claim (above) is notable in two ways; namely his use of the word 'research', and his insistence that education should lead to 'active wisdom'. Further, the idea that personal initiative for inquiry which leads to wisdom should be the aim of education is, of itself, thought provoking. What is this 'research' that he values so clearly? It must be made clear that Whitehead's 'research' was of a much less formalised nature than the meaning that normally comes to mind. Whitehead was writing of 'discursive adventures' involved in learning, which he suggested would avoid

'the paralysis of thought induced... by the aimless accumulation of precise knowledge, inert and unutilised.' p 58

However, it is my belief that Whitehead's comment does embrace the whole range of human inquiry, including what one might term 'professional research'; and that of course raises the inevitable question, what do I mean by 'professional research'? Not an easy question to answer, but I find I have much in common with Stenhouse's (1981) 'minimal definition' that 'research is systematic self-critical inquiry' which:

[... is
'...is founded in curiosity and a desire to understand; but it is a stable, not a fleeting curiosity, systematic in sense of being sustained by a strategy... a persistence of sequential inquiry by curiosity out of patience. And fundamental to such persistence of inquiry is a sceptical temper of mind sustained by critical principles, a doubt not only about the received and comfortable answers, but also about one's own hypotheses.' p103

3.1.2 In contrasting the nature of such inquiry as adopted by historians and scientists, Stenhouse distinguishes between research in science which characteristically seeks 'laws or theories not narrowly conditional upon time' and historical research which 'recognises time as an essential variable in the accounts they give.' The importance of this point lies in the attempts made in scientific research to provide generalisations which are predictive and universal; historical research provides generalisation which is 'retrospective and summarises experience within boundaries of time and place.' To use Stenhouse's words again

'scientists attempt to account for consistencies of occurrence or of the conjunction of occurrences over time or for events which are regarded as inevitable outcomes of preceding causes. Or, to put it another way, scientists are interested in the power of laws and theories which are general and predictive to organise data derived from observations.' p105

3.1.3 The utility of such inquiry is twofold. Firstly, the predictions can provide information about the context of action; secondly, application of the general laws will allow us to estimate the effects of specific acts—two factors which 'strengthen, but do not supercede common sense.' Historical research has similar utilitarian functions by way of its ability to summarise experience to provide considerations helpful in judging how to act, and summarizing experience of action in a manner which helps judgement in planning acts. In the sense that both science and history help to define the context in
which people act, and help to anticipate the outcomes of actions, they have much in common. But, as Stenhouse points out, 'When we apply science we premise high predictability, and when we apply history we premise low predictability. I believe that the acts and thoughts of human beings contain essentially unpredictable elements owing to the human capacity for creative problem-solving and the creation of meanings.' p106

3.1.4 It would seem therefore that there are at least two broad approaches to that research whose aim is to create 'active wisdom'. Anyone having the initiative to undertake a 'discursive adventure' by way of 'systematic self-critical inquiry' would seem to be faced with the need for decision— which route should be taken to arrive at something akin to 'active wisdom'? As with the high road and the low road to Loch Lomond, we have a road of high predictability or low predictability available. But the parallel may not be exact; whichever road one took, Loch Lomond was the eventual destination. It is not as certain that the two research roads lead so clearly to the same point on the map.

3.1.5 A critical factor in such a decision must rest with the nature of the 'problem' which has aroused the curiosity of the inquirer. The research questions which this study is addressing (see 2.9) cannot easily be labelled as belonging to a particular discipline (i.e. chemistry or education). Whilst embracing scientific (or, more precisely, chemical) concepts, the objectives are not to secure a fuller understanding of 'hard' scientific facts. Neither is it intended that the frontier of educational philosophy should be the major focus of attention. In seeking to characterise educational relevance within a framework of chemical education, I am operating in a hybrid field involving the relationship between educational practice and chemical knowledge.

3.2 Implications for science education research.

3.2.1 As Kempa (1976) has pointed out, research in science
education is a relatively new field of activity. Shulman and Tamir (1973) argue that this growth in activity has resulted from the curriculum reform movements in science over the last twenty years or so. Perhaps inevitably therefore, much of this research has been largely 'empirical' in nature (i.e. on the road of high predictability) and has led to valuable critical questioning in areas where value judgements had previously prevailed, as for example with the merits of 'learning by discovery', and the transferability of Piagetian notions from a wider context to that of specific fields of learning. Without diminishing such achievements, it must be noted that science education research has its critics. As Shulman and Tamir observed:

'one important characteristic of much of the literature in science education is the vast disparity between the profound and truly important nature of the questions raised by the philosophers working in the field, and the too frequently trivial empirical studies conducted by the empirical researchers in the field.' (p 1138)

3.2.2 Such comment, it can be argued, arises from the inevitably practical context of science education tending to generate rather specific 'problems'. This context-dependency seems to have a limiting effect on the wider application of research findings, and hence its utility for informing the more profound issues. Perhaps science education research should thus attempt to reduce this context dependency, or

'What is needed is more decision oriented research i.e. research which gives rise to findings on the basis of which positive decisions about instructional strategies, curricular content, and other issues concerning the effectiveness of science education, can be taken.' (Kempa op cit p99)

In making this plea, Kempa also notes that the majority of recent science education research (that is, pre 1976) had been within a 'psychometric paradigm', involving the development of instruments, the collection of data, and their subsequent statistical analysis. The reasons for this, he suggests, have been twofold:

1. The relative ease with which such research is facilitated.
2. The natural instinct of the science education researcher,
with his 'closeness to the sciences', for 'hard data'. This of course assumes that all science researchers have a 'hard science' background, an assumption which may not be fully justified.

3.2.3 Whilst 'hard data research' has its values, it has its limitations, as Kempa points out:

'Researches done in the best tradition of good 'experimental designs' tend to generate from a priori theoretical statements and assumptions for which empirical validation is sought, but rarely lead to the generation of new theories and notions. Workers in other fields of education have recognised this methodological problem and turned increasingly to other modes of research.' (op cit p101).

This point has also been vigorously argued by Phillips (1974), in his suggestion that research following the scientific paradigm is good for checking the existing scene, but not primarily a source of innovation. This, he claims, is far more likely to come from theorising or 'speculation' (as Feyerabend [1968] prefers to call it) - or even simply dreaming, as Kekule did when his studies of benzene structure were seemingly unproductive.

Fensham (1976a) adds a further criticism. He claims that many successful and innovative examples of science teaching are in unique situations which are not amenable to 'sound empirical design', and that quite frequently those involved in such cases regard systematic research as 'low among their priorities of participation'.

3.2.4 What then is the alternative, the road of 'low predictability'? As Gilbert and Pope (1984) observe:

'The educational research world is currently divided on a fundamental issue: what philosophy should inform its activities. The established, or conventional approach is based on an analogy drawn from research in the natural sciences. For that reason it is sometimes known as the scientific method: it is otherwise called the objective or experimental or reductionist approach.
The naturalistic approach is based on an analogy drawn from research in anthropology, i.e. where individuals are studied in their social setting. For that reason it is sometimes called the descriptive or holistic approach. Naturalistic inquiry may be assumed to be any inquiry carried out in a natural setting, using case-study methods, and relying heavily on qualitative rather than quantitative data. Guba and Lincoln (1982) argue that such a description is not, however, adequate, since naturalistic inquiry is for them a 'paradigm of inquiry', 'a pattern or model for how inquiry may be conducted'. For them 'paradigms are axiomatic systems characterised essentially by their differing sets of assumptions, about the phenomena into which they are designed to inquire.' (p233)

<table>
<thead>
<tr>
<th>Paradigm of inquiry</th>
<th>Area of use</th>
<th>Methodology</th>
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<tbody>
<tr>
<td>Adversarial</td>
<td>Jurisprudence</td>
<td>Opposing parties argue their case. Jury believed capable of sifting truth from falsehood in views heard.</td>
</tr>
<tr>
<td>Theological</td>
<td>Religious faiths</td>
<td>Study of revelation can yield answer to any question: necessary truth is directly revealed.</td>
</tr>
<tr>
<td>Judgemental</td>
<td>Art/Literary critique/Music</td>
<td>Experts/critics by virtue of training and experience can recognise truth when they see/read/hear it.</td>
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<td></td>
<td>Academic peer criticism</td>
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TABLE 1 Some commonly used Paradigms of inquiry. after Guba and Lincoln (1982)

3.2.5 Whilst there are many paradigms of inquiry commonly used in everyday life (see Table 1 for example), disciplined inquiry (i.e. the process earlier described as professional research) seems to have been confined almost entirely to the scientific paradigm. In the area of what might be termed the pure sciences, this has
been particularly successful, generating considerable academic respect and status as a mode of research. In consequence, the scientific paradigm provides a well trodden path of techniques and strategies for the analysis of its data. However, as Miles (1979) has pointed out
'the most serious difficulty in the use of qualitative data is that methods of analysis are not well formulated. For quantitative data, there are clear conventions the researcher can use. But the analyst of qualitative data has very few guidelines for protection against self-delusion, let alone the presentation of unreliable or invalid conclusions'.

3.3 Choice of Paradigm.
3.3.1 If the application of the scientific paradigm in science education research has been of limited value (Kempa, Shulman and Tamir, Phillips, and Fensham, discussed earlier), then the alternative available would appear to be more of an emerging paradigm in character, and thus a much less 'secure' path to take. For an interesting, brief and readable account of the 'rise of naturalism', see Reynolds (1980). The debate concerning the 'two cultures' [Broadfoot and Nisbet (1981)] is still being energetically pursued. Which 'mode of research', whether it be the 'search for generalities' (scientific paradigm) or the 'study of singularities' [Bassey (1983)] carries the most 'clout' is not a matter of urgency here. Suffice it to say that much has been written concerning research paradigms [Gilbert and Pope (1984), Guba and Lincoln (1982), Coher and Manion (1980), Rist (1980, 1977), Guba (1978), Fensham (1976a), Parlett and Hamilton (1972)], the most significant point arising for my purposes being the use of the term 'paradigm', and the influence of Tomas Kuhn's (1970) ideas concerning the nature of science.

3.3.2 Rist (1977) quotes a helpful amplification of Guba and Lincoln's definition of 'paradigm', derived from Kuhn's work:
'A paradigm is a world view, a general perspective, a way of breaking down the complexity of the real world. As such paradigms are deeply embedded in the socialisation
of adherents and practitioners telling them what is important, what is legitimate, what is reasonable. Paradigms are normative, they tell the practitioner what to do without the necessity of long, existential or epistemological consideration. But it is this aspect of a paradigm that constitutes both its strength and its weakness - its strength in that it makes action possible, its weakness in that the very reason for action is hidden in the unquestioned assumptions of the paradigm.'

(Patton 1975, quoted in Rist p43;)
my underlining.

3.3.3 Without questioning these assumptions there is a real danger of 'reification' (Rist 1977) of methodology constricting open, un-prejudiced attempts to inquire into natural events; a strict, almost blind, adherence to paradigmatic rules which make methodology an end in itself. (Miles 1979). My own reaction to this potential extreme polarisation was voiced in the parable of Xoat, written in response to discussions held with my research colleagues at Surrey University (see Appendix 1).

3.3.4 Rist (1977) has argued strongly for the need to 'ferret out the unquestioned assumptions' before assessing the value of various research strategies. The issue involved is not the research strategy per se:
'the adherence to one paradigm as opposed to another predisposes one to view the world and the events within it in profoundly different ways...'. The power and pull of a paradigm is more than simply a methodological orientation. It is a means by which to grasp reality and give it meaning and predictability... the research orientations are themselves grounded in a perspective beyond simple of methodological procedure... we are in the final analysis, speaking of an inter-related set of assumptions about the social world which are philosophical, ideological and epistemological. They encompass more than empty data gathering techniques.' (p43)
3.3.5 Thus the selection of any particular methodological stance should be seen as profoundly theoretical. The implication is thus that the choice of any one methodology should also involve the reasoned rejection of the other methodologies. It must necessarily relate to the beliefs and values one holds about the very nature of reality, if the intention is to try to understand that reality. Choice of method should not therefore be a question of 'will this inquiry fit into the prevailing paradigm?', but 'which paradigm fits the nature of the inquiry, and my own inclinations?'

3.3.6 I have argued, thus far, that 'professional research' consists of a systematic self-critical inquiry which is driven by a desire to understand. The strategy one adopts in attempting an inquiry is not solely dependent on the methods available for conducting it. One must consider also the basic philosophical, ideological and epistemological assumptions implicit in the various methodologies and with which the researcher can be compatible. These must then be related to the nature of the problem inquired into. My own inquiry is not in pure science, but in science education. For many, research activity in science education has frequently not looked carefully enough at the research mode used, with a consequent lack of understanding and utility. My inquiry considers a small part of the educational process - a process which contains many parameters with complex interrelationships between them. It is also a dynamic process involving change, and thus it could be claimed that, over time, many of the parameters are themselves far from invariate. Any inquiry in such an area requires a methodology which will most effectively illuminate the problem.

'Finding a paradigm that can tolerate real world conditions surely makes more sense than manipulating those conditions to meet the arbitrary design requirements of a paradigm.'

3.4 Justifications.

3.4.1 After a review of research articles, Gilbert and Pope (1984) have suggested the following list of contrasting descriptors for the available research paradigms:

<table>
<thead>
<tr>
<th>Paradigm 1</th>
<th>Paradigm 2</th>
</tr>
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<tbody>
<tr>
<td>traditional</td>
<td>non-traditional</td>
</tr>
<tr>
<td>scientific</td>
<td>artistic</td>
</tr>
<tr>
<td>experimental</td>
<td>naturalistic</td>
</tr>
<tr>
<td>reductionist</td>
<td>holistic</td>
</tr>
<tr>
<td>prescriptive</td>
<td>descriptive</td>
</tr>
<tr>
<td>quantitative</td>
<td>qualitative</td>
</tr>
<tr>
<td>nomothetic</td>
<td>idiographic</td>
</tr>
<tr>
<td>experiment</td>
<td>case-study</td>
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</tbody>
</table>

**Experimental:** the researcher intervenes in a process and manipulates certain variables, as opposed to

**Naturalistic:** the researcher attempts to find out what happens in natural settings without using a deliberate experiment.

**Reductionist:** particular components are deliberately isolated for study, without reference to overall context.

**Holistic:** a description of the context and a wide range of variables operating in that context.

**Descriptive:** the natural setting is described as fully as possible in order to achieve a better understanding of events.

**Prescriptive:** focusses on interrelationships between particular variables in order to ascribe cause and effect, and allow prediction.

**Nomothetic:** data is collected from a number of cases and related to the search for general laws or 'norms'.

**Idiographic:** relating to the study of individuals, or a small group of individuals making up the 'case' to be studied.

3.4.2 On the basis of these descriptions, my own inquiry clearly falls into Paradigm 2, since I am attempting to describe selected individual's views concerning educational relevance. Further the inquiry seeks to embrace as many factors in the scenario as possible, including as it does teachers, students, chemical
industry practitioners, and documentary evidence. I have not attempted to set up experimental situations, since one of my main aims is to identify variables not control them. Further, I hope to show improved understanding of the context of educational relevance through description, the notion of prescription not really being applicable. The inquiry is idiographic in that it is a study of a group of individuals; no attempt is being made to set up norms, though some search for 'regularities' has been essential. In no way could this be described as a search for a 'general law'. The techniques used comprise the semi-structured interview, and questionnaire. Table 2(p30) indicates clearly how my inquiry falls into Paradigm 2 on this basis, including choice of technique and type of data.

3.4.3 Five basic axioms which distinguish the two paradigms have been identified [Guba and Lincoln (1982)] as:

1. The nature of reality.
2. The relationship between the inquirer and the subject.
3. The nature of truth statements.
4. Attribution or explanation of action.
5. The role of values in the inquiry.

These may be applied to Paradigms 1 and 2 as shown in Table 3; it is worthwhile briefly discussing these axioms since, through them it is possible to justify the applicability of one or other of the two modes. (see p31)

3.4.3.1 The nature of reality.
In the rationalistic version reality is taken to be a singular tangible reality which can be reduced to independent variables and process, any of which can be studied independently. Inquiry can converge on this reality until finally it is predicted and controlled. In the naturalistic approach there are multiple intangible realities which can only be studied holistically. Any attempt at fragmentation changes the whole context. Inquiry into such a multiple situation must inevitably diverge, raising more questions than it answers. Prediction and control are unlikely,
TABLE 2: Features of the two research paradigms. (from Gilbert and Pope 1984)
though a measure of understanding is possible. My own inquiry centres around people's perceptions of a particular feature of their education. This must clearly be a multivariate situation, the variables being either so closely interwoven as to be inseparable or not readily identifiable. Any attempt to isolate and control variables would mean that individual's perceptions would have to fit a predetermined experimental situation, and, I suggest, become distorted in the process. Although the hope is that some focussing will occur by way of meta-commentary, this can only be by way of clearer description and understanding.

<table>
<thead>
<tr>
<th>Axiom</th>
<th>Paradigm 1 (Rationalistic)*</th>
<th>Paradigm 2 (Naturalistic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Reality</td>
<td>single, tangible, convergent, fragmentable</td>
<td>multiple, intangible, divergent, holistic</td>
</tr>
<tr>
<td>2. Inquirer/object relationship</td>
<td>independent</td>
<td>inter-related</td>
</tr>
<tr>
<td>3. Nature of truth statements</td>
<td>context-free generalisations nomothetic statements focus on similarities</td>
<td>context-bound working hypotheses - idiographic statements - focus on differences</td>
</tr>
<tr>
<td>4. Explanation of action</td>
<td>'real' causes, temporally precedent or simultaneous manipulable, probabilistic</td>
<td>attributional shapers, interactive feed forward and feedback non-manipulative, plausible</td>
</tr>
<tr>
<td>5. Values</td>
<td>value-free</td>
<td>value-bound</td>
</tr>
</tbody>
</table>

TABLE 3: Paradigmatic axioms. after Guba and Lincoln (1982), p237

* Footnote:

Guba and Lincoln prefer the term 'rationalistic' rather than 'scientific', to avoid any consideration that the naturalistic paradigm is inferior 'because of the enormous legitimation accorded to anything scientific in our culture', and because the term 'scientific' is open to various interpretations. Both points seem valid to me, and I have therefore adopted this term in all further discussion of the two paradigms.
3.4.3.2 The inquirer-object relationship.
In rationalistic inquiry, the inquirer can maintain a distance between himself and the object of inquiry, although this may be somewhat difficult when people form the object. The naturalistic inquirer interacts with the object of inquiry and although this mutual interaction may prove problematical in certain circumstances, it forms an inevitable and even essential part of the process. It is essential therefore that any such interaction is made explicit.

Any attempt to ascertain what makes the learning of particular concepts relevant for individuals or groups, must take account of personal perspectives. The use of methods which isolate the inquirer would result in the collection of responses to pre-determined probes. Inevitably, the individual would thus select a best-fit response. Such a process would lose all the subtleties and nuances which flow from face-to-face interaction with the inquirer. As Power (1977) has pointed out such an interactive process can 'add a long neglected dimension (viz subjective reality) to research'. In view of the nature of this inquiry, the naturalistic mode seems more appropriate.

3.4.3.3 The nature of truth statements.
Rationalistic inquiry attempts to provide a nomothetic body of knowledge, encapsulated in generalisations; that is, truth statements of enduring value that are context free. This most frequently requires a search for similarity in data, with differences being taken as basically uninteresting. The aim of naturalistic inquiry is to produce an ideographic body of knowledge, through a series of working hypotheses describing individual cases. Thus generalisation is rarely possible since the inquiry is neither time- nor context-free, though cautious transfer from situation to situation may be possible if temporal and contextual differences between situations are not high. Frequently, in such inquiry, differences in data are as important as similarities (sometimes more important).
The concept of relevance in education is frequently used as if it were a nomothetic generalisation. It must be common experience, however, that such nomothetic use is a blunt instrument. Each individual sees relevance from a personal perspective; groups (e.g. teachers and university examiners; teachers and parents; teachers and employers) frequently argue about relevance in the curriculum. It should be noted that students do not appear in the list of groups above—relevance from the student point of view is frequently overlooked or ignored. The application of a rationalistic mode of inquiry in such a situation would not, in my opinion, help to clarify the issue of relevance; it would more likely reinforce the 'status quo'.

3.4.3.4 Explanation of action.
Every action can be explained as the result of some precedent cause, in the rationalistic mode of inquiry. The cause-effect relationship, using appropriate methods, can be clearly described either in functional form, or in some probabilistic manner. The normal method of inquiry is to demonstrate experimentally that a change in A produces a particular change in B. Naturalistic inquiry accepts that, in a poly-variate situation, the best that can be done is to establish 'plausible inferences about the patterns and web of such shaping' (Guba and Lincoln op cit). This implies the use of holistic field studies, so that the natural context forms part of the inquiry.

It might be possible to design experiments whereby changes in curriculum material, or changes in teaching techniques could be assessed for improved relevance. However such an inquiry would have at least two major problems; on the one hand it would be a limited study concerning a particular situation; on the other, there would be little opportunity of assessing relevance outside that limited context. It would be a context-bound inquiry. Educational relevance, I suggest, is not context-bound in that particular sense. Individuals or groups may use their own contexts in valuing relevance, but these contexts are not necessarily identical. This implies the need for an holistic method of inquiry.
3.4.3.5 Role of values in inquiry.

Rationalistic inquiry claims that one of its major features is high objectivity. As such its data are value-free in terms of inquirer-neutrality. In naturalistic inquiry, all data are value-bound for the following reasons:

a) the inquiry is shaped by the inquirer, whose own values are involved in framing, bounding and focussing the problem.
b) there are values inherent in the context of the inquiry relating to human social/behavioural factors.
c) the paradigm selected to guide the inquiry introduces particular values.
d) the choice of substantive theory and the methods used in the inquiry introduce particular values.

In attempting to characterise notions of educational relevance, in however limited a field of education, one task must surely be to identify and clarify the values which operate, whether through individuals or groups or organisations. Rationalistic inquiry would be inappropriate in such a complex and holistic appreciation.

3.4.4 In reviewing these axiomatic assumptions, the choice of a naturalistic medium for this study would appear obvious. The case is further strengthened if one looks more closely at some of the shortcomings of the rationalistic mode when applied to educational situations. Parlett and Hamilton (1976) have spelled out five main areas of difficulty:

1. Educational systems are characterised by numerous parameters and hence application of rationalistic methods requires either randomised large samples or strict control of parameters. The former requires a major research effort, whereas the latter (simulating laboratory conditions) 'is both dubious ethically, and leading to gross administrative and personal inconvenience'. This according to Parlett and Hamilton can produce serious artificiality and lead to irrelevancy, and because the researcher is thinking
in terms of parameters and factors more than individuals there is a separation from reality.

2. By definition, parameters are pre-specified. Thus variables which may emerge during the study are likely to be overlooked. Also, there is an assumption that parameters do not change during the process, which, in educational studies, rarely happens.

3. 'Traditional' methods impose arbitrary and artificial restrictions on the scope of the study by concentrating on objectivity, and disregarding 'subjective', 'anecdotal' or impressionistic data. Parlett and Hamilton argue that such disregarded data may be highly important in assessing the context and value of quantitative data.

4. Large randomised samples cannot reflect small 'local' differences, which may be important.

5. 'Traditional' methods involve an 'objective truth' equally relevant to all parties. Such studies thus rarely acknowledge the diversity and variety of concerns of those involved in the study.

3.4.5 As pointed out previously (p 27) the nature of the focus of this inquiry would, if a rationalistic approach were taken, confront all the above problems. The choice of a naturalistic approach seems all the more logical. The previous arguments concerning such a choice may be neatly summarised diagrammatically, (Table 4), using as 'co-ordinates' the extent to which the researcher attempts to control variables, to define an enquiry 'space'. (see p36)

3.4.6 One further assumption that I am making which is involved in adopting a naturalistic methodology, is that, the dominant research mode has been that of collecting the relevant facts and looking for patterns to reveal the laws governing them. As Pope, Watts and Gilbert (1983) suggest, this is not entirely surprising since Western educational thinking has been dominated by a 'cultural transmission' view of the educational process.
Many of the theories on the nature and development of people, embedded in this approach, adopt a mechanistic model of human behaviour. Many researchers have been critical of such an approach, which assumes an unchanging nature in those being investigated, and allows the researcher autonomy and rationality, but denies the same processes in the 'naive' subject [e.g. Bakan (1967)], and ignores the importance of interaction between researcher and subject [Rosenthal (1966), Torbert (1981)]. The growing move away from such a model, using alternative methodologies [see for example Chanan and Delamont (1975), Sheldrake and Berry (1975), Parlett and Hamilton (1972), Laurillard (1979), Zubir (1983), Watts (1983)] shows increasing regard for the dignity and autonomy of the research subjects, and aims at an holistic understanding of human behaviour, and the personal reasons for such behaviour (Rowan and Reason, 1981). The 'honeymoon' between psychology and education seems to be at an end (Biggs, 1976), and much of the recent educational research has used a sociological and anthropological base, rather than one of psychology. This no doubt is in response to educators' current scepticism about
the value of psychological models (Pope and Keen, 1981). Salmon (1981) has advocated a clear acknowledgement of the 'particular reality of the learner'. Novak (1981) notes that 'ignoring or negating the internal world of people misses the essence of their personhood, flattens human reality and leads to educational practices which are mechanistic and lacking in respect for the basic integrity of the person'.

3.4.7 In also rejecting such deliberate oversight of the internal world of the individual, my own approach is based on a constructivist model in psychology, which seems to have much in common with more sociological approaches, as for example in ethnomethodology [Garfinkel (1967); Cicourel (1974)], symbolic interactionism [Mead (1934), Berger and Luckman (1967)] and others. [A useful summary of other constructivist views in research appears in Magoon (1977)]. Kelly's (1955) ideas seem particularly fruitful, and personal construct psychology based on his original work has informed this study and is having considerable impact on current educational practice and research (see for example Britton, 1972; Nash, 1973; Salmon, 1981; Candy, 1982). Kelly rejected the absolutists' view of truth and for him, reality was personally constructed, and thus an active, creative, rational, emotional and pragmatic process. He rejected the idea that knowledge is a growing collection of substantiated facts ('nuggets of truth') independent of human reconstruction. In setting aside this 'accumulative fragmentalism'. Kelly assumed '.... that all of our present interpretations of the universe are subject to revision or replacement. We have to stand that there are always some alternative constructions available to choose among in dealing with the world.... We call this philosophical position constructive alternativism.'

3.4.8 Further, Kelly suggests that the way scientists perform science is essentially the same as the way people lead their normal daily life: both are viewed as engaged in making sense of their worlds. In order to cope with daily life people develop systems of 'personal constructs' or hypotheses, which are the
tools for testing out personal explanations of the world. These are constantly revised should they prove useful in giving meaning to experience. This 'constructive alternativism' shows some striking resemblances to those philosophies of science which developed in the 60's and 70's and which have seriously questioned the dominant 'objective' vision of science [see Polanyi (1958); Popper (1963); Kuhn (1970); Lakatos (1970); Feyerabend (1975); Ziman (1978)].

In terms of this study, the constructivist view of knowledge implies a concern for personal views. As Kelly (1969) suggested, the 'ultimate explanation of human behaviour lies in examining man's undertakings, the questions he asks, the lines of inquiry he initiates, the strategies he employs rather than analysing the logical pattern and impact of the event with which he collides.'

This lies within the tradition of the 'verstehen' approach rather than the 'erklären' - a central tenet is thus the importance of coming to an understanding of the view that people have of the world, from their particular situation. Personal construct psychology thus provides theoretical support for the study of the individual and the views of those involved in a particular educational issue. Further, it has considerable congruence with modern philosophies of science, which provides a bridge between science and education when the issue studied relates to science education.

3.4.9 In this chapter, I have argued my reasons for adopting a naturalistic mode of inquiry. This choice is not without its problems, and these - together with a discussion of the research strategy adopted - form the basis of the next chapter. It has been difficult not to paint a picture of a choice between opposites. From my own conviction, I do not believe this to be the situation. Cook and Reichardt (1979) have argued forcefully that qualitative and quantitative approaches are not incompatible either operationally or paradigmatically, and object to the stereotyping of research and researchers as either
Whilst agreeing with Kushner and Norris (1981) that 'we should be wary of seeing them as compatible, or even complimentary, forms of inquiry', it is also true that 'without science we lose our credibility. Without humanity, we lose our ability to understand others.'

Agar (1980) p13

3.4.10 It is I think, the very issue of 'credibility' which is the greatest problem for the naturalistic researcher, since that will have implications for the shape or design the inquiry is given. It is my belief that, given adequate credibility, it is not so much the paradigm of research that is important. As Broadfoot (1979) has most succinctly put it:

'The crucial distinction... is that between a positivist and a relativist view of the educational enterprise... fundamentally it emphasises the problematic nature of education itself. The distinction is essentially that between regarding the concept of what it is to be 'educated' as a fixed and immutable absolute - a philosophical concept of the Hirst and Peters variety - and regarding 'education' as a social process with important political, economic and socialising functions which therefore varies from time to time and from society to society.'

* * *
Chapter Four

From paradigm to process.

In which the overall process for this study within the chosen paradigm is discussed.

4.1 Paradigm to procedure
4.2 Design features
4.3 A structure for the inquiry
4.4 Models compared
CHAPTER FOUR.

4. FROM PARADIGM TO PROCESS.

"Enough to reach the ground, as Lincoln said when asked about the proper length of a man's legs."

quoted in Miles and Huberman (1984) p28

* * *

4.1 Paradigm to procedure.

4.1.1 My research procedures, and their design, follow a pattern which is both in agreement and in conflict with ideas expressed in the literature. Perhaps almost by definition, no one approach to naturalistic research will provide a model procedure. Interest in this style of educational research is certainly growing, not only in the U.K. As Terhart has pointed out in his review of the West German situation: "although a growing number of scientists are convinced of the interpretative approach (i.e. qualitative), we are still lacking a 'box of tools', that means, the lack of adequate research instruments for practising this methodological paradigm."

quoted in Pope (1981) p18

(words in brackets mine)

Terhart was not completely happy with his own words; he felt the phrase 'box of tools' might not be totally appropriate, since there could not be a standardised prescription for interpretative research. I share with Terhart the conviction that we need a repertoire of approaches that are consistent with the underlying philosophy of naturalistic study. The accumulation of such a repertoire requires that researchers make very explicit exactly what they have done and why. It is for this reason that I have devoted a considerable portion of this chapter to discussing those factors influencing my own procedures.
4.1.2 The classical model of educational research borrows three
criteria from the rationalistic research paradigm; validity,
reliability and replicability. These concepts are clearly
useful in assessing the value of particular test instruments
relating to quantitative data. Whether the test measures what
it is intended to measure (validity); will measure the same
thing at different times (reliability); or is capable of
repetition in the same sort of situation but by a number of
different researchers (replicability), affects the credence
one can put in the test results. The temptation to 'borrow'
these concepts to provide authenticity for this study has
firmly been resisted. The need for credibility remains, but
not based on the same tenets and axioms as rationalistic inquiry.
I would argue that a validation process which implies measurement
of a clearly identified (or identifiable) variable is not
relevant to the majority of techniques used in naturalistic
research. It is unlikely that the researcher will find identical
natural situations for inspection over a period of time, given
the unpredictability of the human element [see Stenhouse (1981)
p 21]. Reliability thus is not really a compatible concept.
Further, the necessarily interactive nature of naturalistic
research has two particular effects which affect the notion
of replicability:-

a) different researchers will bring different personalities
to bear, providing uniquely different interactions;
b) the interactive process is in itself educative, and thus
produces an element of change in those involved (see 5.2.6).

4.1.3 The chances of reproducing a particular inquiry to any
great extent seem remote. Any attempt to apply these three
concepts equally to both paradigms suggests that the paradigms
share the same axioms, a view which to my mind is equally as
false as its opposite assumption, namely that the quantitative
approach 'is the mirror opposite' of qualitative methods (Rist
1977). Several writers have discussed the problems arising
in attempting to apply these psychometric criteria to naturalistic
studies [e.g. Sheldrake and Berry (1975), Giorgi (1975).
It is clear, as Guba and Lincoln (1982) have pointed out, that the 'trustworthiness' of naturalistic inquiry should be checked by appropriate criteria. They have suggested that the inquirer should consider four questions:

1. How can one establish confidence in the 'truth' of the findings?
2. How can one determine the extent to which the findings may be applicable in other contexts?
3. Is it possible to determine whether the findings would be consistently repeated if the inquiry were conducted in the same or similar circumstances?
4. How far are the findings a function solely of the respondents and the conditions of the inquiry (as opposed to the biases of the inquirer)?

These, they claim, are the four criteria which any naturalistic study must recognise, and which they term:

1. Credibility
2. Transferability
3. Dependability
4. Confirmability

However expressed, the need for authenticity cannot be ignored. In this inquiry, I am looking for 'truth' by observing and describing reality, and hence relying heavily on 'face validity' - 'the judgement that the results seem to fit the reality' [Walker (1980)] — a characteristic which provides problems of acceptability when different audiences are involved. As Walker points out:

'Descriptive accounts... may be accepted as true by practitioners, but they are not likely to create appropriate and convincing bases for policy or decision making. The problem seems to be that such descriptive accounts are highly persuasive to a primary audience, but not to secondary audiences.'

This 'secondary audience' effect may be due to a low 'indexicality'...
[Agar (1980)], (the amount of shared background knowledge necessary for understanding when two parties are attempting to communicate) — another good reason for making explicit the background to research decisions.

The need to meet criteria for credibility and wide acceptability, has thus influenced the design of this study.

4.1.5 It has been argued that, without explicit methodological development there is the danger that we may be 'doomed to a future as mediocre poets or amateur experimentalists.'

Agar (1980) p ix

To avoid such a fate, I believe it is necessary not only to be explicit about the selection of procedures used in the design of an inquiry. I would argue further that the 'research subjects' — or preferably the research participants — should be given every opportunity to negotiate the values and meanings generated in their statements at interview, etc. This becomes more than a matter of the data being believable and acceptable to researcher and researched alike. As Kushner and Norris (1980), Walker (op cit) point out, this also relates to the creation of a 'democratic' ethic in the inquiry, whereby trust is built up between the participants. Any case-study (such as this) is heavily dependent on personal trust, but such a relationship should be enhanced by 'holding strongly to a carefully formulated ethic.'

'The trust we seek depends on generating a style of educational research in which methods and procedures are explicit and visible. We are interested in attempting to play down the personal expertise of the researcher in order to enhance his professionalism. 'Just as people will put trust in a doctor, or policeman... so we believe it should be possible for the educational case-study worker to establish a similar identity. ""... the gain could be that case-study research will gain in credibility and begin to be used more effectively by educational practitioners.'

(Walker 1980)
4.2 Design features.

4.2.1 How 'tight' therefore, should the design of this inquiry be? Is it necessary to start with an explicit conceptual framework? Should one begin with research questions? Should data collection procedures be decided on first? To some extent the answers to these questions depend on the perspective of the study. In an exploratory inquiry 'tight design' can be kept to a minimum, since social realities may be taken to be too complex to respond to pre-structuring and standardised instruments. Hence a 'loose' emergent, inductively 'grounded' approach is useful:

'The conceptual framework should emerge empirically from the field in the course of the study; the most important research questions will become clear only later on; the most meaningful settings and actors cannot be predicted prior to fieldwork; instruments, if any, should derive from the properties of the setting and from the ways its actors contrive them.'

Miles and Huberman (1984) p25

However, qualitative research may also be used for confirmatory studies when concerned with some better understood social phenomenon. This would be true of a study based on a particular point emerging from a broader study. In such confirmatory cases there may well be some pre-structuring of the conceptual framework and some pre-determined notion of the appropriate methods to use. This can involve the use of more quantitative methods within a naturalistic framework - an instance perhaps where 'paradigmatic incompatibility' should be questioned? (see 3.4.9).

4.2.2 In practice, the design difference between an exploratory and a confirmatory inquiry appears to rest with the degree of 'focussing' that is involved. It would seem from the literature that many naturalistic studies progress from loosely focussed exploratory inquiry to a more tightly focussed form of confirmatory inquiry. A frequent pattern is the use of a pilot study, followed by a developmental phase, and then some form
of triangulation process.
At the early stages of an inquiry, 'parameters' are frequently not known to any great extent, and thus choice of specific methods is 'open'. As the extent of focussing increases with the development of conceptual frameworks, some choice of procedure becomes logical. As Agar (1980) has suggested:
'The strategy is to selectively narrow the focus within a previously explored broad field... the 'funnel approach' p8
The implication of the 'funnel approach' is that data collection and data analysis should have a concurrence that will inform the development of the inquiry. The processes of collection and analysis should form a dialectic, and not be linear. As the focussing and bounding develops, a useful 'anticipatory data reduction' [Miles and Huberman (1984)] can occur - a form of pre-analysis which may then provide a basis for decisions on further inquiry. The 'looser' the initial design, the less selective will be the collection of data, which brings us back to the question, to what extent should the inquiry be pre-structured? Miles and Huberman's answer to this question is given in the quotation heading this chapter:

4.2.3 Nevertheless, initially the question which demands an unambiguous answer is 'how do you get the data?' Case study procedures were chosen for this inquiry because they were seen to provide adequate opportunity to meet Guba and Lincoln's (1982) criteria, could be reported in a way which enhanced acceptability and were flexible enough to allow for both exploratory and confirmatory study. Additionally, and at least as importantly, such procedures were seen to match the nature of the questions I was asking.

This study is an attempt to 'understand and document' [Parlett (1974)] perceptions held by people in a context. The research is thus grounded in a real situation, an approach which Parlett described as 'illuminative'. Further it is ideographic in its attempts to describes the perspectives individuals have of a situation which indicates a phenomenological approach within case-study [Giorgi (1975)]. Walker (1980) defines case-study
as 'the examination of an instance in action. The study of particular incidents and events, and the selective collection of information on biography, personality, intentions and values, allows the case-study writer to capture and portray those elements of a situation that give its meaning.' Nisbet and Watt (1978), make the point that case-study 'is more than just an extended example or an anecdote interestingly narrated' since it is systematic and concerned essentially with interactions. The 'instance' in action 'may be an event or a person or a group, a school or an institution, or an innovation', etc. Walker has a succinct discussion of the pros and cons of case-study. The use of a case-study technique is supported by MacDonald and Walker's (1978) claim that the method 'gives weight into specific instances, events or situations' which enable the researcher to describe participants' experiences as they relate to their own circumstances, concerns and preferences'. Hodgson (1980) also suggests six reasons for adopting case-study [based on the propositions of Adelman, Jenkins and Kemmis (1976)]:-

a) Case-study is strong in reality: the reader can thus use the same processes of judgement used to understand everyday life.
b) Case-study allows generalisations, either about instances or from an instance to a class.
c) Case-study recognises the complexities and discrepancies contained in and between participants' viewpoints.
d) Case-study provides a rich descriptive data source for other researchers.
e) Case-study occurs in a world of action and may contribute to it.
f) Case-study at its best allows the reader to judge the implications for himself.

In terms of this inquiry, therefore, a case-study approach would appear to be an attractive and powerful tool.

4.2.4 The problem of credibility still features strongly:
'The very sensitivity and flexibility which are the essence
of illuminative research are also its Achilles heel. The insights which emerge from qualitative research reports can appear too much the product of the researcher's personal perspective and of the idiosyncracies of the specific situations examined. But good qualitative research can, through cross checking of interpretations and through an awareness of its limitations, provide evidence as strong in its own way as that derived from conventional approaches.'

[Entwistle and Hounsell (1979)] p61
The allusion to 'cross checking' raises the need to adopt more than one method within the overall strategy, or to use Denzin's (1978) terminology, 'between method triangulation'. This involves the selection of two or more different methods of data collection, and applying them to the same research situation, involving
'a complex process of playing each method off against the other so as to maximise the validity of field efforts.'
Denzin (1978) p304

4·2·5 Other researchers have also pointed to the value of using different but compatible methods in order to increase credibility [Sheldrake and Berry(1975); West(1979); Entwistle and Hounsell(1979)], in some cases echoing Cook and Reichardt's (1979) rejection of the incompatibility of the 'two paradigms'. The choice of triangulation in this study has been guided by Denzin's four principles:
a) the methods must fit the problem being researched.
b) the methods that are combined should reduce as far as possible 'threats to internal and external validity.'
c) the methods chosen must have theoretical relevance to the field of study, to 'maximise the theoretical value' of the study.
d) no investigation is static; to use Denzin's words: 'Researchers must be ready to alter lines of action, change methods, reconceptualise problems and even start over again if necessary.' (p304)
4.2.6 Nisbett and Watt (1978) have also commented on the importance of a readiness to accept the unexpected. They claim that a major strength of the case-study approach is the capacity to take into account the 'uncontrolled variables, those aspects of a situation - often important ones - which you have not clearly foreseen'[see also Dearden and Laurillard (1977)]. Nisbet and Watt conclude that case-study should follow a phased design, to allow scope for amendment:

Phase one: open phase: a general review without judgement.
Phase two: focusing: identifying important aspects for closer consideration.
Phase three: draft interpretation: a commitment of ideas to paper.
Phase four: check: refer the interpretation to the participants for constructive criticism; then publish the final form.

4.3 A structure for the inquiry.
4.3.1 The main approaches that appear to be in common use in case-study design are:

a) Observation, either as a passive or a participant observer.
b) Interview, with approaches ranging from open to completely structured, and either for individuals or groups.
c) Document review, involving important official statements of policy, opinion and attitudes etc., bearing on the focus of the study.
d) Survey techniques, involving large numbers of participants who may be questioned or interviewed by a large number of researchers.
e) Questionnaires, involving either open- or structured-response questions (or a mixture) which relate to some predefined conceptual framework.
f) Records search, which may involve pictorial (film) as well as written records.

This study began with a fairly clearly defined purpose - to determine what were the perceptions of science held by practising scientists. As a researcher working on the project
in his 'spare-time' (having other full-time employment) any survey method was out of the question, even if relevant. Further, survey questionnaires in general provide a very structured response, which was felt inappropriate at this stage. Record and document searches could well provide useful information, but not of individual's perceptions, and initially it was not clear which areas for review would be most fruitful. Thus the interview technique was chosen as the primary technique for data collection.

4·3·2 This raised the problems of deciding who to interview, and how to arrange access for interview, difficulties of a different order from deciding which format the interviews should take. These points are discussed in detail in Chapter 5. In discussing the design of this study, it is only necessary here to record that it was decided that the interviews should follow a semi-structured format, and that a limited number should be undertaken as an Initial Phase(IP). The reasons for these decisions lay in the degree of focussing that already existed in the inquiry (being confined to perceptions of two conceptual areas of chemistry), and a perceived need to 'probe' the problem area before deciding on further action. To some extent, also, the availability of 'personal time' was a factor; as a part-time researcher, I was not in a position to evolve an intensive period of inquiry. It is worth recording at this point however, that all the literature reviewed in connection with methodology related to this study, appears to assume that the researcher is employed full-time as such! In its origins, therefore, this study had a fairly strong degree of pre-structuring and focussing, despite the fact that it was exploratory in character.

4·3·3 The analysis of the IP interviews proved to be highly significant. The conceptual framework that emerged (see 6·3) provided a tentative model for thinking strategies associated with the chemistry in question.
Certain features of this model, in juxtaposition with other features of the interviews (for example statements concerning Higher Education, responses to deeper probing concerning chemical practice), proved to be the catalyst for a major shift in the focus of the study, towards attempting a characterisation of the notion of educational relevance (see Chapter 6). It might be argued therefore that the IP interviews stand apart from the rest of the inquiry. My own opinion is that they do not. This 'catalytic' effect is an excellent example of the dialectic character of naturalistic research, and the importance of a readiness to 'reconceptualise problems' (see 4.2.5).

4.3.4 On the basis of the Initial Phase it was decided to widen the sample of interviewees (Extended Phase - EP), still using the semi-structured interview and the conceptual framework evolved. At the same time, a clear line of document inquiry had opened up in the area of 'education relevance'. Analysis of these E.P. interviews provided the grounds for the development of a model of 'perceptual space' for the chemical concepts involved, as well as containing some interesting data concerning educational relevance.
The documentary review provided the basis for a triadic model of educational relevance, and allowed a map of possible relationships between the three models to be evolved (discussed in Chapter 9).

4.3.5 Whilst the procedure adopted for the interviews allows negotiation with the interviewee, and hence provides some degree of credibility for such data, much of the other development of the study could easily be taken as 'speculation'. Thus it was at this stage that 'between method triangulation' [Denzin (1978)] was undertaken, using a confirmatory questionnaire (discussed in more detail in Chapter 9).

With the analysis of the exploratory and confirmatory inquiries complete, the implications of the study could then be reviewed (see Diagram 5, p53).

4.4 Models compared.
4.4.1 As suggested at the beginning of this chapter, the procedural pattern adopted has not been totally in agreement with other 'models' suggested in the literature. Agar's 'funnel approach' requires a broad based open inquiry which
progressively focusses on matters of interest arising. The focussing leads to a conceptual framework, which can then be reflected back on the original base, as well as being applied to new instances. The information gained leads to further focussing and eventually to generalisation. This might be represented diagrammatically thus:-
4.4.2 My inquiry began with a strongly focussed study due to clearly defined initial intentions. The outcome of this initial phase was not only a conceptual framework to inform further development, but a redefinition of intentions. In terms of the 'funnel approach' this might be described diagrammatically as follows:

![Diagram](image)

**DIAGRAM 7: Inquiry defined in Agar's terms.**

4.4.3 The comparison of the procedures adopted in this inquiry with the 'funnel' model should not be taken too far. The value of the 'progressive focussing' approach is nicely demonstrated, particularly since it seems to be effective with both open and defined initial intentions; but I repeat my reservations concerning prescriptions for naturalistic research (see p42).

Miles and Huberman (see p47) have suggested that exploratory inquiries should adopt a 'loose' design, and move to a 'tighter' model as more confirmatory aspects are involved. This inquiry began with an attempt to explore people's perspectives of certain concepts, using -I believe quite appropriately - a 'tight' procedure. It has continued in a
similar vein, through to the confirmatory triangulation. Nisbet and Watt (see p49) offer a phased procedure for case-study, and here again it is the **open** phase that brings divergence from my own procedures.

4.4.4 I would suggest that it is the nature of this particular inquiry which is at the root of the differences rather than any 'methodological inexactitude'. Each particular inquiry demands a particular process, generated as the work progresses. Broad ethnographic studies demand broad initial procedures. Research having more clearly defined objectives begins with a more focussed baseline, as, for example, with illuminative evaluation of curriculum innovation. Further, as both Denzin and Nisbet and Watt have pointed out, the researcher must be ready to 'alter lines of action' and even 'reconceptualise the problem'. The process by which this occurred in my inquiry is detailed in the next chapter.

* * *
Chapter Five

The Interview Programme.

In which the approach to research interviewing throughout a phased programme is developed, and the techniques of analysis used in the inquiry described.

5.1 A phased programme
5.2 A trial interview
5.3 The research interview
5.4 Modus operandi
5.5 Editing and analysis.
CHAPTER FIVE.

5. THE INTERVIEW PROGRAMME.

'And thus do we of wisdom, and of reach with windlasses, and with assays of bias, by indirections find directions out.'

Polonius: Hamlet II.i line 66

(W. Shakespeare).

* * *

5.1 A phased programme.

5.1.1 As explained in 2.6, I have confined myself to the conceptual areas of chemical kinetics and chemical equilibrium, and in particular to practitioners' perceptions of these focal concepts. The chosen technique has been the research interview (4.3.1). During my educational career, particularly when acting as an Admissions Officer, I had gathered considerable experience as an interviewer. The research interview, however, seemed to be a different operation altogether from the undergraduate applicant situation in which I was judge over performance and achievement—a strongly normative function. To obtain the sort of information that would be acceptable as research data in this inquiry, my relationship with the interviewee would have to be somewhat different. Parlett (1978) has stated that:

'Interviewing is an art form as well as a research technique. It is a mode of communication between two individuals... and it falls between conversation (undirected, very informal, open, rambling) and interrogation (highly structured, information producing, control vested in the hands of the interrogator, often pre-ordained or worked out in advance, clear direction). There is no degree of structure which is correct, in an absolute sense, without careful regard to the nature of
the study and what kinds of information and degree of detail are required from this portion of the investigation. The important thing is to judge appropriateness.' (p4)

5.1.2 The strong initial focussing of the interviews, and my lack of experience in the techniques demanded, was a major consideration in adopting the phased procedures already described(4.3.2). It was thought that the Initial Phase (IP) of interviews would allow a preliminary analysis which might inform an Extended Phase (EP) in two ways:
   a) by establishing some form of conceptual framework for the EP interviews.
   b) by enabling some judgement of 'appropriateness' of my interview technique for the EP interviews.

5.1.3 Additionally, a Trial Interview was undertaken before the IP interviews, to gain some experience of the 'art'. Thus the interview programme followed the sequence:

| Trial Interview | IP Interviews | EP Interviews |

In describing the interviews according to this sequence, there is a danger that the integral nature of the interviewing programme may be lost. However, the advantages gained in highlighting important developments as the study progressed do, I believe, make the risk worthwhile.

5.2 A Trial Interview.
5.2.1 An interview was arranged with a chemistry teaching colleague at Roehampton Institute. It seemed appropriate to structure the interview to some extent, given the intention to elicit information about perceptions of the focal concepts. At this time no consideration was given to taking a theoretical stance on the choice of interview method, my decision being guided as much by intuition as experience. A list of
structuring questions was drawn up and typed out on a card for easy reference, and the interview audio-recorded in my own study in the Department of Sciences. Video-recording was considered, but was rejected on the basis of organisational difficulty. At that time, it would have been necessary (institutional regulation) to have had a technician present, and I was not happy with the impact this might have on either the interviewee or myself! Additionally, transcription would have presented major difficulties in technique, which did not seem warranted in terms of the data being sought.

The structuring questions used were:

1. Where did you study Chemistry?
2. Which chemical topics interest you most?
3. Which do you think are the main concepts within the area of reaction kinetics?
4. Which do you think are the main concepts within the area of chemical equilibrium?
5. Do you see any link between these two areas of Chemistry?
6. How do you think these areas should be taught?

5.2.2 In the event, the 45 minute interview proved, by mutual consent, to be both enjoyable and significant. Important points became obvious upon reflection:-

(a) The question of confidentiality arose, when it became clear that there was some concern on the part of the interviewee on two counts:
   i) would the interview become public knowledge, attributable to him; and in consequence
   ii) how 'open' could the interviewee be in responding to questions?

A note was made to raise this point before all future interviews, and a protocol adopted requiring that all matters relating to and including the interview should be under a cloak of 'research confidentiality'. Nothing should be quoted in articles, journals etc., without prior permission.
having been obtained.
b) The structuring questions could be as much of a hindrance as a help. To maintain 'flow', areas of information not directly embraced by the questions, were revealed. These areas in themselves were of interest, and a potential strategy seemed to emerge of 'indirect questioning' - i.e., the use of a related question to 'attack' a particular point without directly confronting that point.

5.2.3 The following extract makes this latter point clear; we had been discussing matters arising from the first structuring question, 'Where did you study Chemistry?'

9.1 Where did your crystallography interest come from?

9.4 It was pure accident. I was put right off crystallography by [--------] College, perhaps unfairly but the regime that was operated there was extr... was very strict - - - - but also it wasn't taught very well - but at least I didn't think it was taught very well, and I took the M.Sc in Crystallography [--------] because of a chain of circumstances ----

[excerpt from TR (transcript), lines 48-55]

A's comment continues to be critical of experience in Higher Education. Here, clear attitudinal statements are being made which are obviously important to the interviewee in representing perceived influences on career progress. The Interviewer's question was not directly framed to elicit that information.

5.2.4 The implications of this were seen to twofold:
a) the structuring questions should not be taken as a straight-jacket; room for manoeuvre around the questions could be productive, and provide a basis for further probes in different but related directions.
b) data analysis would have to accept 'off-line' comment, not just as a plain statement, but embedded in a particular context.

Why should A feel it necessary to comment on teaching, when the question did not demand such a response? My question had
been framed with the intention of probing whether crystallography was seen to be an interesting field of scientific knowledge. I would suggest that A's interpretation was slightly different, involving those positive and negative factors influencing his choice of crystallography. Differences between interviewer and interviewee 'meanings' are clearly going to be inevitable, but these differences can be a rich source information if some attempt is made 'to recognise' and 'unpack' them. This point will be taken up again in the discussion of data analysis (5.5)

5.2.5 Another significant feature to emerge from this 'trial' interview, was a tendency on my part to lapse from being a probing interviewer, into a more conversational style. It must be said that I felt more comfortable in the latter style than the former. The extent to which this resulted from the interviewer being a colleague, is not clear. A review of the interview transcript does not reveal any direct evidence of the change producing difficulties for the interviewee.

5.2.6 During one of the more conversational intervals, a further interesting point developed. The 'conversation' was revolving around the importance or otherwise of the interviewee having advance notice of questions, and so being able to prepare for the interview:

64 JA: Yes... I think probably if you get the - so to speak- unrehearsed responses it might be more productive.

65 I: Yes and no... I'm not exactly trying to catch people unawares in all this as it were.

65 JA: I think it's a good idea actually. I mean... this is one of the - I won't say it's the first time- but there haven't been many times when I've actually had a conversation with anybody where we've looked at these sorts of things.

[TRI lines 342-351]

Here, I suggest, is evidence of the interview being more than
simply data gathering. For the interviewee, it had been an
instructive event. Questioning had brought about an element
of personal reflection that had proved satisfying, had been
valued, and had also restructured some of A's thinking.

5.2.7 In terms of developing a conceptual framework for
kinetics and equilibrium, one interview clearly provides
inadequate data from which to draw inferences. In attempting
to 'read out' the interviewee's perceptions, however, one
difficulty was confronted. The interview had been transcribed
verbatim, with every attempt made to be faithful to the sounds
on tape. The transcript made difficult reading - not through
content, but through disruptions and inarticulations. It was
decided therefore to edit the transcript and cut out the
background 'noise', concentrating on those statements, questions
etc., which related to the concepts involved [a technique used
by Laurillard (1979), but for slightly different reasons].
This raised a further potential problem of biased selection.
The edit was therefore presented to the interviewee, with a
copy of the original transcript, and a request for comment on
the editing. The possibility of negotiating any 'conflict'
was also offered (see 4.1.5). In this case the interviewee
took no exception to the edit, and made clear his pleasure at
being involved in what might termed 'data processing'. He
clearly felt much more secure in the knowledge that his words
were being used as just that - his words. From those words,
a cameo of his perceptions could be drawn; in this case
kinetics lead to reaction mechanisms; equilibrium studies
formed a special case of chemical thermodynamics, with a
deliberate mental separation from kinetics [ 'I seem to
compartmentalise them'(edit 1: line 65)] and a strong tendency
to involve quantitative accuracy through Mathematics [ 'to
get across fairly early on an equation like the Arrhenius
Equation'(edit 1: line 32)].

5.2.8 From this first experience of a research interview,
certain questions arose which needed attention before undertaking further interviews:-

a) was this the right type of interview for my purposes; what other interview approaches were available?
b) what ethical protocol would be suitable in future interviews, concerning confidentiality?
c) how could I, as interviewer, best use my 'probes' to promote interviewee confidence and a good flow of articulate and thoughtful response?
d) how valuable was the 'indirect questioning' approach, and to what extent could it be premeditated?
e) how much attention should be given to 'off-line' comment vis-a-vis the stated purpose of this inquiry?
f) to what extent should the product of the interview be negotiated with the interviewee?
g) to what extent should the data obtained be analysed?

5·3 The Research Interview.
5·3·1 My reading of the relevant literature indicated that there is no consistent terminology for describing the various types of research interview. At one extreme, the term 'interview' may refer to a verbal response to a single question [e.g. Cannell and Kahn (1968)], whilst at the other, it may refer to an unstructured and complex exchange between two people discussing a specific problem [e.g. Davis(1975)]. Whyte (1960) has a typology of informal interviews using a dimension of 'directedness': the least directed being a simple reflection back of the interviewee's last statement with an invitation to be more explicit; the most directed being an interviewer's insistence on concentrating on one topic. Agar (1980) has distinguished between informal and formal interviews, and his dichotomy can be characterised thus:

[see over]
Informal
No written questions, but a repertoire of question asking techniques.

Questioner gives the interviewer the lead, and follows his/her ideas.

Need not be an isolated 1 to 1 situation.

Everything occurring is negotiable between questioner and interviewee.

Formal
Structured by written questions; questioning techniques 'built-in'.

Questioner controls the flow and choice of information.

Is an isolated 1 to 1 situation.

Little or no negotiation possible.

This dichotomy can thus be seen to relate to a control dimension. Agar makes clear that it is 'not a neat dichotomy' since there is a range of possibilities between the extremes. In effect, the extreme, formal interview becomes a face-to-face questionnaire, and it is at this end of the 'spectrum' that we find the survey interview [Brenner (1981)]. Sellitz (1959) has spelled out the advantages of interviewing (as opposed to direct questionnaire) among which he includes the importance of freedom of response, the greater response rate, the increased flexibility available, and the interviewer's ability to make some assessment of the validity of responses (ie. not what people say but how they say it).

5.3.2 Cohen and Manion (1980) indicate that the literature on the research interview reflects three perspectives, which in themselves reflect the researcher's philosophical stance towards issues such as objectivity and methodology. They describe these as:

a) the interview as a means of information transfer. 'Accurate' data is obtained by the precise application
of a formal interview which has been designed to reduce or eliminate bias, cheating and so forth.
b) the interview as a transaction, which has inevitable bias requiring identification and control.
c) the interview as an encounter, similar to many encounters in everyday life. In consequence of this the only valid data is the interview itself, and controls for bias are not therefore needed.

5.3.3 Konold and Well (1981) adopt a different analysis, based on the type of comments (probes) the interviewer is allowed to make. Their 'interview formats' consist of:

a) the thinking aloud interview, in which subjects are given a problem and asked to verbalise their thoughts as they attempt to solve it. Probing, if used at all, is generally restricted to encouragement.
b) the in-depth interview, or clinical interview, which also involves presenting a problem and requiring a solution. Probing, however, is much more flexible, with interviewees being asked to reflect back, and perhaps being offered subtle challenges to their thinking. The questioner, though, should never give evaluative responses, nor provide hints.
c) the tutorial interview, where the interviewer is attempting to elicit a correct solution with the minimum of help. Probes guiding the interviewee towards new strategies for solution, are permitted.

Though Konold and Wells were mainly concerned with cognitive development research interviews, there is an element of generalisability in their analysis, and an important point to note is their suggestion that a single interview can proceed through various phases relating to these formats.

5.3.4 A common theme running through all these classifications is the extent to which an interview is structured, as shown in Table 5 (see p66).
<table>
<thead>
<tr>
<th>Highly-structured</th>
<th>Semi-structured</th>
<th>Un-structured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face-to-face questionnaires, written instructions and questions dominate interaction.</td>
<td>Written or mental notes of questions to be raised. Precise order and wording not predetermined.</td>
<td>Minimal interviewer control. Freedom given to express feelings, ideas, etc. as fully and spontaneously as possible.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Konold and Well (1981)</th>
<th>Tutorial interview</th>
<th>In-depth interview</th>
<th>Thinking-aloud interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agar (1980)</td>
<td>Formal interview</td>
<td></td>
<td>Informal interview</td>
</tr>
<tr>
<td>Whyte (1960)</td>
<td>Total interviewer direction</td>
<td></td>
<td>Minimal interviewer direction</td>
</tr>
</tbody>
</table>

**TABLE 5: Research Interview Typologies.**
My own test interview, by design, fell into the semi-structured category. Nothing I have read in the literature has made me think that there is a more appropriate interview style for my purposes.

5.3.5 The next step was to investigate the most effective method of conducting this type of interview. Parlett (1978) has some extremely helpful observations in this respect. He points out that the advantages or disadvantages of using structured or unstructured interviews are not only important in terms of the nature of the inquiry. In his words it 'also has to do with whether the interviewee feels confident or not', and that some flexibility of style is important to protect the relationship between the inquirer and participant. Further, he spotlights the importance of the 'interaction contract' set up at the beginning of any 'dyadic transaction and intercommunication'. He suggests that when two people meet, a whole series of decisions are made, generally implicitly and unconsciously about the 'social appropriateness' of certain kinds of disclosure. It is thus necessary for the interviewer to be aware of the type of interaction contract being set up, and possibly to intervene to ensure the most helpful situation pertains. Further advice concerns 'tips of the trade'. Parlett suggests that whilst there are interviewing strategies that can be learned, interviewing

'... is not a technique that can be 'administered' in a technical fashion. It is a human interaction and the personalities of the two individuals are critically significant to the success of the interview. The rule is to develop one's style and not to be inhibited from doing what 'feels right' to you as an individual.'

(p5)

5.3.6 With regard to questioning technique, it is pointed out that it is not always necessary to ask questions; inquirer's statements followed by a request for comment also form a
useful 'probe'. **Key questions** should be worked out in advance, and there may be some value in using the same questions with every interviewee; it can produce more readily comparable data. **Supplementary questions** may be used to explore in greater depth points raised in answer to a key question. **Leading questions** should be avoided. Whether questions are open or closed may determine the nature of the reply, whilst **filter questions** are useful to direct the interview on to some other train of inquiry. The **structure of a question** is also important in influencing the length of response obtained. All the above points require some practice and skill. The most fundamental requisite, however, is 'a capacity genuinely to listen'. The quality of listening is 'a way of signalling interest and concern'.

5.3.7 Heron (1975) has discussed some useful 'intervention strategies' which may be used in interview situations and elsewhere. In particular his 'eliciting interventions' form useful guidelines for the interviewer in attempting to obtain unconstrained responses from the interviewee. These may be summarised as follows:-

a) **Active listening**, in which non-verbal communication plays an important part. The interviewee should not be given the impression you are searching your mind for the next question!

b) **Reflection**, where the inquirer echoes the last few words spoken by the interviewee, either literally or re-phrased. This frequently leads to the interviewees expanding on their previous thoughts.

c) **Interviewee centred questioning**, inviting the interviewee to say more about some aspect or idea.

d) **Checking for understanding**, where the interviewer summarises a point made by the interviewee, and asks whether that is a fair reflection of his ideas.

5.3.8 Elliott and Adelman (1975) have suggested seven principles
of interview procedure, aimed at establishing interview situations in which the interviewer minimizes the demand for accountability (i.e. requires reasons for conduct) and encourages and validates a concern for truth. The interviewer:-

1.···· clearly indicates his belief that the interviewee is in a position to give an honest account of his actions.
2.···· asks questions which sincerely indicate a willingness to increase his own understanding.
3.···· refrains from utterances which indicate attempts to elicit a particular interpretation.
4.···· refrains from imposing his own interpretations on the interviewee.
5.···· refrains from indicating approval or disapproval of the facts cited in the account as it emerges.
6.···· allows the interviewee's values to determine the descriptions and explanations he gives.
7.···· respects the integrity of the context by promising the interviewee complete control over other people's access to his account.'

The concern behind these principles is an attempt to reduce the element of subjectivity in the data generated.

5.3.9 It was interesting to note how closely the intuition and experience used to plan the first interview had matched many of these points, not only in the structuring but in my own interview 'technique'. Armed with a renewed confidence that my approach was justifiable, and with some increased experience in interviewing through the Research Methods course (Surrey University), the research interview programme was now undertaken.

5.4 Modus Operandi.
5.4.1 As a result of the trial interview and literature review, a model for the full programme of interviews was devised. The model was not intended as a straight-jacket for the inquiry, but intended to provide a 'modus operandi'. The model included
a set of key questions to structure the interviews, but with a clear note to myself to allow 'space' for some of the eliciting techniques to be used. In particular, the first two questions were used as 'relaxers', giving the interviewee chance to come to terms with the interview situation. From these questions lines of discourse could be followed and guided towards the remaining semi-structuring questions. (see Table 6).

<table>
<thead>
<tr>
<th>Semi-Structured Interviews.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Key Questions.</strong></td>
</tr>
<tr>
<td>1. Where did you study Chemistry?</td>
</tr>
<tr>
<td>2. Which chemical topics interest you most?</td>
</tr>
<tr>
<td>3. Which do you think are the main concepts within reaction Kinetics?</td>
</tr>
<tr>
<td>4. Which do you think are the main concepts within chemical equilibrium?</td>
</tr>
<tr>
<td>5. Do you see any link between these two areas of Chemistry?</td>
</tr>
<tr>
<td>6. What do you see as the main importance of these areas of Chemistry in industry?</td>
</tr>
<tr>
<td>7. How do you think they should be taught?</td>
</tr>
</tbody>
</table>

N.B. Check that the use of the word 'concept' does not provide difficulty: 'ideas' also acceptable.

TABLE 6: Key Questions for research interviews.

5.4.2 The audio-recorded interviews generated using the key questions were transcribed verbatim by myself, and the transcripts agreed with the participants before being edited, as described in 5.5.1. This edit was then also agreed. At a minimal level this was intended to ensure that the data were known to the participants; at a maximal level, amplification and clarification could occur. Overall, the intention was an increase in authenticity. I believe that such a dialogue between researcher and participant is fundamental to case-study,
though I do not totally accept Elliott's (1980) argument that, once negotiated, the validity of an account has been demonstrated. Whilst Macdonald (1977) gives some support to Elliott's claim, Stenhouse (1978) points out that though negotiation may be a necessary condition for authenticity, it is not in itself sufficient. All case-study inquiry should also be open to 'public' criticism. (see 6·4·3)

5·4·3 With the agreed transcript and edits available, cameos of each participant's views were drawn from which patterns, similarities and differences could be sought. This formed a basis for analysis in detail. The pre-analysis phase was also referred back to the participants for comment in order to further reduce the risk of researcher bias being implicit rather than explicit. This 'modus operandi' is shown diagrammatically in Diagram 8.

Diagram 8: Data processing model.

5·5 Editing and analysis.
5·5·1 The editing process had two phases:

a) the elimination of pauses, repetitions, 'ers' and 'ums' etc.,
b) the selection of important content (passages, sentences etc.) which were thought to best represent what the participant was trying to say[ note: not what the interviewer was looking for].

The editing was concentrated on statements relating to the focal concepts, though not restricted to them. An example of this editing technique is given in Appendix 2 (p A2 ).

Whilst this editing technique sharpened participants' statements into a more readable and manageable form for analysis, it also meant a loss of peripheral information (e.g. evidence of a struggle to remember, or to describe). Thus the edits have always been read in conjunction with the original transcript, so that both levels of information have been available during analysis.

5.5.2 Interview data analysis is not just 'an attractive nuisance'. [Miles (1979)]; apparently it has been largely unscripted. Seiber (1976) examined seven 'well respected texts' on field methods and found less than 5-10% of the pages devoted to analysis. More recent writing has begun to reverse this position [Patton(1980); Agar(1980); Guba and Lincoln (1981); Bogdan and Bilken(1982); Hull(1984); Miles and Huberman(1984)].

Miles and Huberman suggest that attitudes to analysis range from it being an 'art' involving totally intuitive processes, through to an almost anarchic position where no 'robust methodology is needed' since there is no social reality 'out there' to be accounted for [see also Dreitzel(1970)]. When we consider, however, that the data to be analysed is verbal, not numerical, then some form of processing must be undertaken if any 'account' is to be given. Agar (1980) describes such a process as

'... the ability to decode rather involved sequences of verbal and non-verbal behaviour, and then encode our understanding of the meanings of that sequence into some utterances to check whether or not we understood what just occurred. It is in this special sense that I speak
of giving an account.'

(p 79). (original emphasis)

5.5.3 Agar also points out that the emphasis is on the use of language as metalanguage:

'.... one of the confusing things about human language is that it is both object language and metalanguage. As object language it is part of the flow of behaviour that occurs as group members do the activities they do, but is it also metalanguage, used to talk about that flow ... An account is given using the group language as meta-language.'

(p 79). (original emphasis)

One consequence of the transformation from 'object language' to 'metalanguage' is that the interviewer/analyst cannot avoid using what Stenhouse (1979) has referred to as the 'second record' of understanding developed during the interview process, that is in the (literally) unrecorded understanding gained in interviewing research participants. Hull (1984) has pointed out the full significance of this, in suggesting that the researcher is thus in a privileged position as analyst:

'.... these black market understandings put field worker/analysts in a rather more powerful position than researchers should perhaps aspire to, since their interpretations are not accountable to what is available to others as 'project data' but contingent upon understandings unique to their participants in the live situations from which the data are distilled.'

(p 8)

5.5.4 An aim in analysis has been to provide access to participant's perceptions as voiced at interview, and hence disclose significances in the transcripts. One level of negotiation undertaken has thus been to give confidence that the participants' views are reflected in the transcripts. Care has been taken to avoid undue identification of my views with
those of the participants through what might be termed 'over-negotiation'. The level of analysis undertaken however has gone deeper than this. Using Konold and Well's (1981) ideas, analysis may be conducted at three levels:

a) Coded analysis, involving the identification of key elements of interests by specific codes so that presence or absence of the elements may be rated ('elements' here could be for example key words or phrases etc).

b) Descriptive analysis, involving a clear restatement of what the the participants said or did with no inferences being drawn with regard to reasons or meanings.

c) Interpretative analysis, where inferences are made about the deep structures of the participants reasoning or understanding.

In searching for patterns in perceptions, coded analysis would not seem appropriate, involving as it does rather more detailed and structural information than required. The mode adopted therefore has been at both the descriptive and the interpretative level.

5.5.5 The first step, as already mentioned, has been to fully transcribe each interview, a difficult task but which enables the researcher to know the data well. The full transcripts were then read several times in entirety, before any editing or negotiation took place. If any transcript revision was necessary through negotiation this was undertaken at this stage. Only when the transcripts had been edited and agreed were they considered for analysis. The view was taken that whatever the status and structure of the ideas contained in the data at this point, they were acceptable on the basis of the integrity of that person [Pettit(1978)]. Further, it was thought necessary that all statements should be given equal status, however illogical or inconsistent they may have seemed when compared with other statements by the same person, and taken seriously unless the content made it clear that flippancy was involved [Sinclair and Coulthard(1975)].
5.5.6 Analysis was based on three main steps:-
   a) The transcripts and edits were read together several times.
   b) 'Significant ideas' were marked, the most important statements being established with a highlighter pen.
   c) The highlighted statements were cut out and pasted into files specific to that particular comment.

The IP interviews were dealt with 'en bloc', providing a series of factors from which a conceptual framework was obtained (see 6.3). Constant cross referencing between these IP interviews took place, producing a dynamic process.

5.5.7 As the EP interview transcripts came 'on stream' each was put through a similar process, except that the conceptual framework derived from the IP interviews was used to inform this process. Thus, this was not an 'en bloc' analysis; constant cross referencing took place with all the precedent interviews (see 4.2.2). In an attempt to avoid overlooking important but not recurring factors, an 'opposite pole' strategy was adopted, i.e. searching for high praise comment to 'balance' high criticism. This repeated combing and cross referencing produced a series of collected comments relating to a range of factors - a somewhat different and extended set than that generated from the IP interviews. Throughout this whole process, ideas were forming and being modified or rejected as the data base developed. Only when the last interview had been assimilated, was it felt right to consider any inferences in detail (see 6.2). Appendix 3 (p A3 ) contains the complete data-base from the analysis process; Appendix 4 (p A4 ) shows how a transcript was typically marked up during analysis, prior to 'cutting and pasting'.

5.5.8 Thus, the analysis procedure consisted of three activities:
    i) data reduction
    ii) data display
    iii) data inferencing.
and thus parallels the process outlined by Miles and Huberman (1980) and represented in Diagram 9.

These activities were not linear and discrete, being more cyclical in nature. As new data became available, differing ideas and perceptions were evident. The display boxes full of significant ideas thus were open to change. The categories finally emerging are shown in Table 7. It will be noted that not all the categories relate directly to the focal concepts. This may be an indication of the value of the indirect questioning technique employed (see 5.2.2). Full discussion of the inferences drawn from these factors is given in Chapter 7. (For Table 7 see p77)

5.5.9 In consequence of the trial interview, several questions were posed concerning the conduct of the research interview programme (see 5.2.8). I believe that the processes adopted in the inquiry have answered those questions. The style of interview has been justified; an ethical protocol has been adopted (5.2.2a); the value of indirect questioning techniques
has been evident; many 'off-line' comments have provided very useful information; a system for data analysis has been effectively adopted.

5.5.10 As explained in 4.3.5, the need for triangulation of methodology to enhance authenticity was recognised.

<table>
<thead>
<tr>
<th>CODE</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Personal attitudes to Equilibrium/Kinetics/Thermodynamics</td>
</tr>
<tr>
<td>B</td>
<td>Books - importance/influence</td>
</tr>
<tr>
<td>C</td>
<td>Relationship between focal concepts</td>
</tr>
<tr>
<td>E</td>
<td>Perspective on equilibrium</td>
</tr>
<tr>
<td>EI</td>
<td>Effect of interview</td>
</tr>
<tr>
<td>F</td>
<td>Importance of focal concepts</td>
</tr>
<tr>
<td>H</td>
<td>Personal response to Higher Education</td>
</tr>
<tr>
<td>I</td>
<td>Industry related experience</td>
</tr>
<tr>
<td>K</td>
<td>Perspective on Kinetics</td>
</tr>
<tr>
<td>L</td>
<td>Influences in learning</td>
</tr>
<tr>
<td>M</td>
<td>Mathematics related factors</td>
</tr>
<tr>
<td>N</td>
<td>Nature of chemical reaction</td>
</tr>
<tr>
<td>P</td>
<td>Personal philosophy of science</td>
</tr>
<tr>
<td>R</td>
<td>Relevance of courses</td>
</tr>
<tr>
<td>RC</td>
<td>'Realism' in Chemistry</td>
</tr>
<tr>
<td>T</td>
<td>Teaching approaches in undergraduate courses</td>
</tr>
<tr>
<td>U</td>
<td>Choice of undergraduate courses</td>
</tr>
</tbody>
</table>

**TABLE 7: Final categories from analysis.**

The categories which emerged from the analysis (see Table 7), were therefore used as a basis for the design of a questionnaire, to be sent to all the interview participants, as well as other non-interview participants. The rationale, analysis and outcomes of this questionnaire are reported separately in Chapter 9.

* * *
Chapter Six

Focussing.

In which the implications of the IP interviews in focussing the inquiry and informing the interview sample for the whole inquiry are discussed.

6.1 Research access
6.2 IP interviews
6.3 A conceptual framework
6.4 A new focus
6.5 The research sample
6.6 EP interviews
CHAPTER SIX.

6. FOCUSSING.

'Forward, forward let us range
Let the great world spin for ever down
The ringing grooves of change.'

Alfred Lord Tennyson
Locksley Hall (line 181)

* * *

6.1 Research Access.

6.1.1 Obtaining access to interviewees is not, in general, an easy process. Agar (1980) suggests that three things are required, in some combination or other:-

a) an institutional affiliation in the area of the inquiry.
b) accountability, that is the need for a background reputation; the 'introduction effect'.
c) a mediating group or person as contact; the 'colleague effect'.

I have found this to be a very accurate assessment of the situation during this inquiry. The majority of my interviews have been arranged using the 'introduction effect', but this alone would not have sufficed. The status afforded by my association with the University of Surrey has been particularly useful in the industrial sector of my programme, whilst my own career affiliations have helped in the education sector. Even so, without the third factor, the 'colleague effect', many of the interviews could not have been arranged. I remain deeply indebted to those friends and colleagues who have given their time, and shown enthusiastic interest, in opening doors into various Companies and Institutions.

6.1.2 The major problem met in seeking access resulted from
the 'high prestige' situations I was seeking to enter. My research participants were all busy people undertaking exacting roles. This led to some difficulty in finding mutually convenient appointments, and to limited control over the situation in which interviews were held and recorded. Negotiation of transcripts and edits has also largely been confined to correspondence and telephone conversations for the same reason. The overall time-span of the interview programme has thus been rather more prolonged than I would have wished (February 1982-Dec. 1985). I believe this not to be of great significance in this study in which the temporal dimension is not critical.

6.1.3 Very few 'sensitive' areas have arisen in gaining access, and few were expected. However, one point which arose on several occasions links with the need for a research protocol on confidentiality (see 5.5.2a). Several industrialists were concerned to ensure that any research access gained should be properly used, and not become a medium for what, perhaps rather dramatically, might be termed 'industrial espionage'.

6.2 IP Interviews.
6.2.1 Access for the IP interviews was obtained through the kind help of Mr. John Winsor, Education Liaison, BP. Research Centre, Sunbury. Arrangements were made to interview five research personal, selected to cover a wide range of function and experience within the Research Centre (see Table 8, p81). The choice of participants was very much a matter of availability, giving me little control beyond stating my preferred requirements.

6.2.2 The interviews took place in a room adjacent to an office that was clearly a communications focus. Telephones rang and a door banged continuously! The acoustics of the room itself were not good, but there was a convenient conference
<table>
<thead>
<tr>
<th>Participant</th>
<th>Transcript</th>
<th>Type of interview</th>
<th>Qualifications</th>
<th>Employment</th>
<th>Age Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>Trial</td>
<td>B.Sc London</td>
<td>HE</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&quot;PhD &quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>IP</td>
<td>B.Sc Glasgow</td>
<td>RD</td>
<td>4</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>&quot;PhD &quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>IP</td>
<td>B.Sc Salford</td>
<td>RD</td>
<td>3</td>
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<td>&quot;PhD Camb &quot;</td>
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</tr>
<tr>
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<td>5</td>
<td>IP</td>
<td>B.Sc London</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>6</td>
<td>IP</td>
<td>B.Sc London</td>
<td>RD</td>
<td>2</td>
</tr>
</tbody>
</table>

N = 6

HE : Higher Education  Age sectors 1:  ----- 25
RD : Research and development  2: 26-----35
     3: 36-----45
     4: 46-----55
     5: 56-----65

IP : Initial phase

| TABLE 8: IP Interviews. |

table and comfortable chairs. The ambience for the interviewees was thus mixed, and several factors might well have influenced interviewee responses:

i) the formality of the surroundings, and a room which apparently was unfamiliar to them.

ii) possible irritation with background noise.

iii) unconscious resentment at being withdrawn from their working surroundings.

Similarly several factors were influencing my own performance:

i) unfamiliarity with the surroundings.

ii) distraction due to background noise.

iii) a consciousness of the 'newness' of such an activity for me.
6.2.3 The general atmosphere was, however, friendly and supportive, and there is little evidence of the above factors being important in the final transcript (except for the difficulty of hearing the spoken word against background noise in places). What was important, however, was that I had clearly been accepted as 'bona fide'. In arranging the interviews I had made clear my academic status, what my professional role was, and why I had an interest in talking to industrial researchers. This I believe to have been an important factor in producing five effective interviews. One negative factor was present; three interviews were undertaken in the morning, two in the afternoon. Fatigue on the interviewer's part became significant as the day wore on! On reflection, it was clear that fewer interviews in one day should be undertaken. It might also have been more suitable to meet people 'on their own ground'. The 'neutrality' of the interview venue in this instance might easily have reduced interviewee confidence. More importantly there was no possibility of picking up clues about the participants from their 'personal' surroundings, as occurred in later interviews.

6.2.4 The transcription process proved both lengthy and tedious. The decision not to use a professional transcription service was important. The act of transcribing introduced a strong element of familiarity with the data, and also allowed a conscious but unwritten pre-analysis to occur. Ideas could be linked in a way not possible during the interview and points for referral during negotiation noted. Copies of each tape were made, as precaution against loss of original data — although a major lesson learned here involved the accidental erasure of the majority of TR4, fortunately after transcription. Once the transcripts had been agreed by the participants each was edited, and the edit agreed (see 5.5)

6.2.5 The major comment made by the participants on reading the primary transcripts concerned their apparently inarticulate
speech.

Thus, an important secondary function of the edit was to show clearly that the 'inarticulate' quality arose largely from verbatim transcription. The editing process was the most dangerous from the point of view of introducing interviewer bias and prejudice, and hence at this point negotiation was seen to be particularly important. In practice, very little adverse comment was received at either level (transcript or edit), other than error correction and the point about incoherence mentioned earlier:

'I must admit the form of the transcript took me by surprise. I did not realise that speech was so incoherent.'

Participant E:
(correspondence).

6·2·6 In one case however the participant commented at length on the effect of the interview, (factor EI, see Table 7, p77) which had clearly been disturbing:

'...... Such basic chemistry questions that I couldn't answer - it makes me doubt my abilities to be in science at all. It did make me ask the question - have I simply a poor memory or did I never understand the subject?......'

Participant F:
(correspondence).

Further contact with F remedied the apparent effect on personal confidence, and gave rise to other comment which proved to be highly significant at a later analysis stage (see 6·4·4).

6·2·7 With the IP transcripts and edits agreed, analysis was undertaken, as outlined in 5·5. All the transcripts/edits were read through several times, and cameos of each individual's ideas devised. All the scripts were then read through again, this time alongside the cameos. Notes were made concerning
those points deemed to be significant - significant, that is, in terms of the purpose of the interviews (perceptions of chemical concepts). These factors were then checked with each transcript/edit in turn to discover the regularity of the occurrence of the factors. This tabulated information was then condensed down to a list of interesting points arising.

6.2.8 The cameos for the IP interviews are reproduced here in full, to demonstrate how this part of the process operated. The numbers in brackets refer to lines in the edit text.

**Participant B, Cameo 2:**

Senior research chemist of distinction (RIC Gold medallist); most senior person interviewed. Started university career studying Physics, then enlisted in Army (World War II). 1945, returned to Glasgow University and took up second subject (Chemistry); got involved in hydrocarbon synthesis and catalysis. Very clear about the main ideas in area of reaction kinetics (5-17), and claims this as the industrialists' viewpoint. Sees a natural development from thermodynamics -- kinetics, with kinetics as a way of achieving equilibrium quickly (23-34). Equilibrium quite definitely an affair of energy-free energy (40-45) and thus a balancing of energy conditions (98) with rate only important as attainment of equilibrium. Interesting flicker of a different idea in reference to 'back reaction' (55); also, implies molecular effects (55-85). Discussion of oxidation and syngas reactions very interesting since rate seen in terms of attainment of equilibrium despite allowing for molecular factors ('inhibition') (95). In searching for equilibrium resorts to sublimation of ice (140).

Note: i) Takes a thermodynamic overview, but discusses in terms of competing rates on a molecular basis.
   ii) equilibrium determined by conditions (energy) not rate.
   iii) Uses a mass thermodynamic model and a micro molecular model.

**Participant C, Cameo 3:**

Read an Applied Chemistry degree; research degree was mechanistic/synthetic study of azido-quinolenes. Never liked kinetics (3); important in Chemistry (15). Concept of kinetics clearly outlined - rate constant/order/mechanism - but was less convincing about equilibrium, referring to lack of interest (45). Interest in kinetics/equilibrium developed after university experience (55). Approached equilibrium through mechanism (molecular model) (90-181);
admits necessity of thermodynamics in the end. Dislikes thermodynamics due to mathematics involved (140). Refused research grant for this reason. Prefers thermodynamic approach to that of competing rates, but seems undecided when talking about teaching (195). Very critical of university course. Note ease of remembering symbolic information.

Note: i) Claims mechanistic/molecular approach – organic chemist's viewpoint.
    ii) Thermodynamics seen as later stage.
    iii) Equilibrium seen as function of mechanism more than energy conditions.
    iv) Rejects competing rates in favour of thermodynamics, but shows confusion (195).
    v) Importance of Chemistry in context.
    vi) Rate/kinetics different.

Participant D, Cameo 4:

Fairly traditional Hons. Chem. degree, followed by research in photographic Chemistry. Move to Cambridge to take Ph.D in organo-metallic Chemistry. By own admission, more an inorganic than organic chemist. Wished he knew more about focal concepts, but in general clear about kinetics [rate/order/pathways, e.g. SN1, SN2, etc.] (25) and equilibrium [thermodynamic measurement in energy terms]. Viewed reactions in general as being open-ended, and did not like competitive rates idea (55). Kinetics and equilibrium very clearly separated with equilibrium as a theoretical position determined by thermodynamics. Was uncomfortable with reversibility, since rare - most reactions on a spectrum of equilibrium positions (135). Nature of equilibrium clearly seen as dynamic (gave Physics example) but talked of it in static terms. Regrets little use made of university course, and was very defensive. Seemed far more interested in the possibility of reaction than the process of reaction.

Note: i) Equilibrium energy-controlled and all reactions have an equilibrium.
    ii) Kinetics: related to molecular change, can be used to achieve equilibrium more quickly.

Participant E, Cameo 5:

After an Hons. Chemistry degree, undertook research in inorganic stereochemistry for doctorate. Led to current interest in solid state chemistry. Before moving to industrial research, was university lecturer for two years. 'Change' was the most important factor for him. Wide range of ideas associated with kinetics[reactants/products - pathways - how fast? - mechanism? - intermediate compounds - experimental techniques - quantification - mathematical models - uses]. Equilibrium seen through 'change' also, via Le Chatelier's Principle.(45). 'Competing rates' was acceptable for school teaching since it
particularly stressed dynamic equilibrium. Higher education required more rigorous treatments. Thermodynamics nothing to do with kinetics (68). Thermodynamics seen as the 'ultimate principle' (81) and the main starting point for undergraduate physical Chemistry. Statistical thermodynamics will allow derivation of all other points [ echoes A; Cameo 1]*. Interesting comment on the idea of 'working Hypotheses' (28-40), mathematics (5-10), and utility (20).

Note: i) Thermodynamics an over-arching principle, related to 'change'.
   ii) Strong claim to importance of rigour in higher education; this apparently related to theoretical explanations.

Participant F, Cameo 6:

Has a degree in Biology and Chemistry, but no higher degree. Sees herself as a biochemist by training with a strong preference for Biology, but read Chemistry on the basis of its greater employment value. Worked for a while as research chemist and then market research in cosmetics and toiletries. Now researching in surface and colloid Chemistry. Rather confused, and clearly surprised by the substance of the interview. Some nice comment on energy 'humps' and diagrams (memory of symbolic learning). Saw kinetics very much as a matter of 'equations' (Michaelis - Menten ). Equilibrium seen to be where reaction has gone to completion (65). Thinking oscillated between static/dynamic equilibrium (85). Found it difficult to talk about reversibility (105). Physical example of dynamic equilibrium given (85). If rates of reaction were equal and opposite, equilibrium obtained; this seen in molecular terms. Talked of degree of reaction (35-40) and of a 'circular' equilibrium (Krebs Cycle). Thinks kinetics preceeds equilibrium in terms of understanding, but sees the two as closely related (145-149). Finds equilibrium easier to understand, since kinetics dominated by mathematics (165 and 176). Thought she did not use focal concepts in her work until rate implications of flotation revealed (203). Most unhappy with university. Must have 'chemical realism' in examples (216), but employed non-chemical examples herself (127).

Note: i) Strong negative influence from mathematics.
   ii) Effect of interview strong. Needed following up.
   iii) Strong affinity with molecular modelling for both kinetics and equilibrium.

6·2·9 Although the IP interviews were structured to focus on personal perceptions of specific chemical concepts, it is clear from the cameos that other factors were apparent which could not be ignored. There was a temptation here to recognise only those ideas which occurred with greatest regularity. Irrespective of the small IP sample size, such a move could well ignore quite

* N.B. Not included in this review.
significant isolated factors, and even obscure the importance of an idea in some cameos. It is hoped that this has not influenced the selection of significant points arising from this analysis, which were seen to be:-

1. An apparent difference in the views held of the focal concepts. The participants' own interests often formed a starting point for their discussion of such concepts.
2. There were differing views on whether kinetics and equilibrium had separate characteristics or not.
3. Memory of diagrams often prompted thinking.
4. Mathematics was an important factor, particularly with respect to kinetics.
5. This area of Chemistry was not liked in general, despite its fundamental character.
6. There were strong views about university courses in this area of Chemistry.

Table 9 (p88) gives the details of IP interview analysis.

6.3 A conceptual framework.

6.3.1 When dealing with interview analysis, it is verbal data that is being reviewed, and as such, extracted generalisations are frail ghosts of people's ideas. Thus to produce an overview, the scripts were revisited and quotations lifted from the text which seemed best to describe that participant's ideas. Reading through these quotations generated the idea that two 'models of thinking' embraced the interviewees' perspectives of the focal concepts, and which provided possible explanation of the points listed in 6.2.9 above. One, which I have termed the Noetic Model is a macro-process model involving superordinate and elegant theoretical propositions relating to energy. The other, termed the Pragmatic Model, is a micro-process model, involving a strong dependence on molecular modelling and mechanisms in chemical reaction. Table 10 (p90) summarises the two thinking strategy models.
TABLE 9: Analysis of IP interviews.

<table>
<thead>
<tr>
<th>Participant/Transcript.</th>
<th>B TR2</th>
<th>C TR3</th>
<th>D TR4</th>
<th>E TR5</th>
<th>F TR6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relationship between focal concepts.</td>
<td>Linked</td>
<td>Linked</td>
<td>Separate</td>
<td>Separate</td>
<td>No clear comment.</td>
</tr>
<tr>
<td>Kinetics: Rate/ order Reversibility Math. eqns.</td>
<td></td>
<td></td>
<td>**</td>
<td>**</td>
<td>No clear comment.</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>Molecular model</td>
<td>Therm. model</td>
<td>Dynamic/static</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>No clear comment</td>
<td>*</td>
</tr>
<tr>
<td>Pers. approach to focal concepts</td>
<td>Catalysis</td>
<td>Mechanisms</td>
<td>No clear comment</td>
<td>Change</td>
<td>No clear comment</td>
</tr>
<tr>
<td>Maths difficult Kin. too Mathemat.</td>
<td>No clear comment</td>
<td>**</td>
<td>*</td>
<td>No clear comment</td>
<td>**</td>
</tr>
<tr>
<td>Importance in Ind.</td>
<td>***</td>
<td>**</td>
<td>No clear comment</td>
<td>*</td>
<td>No clear comment</td>
</tr>
<tr>
<td>Need for 'Realism'</td>
<td>**</td>
<td>**</td>
<td>No clear comment</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Use of 'Symbolic learning'</td>
<td>No example</td>
<td>**</td>
<td>*</td>
<td>No example</td>
<td>*</td>
</tr>
</tbody>
</table>

continued on next page
<table>
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<tr>
<th>CATEGORIES</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example of equilibrium</td>
<td>Ice subliming</td>
<td>-----</td>
<td>Evaporation</td>
<td>-----</td>
<td>Dissolving</td>
</tr>
<tr>
<td>University course</td>
<td>Disliked separate Depts.</td>
<td>Poor teaching</td>
<td>Highly critical</td>
<td>No clear comment</td>
<td>'Disgusted'</td>
</tr>
<tr>
<td>Other points:</td>
<td>Energy seen as fundamental. Practical work important.</td>
<td>'Conflict' between a mechanistic and an energetic approach.</td>
<td>Regretted poor knowledge of focal concepts. Blames undergraduate course.</td>
<td>Key to physical chemistry is statistical thermo-dynamics.</td>
<td>Confused ideas on nature of equilibrium. 'Conflict' between logical ideas and what is found 'comfortable.'</td>
</tr>
</tbody>
</table>

*** very strong opinion  
** strong opinion  
* clear statement of opinion.
1. Knowledge unified by superordinate principles of thermodynamics.
2. Kinetics and equilibria seen as separate almost isolated areas.
3. Energetic/mathematical mode.
4. Intellectual elegance rated highly.

1. Knowledge unified by processes of chemical interaction.
2. Kinetics and equilibria seen to be fundamentally related areas.
3. Molecular/mechanistic mode.
4. Practical application rated highly.

TABLE 10: Thinking strategy models.

The models are not mutually exclusive; the interviewees not only used different models as individuals, but resorted to using both models themselves when it seemed appropriate.

6.3.2 Although kinetics and equilibria were questioned separately nobody was able to talk of one in isolation of the other. This revealed a major difference in viewpoint. For instance, B clearly saw all the concepts as closely related:

B: 'Well, I think the concept of thermodynamics, and going then into equilibria and into kinetics, in other words the whole lot of what's normally grouped under physical chemistry ... it is absolutely vital that before you start on a piece of research that you must ensure that the thermodynamics are right, that the free energy changes make the reaction permissible and that the equilibrium will give you a reasonable chance of producing the material that you want and finally the rates will tell you that you can produce it at such a rate that it's commercially feasible. That's very much from the viewpoint of an industrial chemist.'

(Tr 2 Edit., lines 6-17)

On the other hand E very forcefully separated these ideas into two camps:
E: '..... the thermodynamics hasn't got anything to do with the kinetics really. Thermodynamics only tells you what the equilibrium situation is assuming you've got all these reactions to occur - it's divorced in a way from kinetics.'

(Tr 5 Edit., lines 66-69)

He also justified his views thus:

E: 'There's a case for putting thermodynamics separately, because it rises above mechanism. The fact it's made of atoms doesn't matter as far as the thermodynamics goes, so thermodynamics rises above it all. I don't really see why you shouldn't teach thermodynamics separately, and the concept of equilibrium and kinetics can be taught separately. If you do any statistical thermodynamics, things like expressions for equilibrium constant fall out ... that's where the link is.'

(Tr 5 Edit., lines 81-87)

Here, the distinction is made on the basis of an over-arching mathematical (thermodynamic) model. Any link that does exist between the concepts is a mathematical abstraction.

D was, in a way, sitting on the fence. He implied a unified conceptual area, with separation on practical grounds:

D: 'thermodynamics (is) a very useful way of knowing where equilibrium is going to lie ... you don't have to know anything about rates.'

(Tr 4 Edit., lines 69-72)

Here we have evidence of the two postulated models of thinking. B used a Pragmatic mode of thinking, E used a Noetic mode. D seems to adopt a compromise position.

6.3.3 The IP interviews contained many such instances. Some of the best examples follow:-

D used the Noetic model when discussing equilibrium:
D: 'It must be an equilibrium in terms of energy, that the system as a whole has come to its lowest energy, and the energy that it's come to will define the actual concentrations of the components.'

(TR 4 Edit., lines 36-38)

C treated this same point Pragmatically:

I: 'What would you say is the main thing you would have to know if you're dealing with chemical equilibrium?

C: (pause) Mm! I'd have thought mechanism.

I: Mechanism? Why do you say that?

C: Well, you've got to get from one thing to the other, and you've got to decide where the equilibrium's going to lie. I think a good understanding of mechanism is the thing.'

(TR 3 Edit., lines 101-107)

B had been discussing equilibrium and the need to determine that 'a reasonable free energy change' existed in a reaction, before finding the 'temperature pressure and concentration regime to provide optimum output' - very Noetic. However, he continued:

B: 'Now, oxidation is the type of Chemistry where equilibrium just doesn't worry you. Once you've burnt the thing down to CO, or you've taken out the hydrogen as water, the back reaction has negligible effect. But, if you're going to syngas reactions where you have carbon monoxide going to, say, methanol, you know damned well that the back reaction methanol to syngas can go very readily.'

(my underlining) (TR 2 Edit., lines 54-60)

This of course is very Pragmatic, with equilibrium being seen as a balance of backward and forward reactions, not in terms of energy states. B was thus at ease using either model.

6.3.4 F, on the other hand, seemed less at ease. In discussing equilibrium she was clear about one thing:
I: 'You said there, 'You have a reaction and it's gone to completion'; what did you mean by that?

F: Well, everything that's going to happen when you put two things together which react, has happened, and it's finished to all intents and purposes.'

(TR 6 Edit., lines 65-68)

This is a static view of equilibrium. Concentrations become constant; the reaction apparently stops. Closer questioning drew this response though:

F: '... you could argue perhaps that some of the crystal surface comes away into solution, and some of the solution goes back onto the surfaces, and so you'll have a movement there, but the system as a whole will remain the same from the objective point of view.'

(TR 6 Edit., lines 72-75)

Here F was using solution as an analogy to explain the dynamic nature of equilibrium. Her first (static) view was basically Noetic; her second view was Pragmatic - but she was not totally committed to this view (note the word 'perhaps'). D. was very open in his view concerning static/dynamic equilibria, although there was an element of 'revelation' indicated by the surprise in his voice when he said:

D: 'I do tend to think of things reacting to give something else, and there's an end of it, and not that they go back, you know, when you get an equilibrium, that things are moving.'

(TR 4 Edit., lines 148-151)

6.3.5 One significant point was that in every case where dynamic characteristics were ascribed to equilibrium, a physical example was cited (solution, snow subliming, evaporation, etc.). Perhaps equilibrium is the point of contact between the two models of thinking. This might be represented diagrammatically thus:-
6.3.6 Thus far, and based on the evidence from the IP interviews, it could be said that:—

1. Industrial researchers hold and use two rather different views of these particular chemical concepts.
2. These views are significantly different in that one is a macro-phenomenon model, the other a micro-phenomenon model.
3. These industrial researchers could use both models effectively, since they are not mutually exclusive.
4. The nature of chemical equilibrium would appear to be a bridge between the two models.

There is some evidence from the interviews, that chemical educators prefer the intellectual elegance (based on epistemic logic) and rigour of the Noetic model and devalue the Pragmatic model. The practitioner seems to require a facility to use both. The evidence appears in three main 'themes':—
1. Attitudes to this part of Chemistry.
2. 'Reluctant Reversibility.'
3. Fear of Mathematics.

6.3.7 Both B and C made very clear statements about undergraduates and postgraduate negative attitudes to these physico-chemical concepts:

B: 'I've had so many people come into the lab... and they've said, 'Oh! my goodness! I wasn't very good at Physical Chemistry and I didn't really like it very much'.

(TR 2 Edit., lines 18-20)

C: 'My view is that it (kinetics) is one of those things at university that perhaps people aren't very interested in... but it's a very important aspect when you come to doing, you know, working somewhere like (X).

(TR 3 Edit., lines 9-14)

and: 'the little bit we did on that (equilibrium) I didn't have great interest in... I know you're picking on the points basically, you know, that people would find disinteresting at university.'

(TR 3 Edit., lines 41-44)

That such attitudes might relate to mismatch is signalled by a further statement from B, talking about Physical Chemistry:

B: 'I've been used to dealing with graduates now for about the last 35 years and they come to me and they usually have a fair grounding in Physical Chemistry... quite a few of them don't really know why they've done it and they don't usually see the utility of it.'

(my underlining) (TR 2 Edit., lines 104-108)

6.3.8 Reluctance to admit the reversibility of reaction with the possibility of dynamic equilibrium was expressed clearly by F:

I: 'Let's suppose we have a reaction where there is quite a noticeable reaction between the products to reproduce....

F: (interrupting) another product presumably!'

(TR 6 Edit., lines 97-99)
This readiness to move forward on a more linear reaction path was also evident in discussing equilibrium with D:

I: 'Would you think there might be some benefit in describing equilibrium as competitive rates?

D: (long pause) No!

I: Why do you say that?

D: I was thinking of conditions where B and C (the products) might want to react further to give other things, and where things would build up and die down.'

(TR 4 Edit., lines 49-57)

6.3.9 The 'interference' of Mathematics in both remembering and understanding was strongly voiced. Interestingly, the high symbolism used in mathematical learning seemed to aid memory but hinder understanding:

I: 'Why did reaction kinetics come into your enzyme Chemistry then?

F: Well, the Michaelis-Menten equation I think was the standard ...

I: So you see that in terms of an equation then?

F: Yes, very much so.

I: A mathematical equation?

F: Mm - hm! (assent)

I: You don't see it in terms of molecules hooking together, and that sort of thing?

F: Not my initial reaction, no!

(TR 6 Edit., lines 13-22)

And from D:

D: 'We were expected to do an awful lot of differential equations. The concepts didn't really seem to get over very clearly; it was a lot more emphasis on the techniques for solving differential equations.'

(TR 4 Edit., lines 99-102)
It could be argued that memory pays more attention to the worst features of a course! It is difficult, however, to escape the importance, in chemical education terms alone, of one recalled incident. C's professor had offered an SRC grant for research in kinetics. In C's words:

C: '...... the professor sent for me and said, 'Do you want to do research, there's an SRC grant there?' I said, 'No, I just don't like it, it's too mathematical and using machines and things'.

(TR 3 Edit., lines 128-130)

6.4 A new focus.

6.4.1 I suggest that chemical education has developed an epistemological approach to the conceptual areas of kinetics and equilibrium, which separates and isolates them. The grounds for this assertion will be argued in Chapter 8. This epistemological approach does not require the separation and isolation of these two areas of Chemistry, however, and one is left to question why this might have occurred. From the evidence gathered in these IP interviews, the 'epistemological niceties' seem to be given low priority by industrial researchers — or rather, are seen from a different perspective. Practitioners seem to need to think of the focal concepts in two ways, and this psychological ambidexterity appears to be very useful. Where chemical education has restricted this flexibility by concentrating on knowledge, then the practitioners appear to suffer through inappropriate modes of thinking and limiting attitudes. It would seem that these difficulties may be overcome during employment through the efforts of individuals, or possibly through company procedures for re-training.

6.4.2 An acceptance of this description of the state of affairs leads to one important question about the relevance of chemistry courses in higher education vis-a-vis eventual industrial practice and research. Does the pursuit of, and fascination for, intellectual rigour result in our chasing knowledge
whilst ignoring wisdom? (Maxwell 1984). Higher education courses clearly are not solely aimed at industrial practice. However, although considerable attention is given to the development of syllabuses and courses that are relevant to industry as evidenced by various Prospecti (see Chapter 8), could it be that manipulation of content distracts from a more important need - that of developing appropriate thinking strategies?

6.4.3 These ideas were made public at a Research Seminar in the Institute for Educational Development, Surrey University (November 1983). During question time, some very interesting points were raised.

a) The 'traditional' introduction to these chemical concepts in school follows a rather boring historical path, starting with Guldeberg and Waage's Law of Mass Action. University teaching normally deals with the most recent ideas in the area, and hence would not involve the older ideas.

b) The two models (thinking strategies) are probably best viewed as one model of possible strategies.

c) The distinction between content and process which is becoming increasingly important in science education may be manifest in the mathematical difficulties expressed. The exercise of differential equations unrelated to real chemical problems, may lead to the accumulation of more content with little understanding.

d) The two thinking strategies could be part of a sequential development of an increasingly sophisticated understanding of the concept areas, moving from a specific (molecular) to a general (energetic) viewpoint.

e) The qualitative difference between transcripts 2-5 and transcript 6 (where there seemed to be less assurance and confidence) prompted the question as to whether post undergraduate education in research made people more adaptive.
f) Two perspectives could be taken on the thinking strategy models, depending on whether the concepts involved were seen to have utility or interpretative value. It might be that different 'value bases' required different models.

6.4.4 In general terms the response to the seminar was supportive and enthusiastic, generating considerable discussion concerning the demands and needs of industry, and the need for a new dialogue between industry and higher education. This seed, fed by two particular comments from one interviewee, germinated and grew in my mind strongly enough to refocus the purpose of this inquiry. The interviewee's comments were:

a) 'I don't think it (the Chemistry course) helped me as a person to go out to work in any way.'

   (TR 6 lines 629-630)

b) 'The teaching system (school/university) seemed to be geared to passing exams: we learned by rote and forgot as quickly. The exams did not test our ability to apply knowledge or 'intelligence' of the subject, but rather the quality of our memories. What is important in the sort of work I'm doing now is that I can remember enough of the subjects I learned at (----) to be able to tie seemingly unrelated subjects together - to draw parallels and 'think laterally' on new topics. Reading up the forgotten details is easy - what is difficult is judging where and how a scientific principle should be applied to unchartered subjects' ...

The work we do at (----) takes on new dimensions when the scientist not only has to consider the scientific principles involved but the practicalities of the idea, the type of people likely to be using it, the economic feasibility and any environmental or political implications which could arise.'

   (F: correspondence)

6.4.5 The seed grew into the three research questions already defined (2.9)

A. What makes concept learning to be of greatest practical /vocational value?

B. What is required to make chemical education courses of
optimum relevance?
C. Is it possible to characterise educational relevance in chemical education?

6.5 The Research Sample.
6.5.1 The conceptual framework developed from the IP interviews (the model of thinking strategies) together with the information on attitudes towards, and relevance of, chemical higher education could now be used to define the base of the inquiry. It is interesting to reflect that by focussing on specific concepts, a wider issue had been highlighted. This largely resulted from the 'indirect questioning' approach first seen in the trial interview. Further, the IP interviews in a small way had followed a funnel model, in taking five data sources and developing a tentative hypothesis or generalisation (Diagram 11).

DIAGRAM 11: Funnel approach for IP interviews.

This generalisation had been publicly tested. I was now in a position to extend the interview field, inquire more deeply into the literature on educational relevance, and look more carefully at the interrelationship of the chemical concepts involved.

6.5.2 In deciding upon the sample for extending the study, it was clear that choices would have to be made, or as Miles and Huberman (1984) put it:

'empirical research is often a matter of progressively lowering your aspirations ... unless you are willing to
devote most of your professional life to a single study, you have to settle for less.' p 36.

The problem faced consisted of the wide range of applications of the focal concepts in industry, and the range of levels of involvement of the practitioners (from technician to post-graduate researcher, for example). Additionally, an analysis of the concept of relevance (see Chapter 8) indicated that three particular groups should be included - industrial practitioners, educators and students. Clearly random sampling was not suitable. Since qualitative research is largely and essentially investigative (Douglas 1976) it follows that sampling must be basically driven by any conceptual frameworks emerging (Miles and Huberman 1984) from any initial and probably opportunistic sampling (Honigman 1970). In my case, it was evident that further interviewing samples would follow a 'judgmental' pattern, that is necessitating my seeking out particular people who were specialists in the areas indicated.

6.5.3 I suppose it may be argued therefore that there is a built in bias to this study - a point which I accept. However, I would also point out that this has been a deliberate and self-conscious feature, a process fully in accord with the theoretical sampling approach of Glaser and Strauss (1967). It is interesting to note here that at a certain point, the data generated from the extension interviews became for the most part the same - 'theoretical saturation' - which led to a modification in the interview strategy. (This will be explained in 6.6.2). It was clear from the outset that I would not be attempting to analyse my data in any numerical fashion. Thus, there was no pressure to consider my sampling in terms of suitability for statistical significance.

6.6 The EP Interviews.
6.6.1 Using processes similar to those already mentioned (6.1) a further 29 interviews were arranged in the following areas:-
a) chemical industrial practice.
b) chemistry teaching.
c) recent chemistry graduates.

This provided an Extended Phase programme of interviews as shown in Table 9 (see page 88). The areas chosen arose from an analysis of educational relevance (see Chapter 8). It was decided that the chemical industrial perspective could best be observed by including both chemical research and development and chemical engineering. These two areas of practice, broadly speaking, provide a significant proportion of practitioner graduate employment. Three areas within research and development were included (petrochemicals, pharmaceutics, foodstuffs) as areas in which the focal concepts were potentially highly significant. It was obvious that teachers in higher education should be involved. Several teachers in secondary education were also included because it was felt that their perceptions on relevance would also have significance. The student perspective introduced special considerations.

6.6.2 Initial attempts to interview individual recent graduates met with a methodological problem. There was either an understandable reluctance to be open about their higher education courses, or a destructive zeal! It should be remembered that I was identified as a part of the higher education system providing their courses. In an attempt to provide more balanced comment, it was decided to use a group interview technique instead of the one-to-one situation. Three or four students were involved in each interview, partly for ease of transcription (reduction of overtalk), but mainly to ensure that all the students present had an opportunity to air their views. The intention was to use peer-group support both to promote and control comment and interaction. Key questions were devised to provide some structuring, if needed (see Table 12, page 103). This revised strategy proved to be highly effective.
Group interviews: structuring questions (work in rota, if possible).

1. When, where did you graduate?
2. What was the basic structure of your course?
3. How effective was your course in helping understanding of Chemistry?
4. How effective was your course in giving enthusiasm for Chemistry?
5. How was chemical kinetics taught?
6. Did you like chemical kinetics?
7. How was chemical equilibrium taught?
8. Did you like chemical equilibrium?
9. Where did thermodynamics fit in?
10. What was the effect of Mathematics?
11. What attempts were made to link with real problems?
12. What makes Chemistry relevant for you?

TABLE 12: Key questions for group interviews.
6.6.3 The potential range for the research sample of this inquiry is enormous. Within industrial practice alone, one could make a case for the inclusion of a wide range of work roles. I would suggest, however, that in attempting to characterise notions of educational relevance, personal perspectives are more important than role-demand. Further, I believe the same status should be given to the perspectives of those who are not directly involved with the focal concepts, as those who are. I do not think therefore that the extent to which various work-roles are represented in the sample is of major significance. Table 13 (see page 105) outlines the complete research sample.

6.6.4 One limiting factor was encountered, over which I had no control. Economic depression and industrial contraction may have narrowed the age-range from which the sample would be drawn within industry, as very few 'recent graduate' practitioners were available. Table 14 presents an age profile for the total sample (see page 106).

6.6.5 It was thought unlikely that students could judge the effectiveness and relevance of their course as an holistic experience, whilst still studying. Such views would most likely reflect a response to their more immediate situation. Not until after graduation was it thought likely that an holistic view could be obtained. The student perspective is thus defined in the same retrospective manner as those of the practitioners and teachers. It differs from the views of these two groups in that it is not informed by work experience in general terms. For all three groups, perspectives on the focal concepts are personal and largely historical, except perhaps where the concepts were being actively used in practice. For the teachers, particularly those in higher education, there is an element of prospective vision in their perspectives. This results from the need for educationalists to predict the material they teach.
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[ ] trial interview  * IP interviews N=36

TABLE 13: Complete Interview Sample.
TABLE 14: Age profile for total research sample.
These slight variations in the overall perspective held by participants in each of the three groups, are not insignificant. There is some evidence from analysis of the transcripts that these variations are on the cutting edge of any attempt to characterise educational relevance. This point will be taken up more fully in my discussion of a model for concept understanding (Chapter 7) and in an analysis of relevance in education (Chapter 8).

* * *
Chapter Seven

Insights.

In which the outcomes of analysis are discussed, and the basis for a discussion of implications is prepared.

7.1 Categories.
7.2 Thinking strategies revisited
7.3 Perceptions of focal concepts
7.4 Perceptual space model
7.5 Personal understandings
CHAPTER SEVEN.

7. INSIGHTS.

'There is no absolute knowledge. And those who claim it, whether they are scientists or dogmatists, open the door to tragedy. All information is imperfect. We have to treat it with humility.'

Bronowski (1976) p353

* * *

7.1 Categories.

7.1.1 Although not all those interviewed were working directly with the focal concepts they all had some knowledge of them. All were graduates (or equivalent) in either chemistry, bio-chemistry, or chemical engineering. Some had higher degrees in chemistry. As the analysis process progressed (see 5.5.7) certain categories of statement occurred with considerable regularity, others in a more limited way. The reading and re-reading of transcripts and edits showed that the interviewees commented on the same points or issues - not necessarily with totally identical opinions or attitudes, but certainly addressing the same idea, as indicated in Table 7 (p77). The regularity with which these categories occurred is given in Table 15 (p111). Prime examples of statements within each category, together with brief notes on each type, are contained in Appendix 5 (p A5). The categories will not be referred to in detail in the following chapters except where required by the argument being pursued. Several of the categories (A, C, E, K, L, M) required subdivision to encompass quite distinctly different views on the same subject. For example, Category C (relationship between the focal concepts) required two sub-divisions depending on whether participants saw the focal concepts as linked or separate ideas:-

(see overleaf)
7.1 Other regularly occurring categories were either too identical to require division, or too general to allow it (F, N, R, T). These might be seen as more peripheral factors in terms of the focal concepts, but are none-the-less important. In the main, these categories arose from interview comment which was not sponsored directly by the key questions. The weak specificity in some of these responses no doubt resulted either from the lack of focussing, provided by key questions, or from the interpretative context used by the participants in expressing their meaning.

7.1.3 There were several other statements within the interviews which seemed significant, though not repeated with any great regularity within the research sample (i.e. less than four instances). In view of the general picture emerging from the more regular ideas, however, these rather isolated comments could not be ignored. Some of the more significant of these were:

- a) Comments relating to industrialists' views on graduates' employment potential.
- b) Instances of 'learning through interview'.
- c) Descriptions of demands made by specific jobs.
- d) Ideas relating to a spectrum of chemical reactivity.

Some of these points (e.g. comment on graduate employment potential), were seen to be significant, as a result of the
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**TABLE 15**: Frequency of appearance of factors (full research sample).
reflective analytical process adopted. For instance, the example quoted above emerged as an interesting parallel with statements made in reference to the relevance of courses for employment, through the 'opposite pole' technique (in this case employer/employee); see 5·5·7. Diagram 12 (see p.113) shows the number of instances of all the categories.

7·1·4 In reviewing the number of instances of each category, two immediate points were evident; one suspected, the other not. On the one hand, those factors relating to the focal concepts were among those having the greatest number of instances - to be expected in view of the key questions. On the other hand, providing almost as many instances, were those factors relating to higher education, factors not directly relating to key questions. In particular, as 'equal first' with 'views on the relationship between the focal concepts' (C), is the factor embracing comment on 'teaching approaches in undergraduate courses'. Thus, of these categories having the greatest number of instances, two sub-sets could be clearly identified.

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<td>(focal concepts)</td>
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<td>19</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>[L]</td>
<td>[13]</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sub-set 2</th>
<th>Category</th>
<th>No. of instances</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Higher Educ.)</td>
<td>H</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>[L]</td>
<td>[13]</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>T</td>
<td>28</td>
</tr>
</tbody>
</table>

A reference back to Table 7 (p.77) will indicate that sub-set 1 contains those factors relating directly to the focal concepts, whilst sub-set 2 concerns those relating to higher education.
DIAGRAM 12: Number of recorded instances of each category.
A: personal attitudes to equilibrium/kinetics/thermodynamics
C: relations between focal concepts
E: perspective on equilibrium
K: perspective on kinetics
L: influences in learning
M: mathematics related factors

A \{ A_1 \text{ Kinetics/equilibrium/thermodynamics 'liked'} \\
A_2 \text{ Kinetics/equilibrium/thermodynamics 'not liked'} \}

C \{ C_1 \text{ Focal concepts seen as linked} \\
C_2 \text{ Focal concepts seen as separated} \}

E \{ E_1 \text{ Molecular model used} \\
E_2 \text{ Energy model used} \\
E_3 \text{ Dynamic/static equilibrium discussed} \}

K \{ K_1 \text{ Energy equations discussed mathematical model used} \\
K_2 \text{ Rate/order/mechanism seen as main concepts} \\
K_3 \text{ Reversible reactions discussed} \}

L \{ L_1 \text{ Symbols} \\
L_2 \text{ Diagrams} \\
L_3 \text{ Equations} \} \text{ used as 'triggers' for memory or mode of explanation}

M \{ M_1 \text{ Mathematical barriers met in learning focal concepts} \\
M_2 \text{ Positive personal attitude to mathematics} \\
M_3 \text{ Negative personal attitude to mathematics} \}

\textbf{TABLE 16: Sub-factors in analysis.}
Category L (influence on learning) seemed to fit equally well in both sub-sets. (see Diagram 13, p116)

7.1.5 The reader is reminded at this point that the key questions for the interviews were deliberately restricted to a concern with the focal concepts. The fact that considerable comment emerged related to teaching and learning in higher education, and the relevance of courses in higher education is, I suggest, highly significant. This indirectly revealed concern may have been sponsored by the participants' knowledge of my own background (freely given before each interview). None-the-less it forms a concern that clearly needed to be expressed, and its strong appearance is a justification of the indirect question technique mentioned in 5.2.2(b), and is also compatible with the new focus for the whole inquiry adopted after analysis of the IP interviews.

7.1.6 In the discussion immediately following, I intend to concentrate on sub-set 1 (focal concepts). I shall argue that this sub-set provides the basis for a revision of the thinking strategy conceptual framework (see 6.3.1-9), as well as for a model of perceptual space, relating to the focal concepts. In Chapter 8, I shall look more closely at sub-set 2 in support of a model for educational relevance. The less frequently occurring categories forming a 'significant other' (SO) sub-set and identified in 7.1.3 will be used to illuminate these ideas as appropriate.

7.2 Thinking strategies revisited.
7.2.1 Analysis of the IP interviews led to the premise that two thinking strategies were involved in those processes leading to an understanding of the focal concepts. These strategies were manifest in the way participants expressed their understanding. Two distinct models of thinking were suggested (6.3) which were not mutually exclusive, and which I termed Noetic and Pragmatic. During the IP interviews, some participants seem to show clear preference for one or other
DIAGRAM 13: Number of instances for sub-sets 1 and 2.
of these, others seemed able to use both. Where both were involved, a more holistic understanding was present which, in the small IP sample, appeared to improve utility and relevance of the focal concepts; a significant point.

7.2.2 Reading through the sub-set 1 statements, the same two thinking strategies are clearly evident. For example:–

I: --- What does chemical equilibrium mean to you?

K: That you have reactions going in opposite directions; the reaction will proceed until the forward reaction's equal to the opposite reaction, due to the adjustment of the concentrations of the reacting substances.

I: What is going on at equilibrium?

K: Reaction in the forward and the reverse direction are both occurring at the same time.

I: So you're getting back to your competing reactions and competing rates that you mentioned under kinetics?

K: Well, yes, indeed since in fact the kinetics are of fundamental importance in the equilibrium reactions in many cases.

[TR 11: lines 133-148]

Here K is using a molecular/mechanistic approach, seeing equilibrium and kinetics as related areas, and also uses molecular interaction as the basis for his ideas. All this is typically pragmatic. On the other hand:–

I: --- What do you see to be the main ideas involved in that [kinetics]?

Q: I would judge reaction kinetics in terms of catalysts and the behaviour of catalysts to perform the job that they're required to do, and how that varies with temperature and pressure. I suppose if somebody mentioned reaction kinetics I would immediately think of catalysts... and the behaviour of catalysts. But then there's, when I think about it as well, there's also the mathematical modelling of reactions, and being able to model them be they 1st order, 2nd order, 3rd order reactions ... being able to produce mathematical models that you can manipulate in order to understand, or to have a good idea, what's going to happen if you alter, sort of, variables involved.

[TR 17: lines 209-223]
Here Q is mainly concerned with a mathematical mode and manipulation of the total system through parameters such as temperature (energy). This is amplified by a later statement:-

Q: --- thermodynamics will tell you about the equilibrium - it will tell you all about the equilibrium - it will allow you to model a chemical system and tell you what equilibrium will be attained, but it won't tell you anything about the rate that it will happen at, you know.

[TR: lines 365-378, original emphasis]

These two statements from Q embrace the main features of noetic thinking - explanation through thermodynamics, separation of kinetics (rates) and equilibria, and an energetic mode. However, the inference from the IP interviews that those participants viewing kinetics and equilibrium as separate conceptual areas, used a mainly noetic model of thinking (3 of 3), whilst those who saw the focal concepts as linked used mainly a pragmatic model (2 of 3), has not been supported. No particular link between thinking strategy and participants' views of the concepts has been discernable in the EP interviews. What does seem reasonably clear is that two thinking strategies were in use.

7.2.3 I have therefore revised the earlier conceptual framework to form a strategy model comprising two modes of thinking. The intention is to strengthen the relationship between the noetic and pragmatic modes, and to stress their value in an overall process of thinking for understanding (see Diagram 14, p119). The descriptions of each mode are for the moment unchanged from those listed in Table 10 (p90).

7.2.4 The revised model allows the interpolation of interview statements in terms of two closely related 'thinking modes' (Tn - noetic thinking; Tp - pragmatic thinking) rather than through two discrete but compatible strategies. A survey of all the transcripts revealed that these thinking modes were
CONCEPT

<table>
<thead>
<tr>
<th>Thinking Mode</th>
<th>Tn</th>
<th>Tn/Tp</th>
<th>Tp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noetic</td>
<td>6</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Pragmatic</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ZONE

DIAGRAM 14: Revised thinking model.

regularly in use, and sometimes used in combination, as shown in Table 17:

<table>
<thead>
<tr>
<th>Kinetics</th>
<th>Equilibrium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tn</td>
<td>6</td>
</tr>
<tr>
<td>Tn/Tp</td>
<td>7</td>
</tr>
<tr>
<td>Tp</td>
<td>10</td>
</tr>
</tbody>
</table>

TABLE 17: Instances of thinking modes.

Some illustrations of each of these (Tn; Tn/Tp; Tp) are given below:

a) Tn: Kinetics:

L: [describing reaction kinetics] The things that spring to mind are 1st and 2nd order reaction rates and Arrhenius equations --- things are going through my mind, Gibbs free energy functions, Maxwell rules and equations like that, I think.

[TR12 edit; lines 3-6]

Q: --- I suppose if somebody mentioned reaction kinetics I would immediately think of catalysts and the behaviour of catalysts. But then there's, when I think about it as well, there's also the mathematical modelling of reactions and being able to model them be they 1st order, 2nd order, 3rd order reactions, being able to produce
a mathematical model that you can manipulate in order to understand or to have a good idea what's going to happen if you alter, sort of, variables involved.

b) Tn; Equilibrium:-

V: --- you're looking at the total free energy of the starting system, and you're really balancing the two together ---

AA: --- One's talking about the relationships between entropy changes in the particular system you have under investigation and entropy changes in the rest of the universe that go along with them --- the advantage of an entropy orientated approach to equilibrium, it seems, to me, is that it removes the special chemical characteristic. It makes it a more universal phenomenon than simply chemical equilibrium.

c) Tp; Kinetics:-

M: --- Well, you get, sort of, impression of A and B coming together to interact in a - not a permanent sort of way, but orbital overlap and whatever --- / --- two discrete molecules coming together, overcoming whatever repulsive forces and then subsequently marriage of orbitals and electronic systems.

S: --- a way of looking at the interaction between molecules --- bond-breaking and bond-making I suppose are the two --- er, and timing as well --- But also it's the interactions of atoms in their spatial orientation, as it were ---

d) Tp; Equilibrium:-

I: How would you describe chemical equilibrium?

L: Well, the point at which the decomposition or reversion of products into raw components if you like, is equal to the conversion rate from the starting materials to the product.
N: How would I describe it? --- I suppose the degree to which a reaction can be said to be either on one side or the other, the degree to which a series of reactants have been sort of changed to become the products.

[TR 14 edit: lines 110-113]

e) Tn/Tp; Kinetics:--

O: --- I suppose it's possible that if you have two components there could be different ways in which they could react together. Alright, if you just had one compound and it was degrading - sucrose- could it just split in two, or could you just lose odd bits off - and perhaps looking at the rate of reaction might give you an idea as to --- possibly one reaction which could be the more favoured reaction because it needed lower energy actually to implement it.

[TR 15 edit; lines 37-44]

V: I suppose you can say you've got the speed of reaction and you relate that to, $Ae^{-Ea/RT}$ or $KT$, isn't it? So A is a geometry factor made up of parts whatever they are - the chances of a molecule meeting, molecules meeting and the orientation, I think those are the two factors - and then of course you have the activation energy and Boltzmann constant and the temperature ---

[TR 22 edit; lines 11-16]

f) Tn/Tp; Equilibrium:--

Y: --- again I would say, use the idea of two reactions --- going at a specific rate, and that rate being dependent on a rate constant times a concentration and at equilibrium the rate of the forward reaction and the rate of the forward reaction is equal. We can talk about the thermodynamics of equilibrium constants, you can write down, for example, $\Delta G$ for that process ---

[TR 25 edit; lines 218-225]

Z: --- I'm thinking now in terms of, shall we say, two compounds reacting together to give a third, or third and fourth chemical, and the rate of the forward reaction, such that you reach a point where you have a mixture at any one temperature of all four compounds. Now that can be related to anything --- I mean, all of those reactions in which you have the possibility of a forward and a reverse reaction. In other words, we're now going over to thermodynamics. I'm talking about the fact that the activation energy for the forward reaction is comparable with the activation energy of the reverse reaction --- the equilibrium position of course now depends upon the absolute energies of the two starting materials and the end products.

[TR 26 edit; lines 275-289]
This move from discrete thinking strategies to two closely related modes as the conceptual framework for analysis, has revealed other perceptual polarities. The significance here is not so much in the 'poles' themselves, but more in the nature of the relationship linking them. Three perceptual polarities have been identified:

a) a qualitative/quantitative axis, which appeared to strongly correlate to the use of molecular modelling (basically Tp) or mathematical modelling (basically Tn).

b) a macro/micro axis, apparently relating to the use of energetic explanations (basically Tn), or mechanistic explanations (basically Tp).

c) a kinetics/equilibrium axis which has close links with chemical thermodynamics, and which can involve both Tn and Tp modes individually, and a Tn/Tp combination.

Perceptions of the focal concepts.

Before discussing these perceptual polarities further, I want to introduce to my argument the idea of 'fuzzy sets' [Zadeh (1965)]. I believe it is important at this stage to use some mechanism to avoid any assumption that the polar axes elicited have been constructed from discrete, bounded and homogeneous entities. Further, I wish to stress that any model constructed from these polar axes must itself be seen as 'fuzzy' (in the technical sense, that is!) The implication of using 'fuzzy sets' is that the elements making up, say, the set labelled 'molecular modelling', do not have a unitary characteristic function; 'degrees of membership' of the set are allowable. This should in no way be confused with 'vague' interview statements. The paired 'fuzzy sets' on each axis (qualitative/quantitative; macro/micro; kinetics/equilibrium) should thus be seen as diffuse groupings of similar ideas which shade into each other to a greater or lesser extent. Shaw and Gaines (1980) have proposed a similar use for 'fuzzy set' theory in describing personal constructs, and the approach seems to have had some success in modelling human verbal reasoning and concept processing [see Gaines and Kohout (1977)].
The intended depth of this analysis however does not require that the parallel be extended to the use of 'fuzzy reasoning' [Gaines (1976)].

7.3.2 There are many examples scattered through the interview data of the fuzzy (again, in the technical sense) nature of participants' ideas. One of the best of the many examples in which equilibrium was introduced during discussion of Kinetics, is:-

R: Reaction Kinetics. It means – er- it partly relates to the speed at which reactions go, and assuming one is reasonably far away from equilibrium, it means things like ---

[TR 18: lines 152-154, category K]

Another commonly occurring instance was the introduction of thermodynamics, even though this was not being directly questioned. This most frequently occurred in connection with equilibrium, but this particular example relates to Kinetics, and has been chosen in view of the last few words:-

A: --- there are two 'ifs' about a chemical process, the thermodynamic 'if' and the Kinetic 'if' --- either without the other is incomplete.

[TR 1: lines 6-9, category K]

The ability of participants to focus on one conceptual area and introduce another, either for contrast or extension, is I believe, important evidence of meaningful learning. The ability to group ideas which may often be considered in isolation, (perhaps through an apparent need for academic rigour) and in so doing gain wider meaning and application for them, shows an element of creative thinking. It is to avoid any chance of masking such creative value by labelling participants' ideas with constricting straight-jackets, that I wish to view the elicited perceptual polarities with 'fuzzy' eyes!

7.3.3 The qualitative/quantitative polarity was highlighted
by participant V. In talking of Kinetics, V based his first comments on the Arrhenius equation, but later used a mechanistic, molecular explanation. On drawing attention to this difference, the following conversation occurred:–

V: ---- conceptually you'd still think about it in the same way, but you'd probably be going into it simply more deeply, I suppose, and looking at the mathematics of it.

I: So that by using mathematics you feel you are going more deeply into the subject?

V: ---- I don't know, really --- probably not, just in a different way, I suppose. But you're wanting to quantify it and therefore you have to express things in the form of a mathematical equation – if you wish to do that.

I: You're really drawing a distinction there between quantitative and qualitative –

V: (interrupting) I think that's generally so, yes, yes.

This same idea was echoed by participant Y:–

I: You said 'qualitative arguments'; you mean – what do you mean by that?

Y: Well, I mean, there are qualitative approaches to Kinetics which avoid mathematics completely. You just say that, er, as concentration of A goes down, an intermediate B might increase, and then a final product C will appear at a much later time so you can, if you like just draw curves, on – on a – on a board, or a sh – a piece of graph paper, to account for this. I think the organic chemists use even more quantitative approaches where they say we envisage the reaction in the following sequence of steps, and write down a mechanism, and say we think the second step is the rate determining step, and this is what controls the Kinetics, and they would not attempt to model it – in any way [mathematically] (telephone interruption).

These comments also indicate that qualitative approaches do not involve mathematics to any great extent, but do involve the molecular modelling of reaction mechanisms. This point was amplified during discussion with participant AA:
AA: We talk about reaction mechanisms in terms of -- models of what we believe is happening at the atomic level and on the whole one sticks to a particular set of models because that's the way that your thought processes tend to get stuck so the - the organic chemisterm sticks to the set of models which are derived ultimately from valence bond theory and which he manipulates by pushing curly arrows around the place.

One value of such a qualitative approach was described well by participant O, in talking about what makes chemical reactions 'go':

O: I think I probably look at it in a mechanistic - erm - bit of A reacting with a bit of B - breaks off --- to give you ---

I: Why do you see it in that way; and reason particularly?

O: Probably because it's easier to visualise, you can actually draw out what happens, and it's logical, whereas saying 'in here we need a certain energy ---and you can quantify it' --- it's more abstract.

A shortcoming of a qualitative approach was noted by participant H:

H: --- you can't use it for predictions --- you can't go on with a completely unknown reaction, but with energies, you can find the energies of each reaction, you can then go on and predict ---

7.3.5 Mathematical modelling was of importance to participant L, for:

L: --- with a mathematical model of how a reaction proceeds under given conditions of temperature and pressure, a better understanding of the Kinetics of the reaction can enable you to produce a much better product, or control of the system, more safely - or more efficiently.
mathematical modelling, can be placed a perceived need for a 'rigorous treatment' of the concepts involved, and for improved understanding:–

A: --- one then needs to start looking at the various theories such as absolute rate theory and collision theory; in other words trying to some extent to take the thing in the direction of a molecular level, and then to extend that as far as possible into a rather more rigorous quantitative treatment, to try and demonstrate to people what the peculiar factors or properties are which --- [have] some influence on the way in which molecules interact.

[TR 1: lines 159–165
category K]

and:–

X: --- from a mathematical framework you can understand a lot of things which are otherwise difficult to understand --- we've got this new approach which makes maths a little bit soft --- I think it's very useful for those chemistry students who need to know the theory without really understanding why.

[TR 24: lines 342–357
category K]

These comments suggest that the quantitative, mathematical modelling approach must be taken alongside other approaches in attempting to describe perceptions of the focal concepts. That a qualitative molecular approach interfaces with the above was neatly demonstrated by participant E:–

E: I then begin to think about reactants, I suppose, --- what are the products - more than one product likely - lot of pathways - how fast does it go? - how does it occur? - any intermediates involved between the beginning and the end? - how can I study it experimentally? --- how do I quantify it? can I describe the process in some way mathematically ---?

[TR 5: lines 241–247
category K, original emphasis]

7.3.6 The examples given in 7.3.3–7.3.5 are typical of much other comment in the data. It is notable that most of the quotes are from category K; this is, I believe, largely due to the fact that kinetics is particularly open to either a mathematical or molecular explanation. It is also an area
complicated by mathematics, according to many statements in the transcripts (this point will be discussed later; see 10.4.15)
There is however, evidence of a similar perceptual polarity with regard to equilibrium, through discussion of balance of energy or reaction rate (for details see Appendix 3). It is on such cumulative evidence that I postulate the first perceptual polarity involving two fuzzy sets, which may be represented diagrammatically thus:

DIAGRAM 15: Postulate 1.

7.3.7 As part of a discussion on the relative importance of mechanistic versus energetic considerations in describing chemical reactions, participant P drew a neat comparison:

P: Well, let us take an example. If I have a box which is full of metallic chlorides, gaseous for example, and I pop in some oxygen through a little tube. Now there's a sort of goodness, that if I pop in a certain amount of oxygen and mix it all up and wait for an equilibrium to occur, that preferentially some of those metal oxides - maybe two or three separate species - will form oxides, sorry the metal chlorides will form oxides and chlorine, and the oxides are solids. Now, I may be able - if I have titanium chloride and ferrous chloride and antimony chloride, or something which the gas is - I may be able to convince myself that if I only put in a little bit of oxygen, that the oxide will all be iron chloride, because that's what's favoured thermodynamically. But the oxygen comes in, sees this mixture, reacts with what it can hit, and it forms oxides, and they're lost from the match, and it doesn't in fact favour iron oxide, it favours what it first 'sees' - yes? And it's got nothing to do with equilibrium, or - you know - working out a balance of perfection based upon 'I've got this set of species starting, what's going to happen?', as if the whole thing is mixed up instantaneously, reacts instantaneously. It isn't. It's there at a point, and the reaction occurs and the oxygen reacts with what it 'sees' first, not with what the theory says it should react with.

[Tr 16 edit; lines 61-80 category E] original emphasis.
The point being made was a distinction between the micro-process (what happens between individual molecules) and the macro-process (what one expects to happen on the basis of bulk properties). P insists that a reaction need not behave microscopically, in concert with macroscopic expectation. Further, the macroscopic expectation is, apparently, largely based on energetic (thermodynamic) considerations. The micro-system is not necessarily congruent with the macro-system.

7.3.8 Other evidence exists in the data to show that either a mechanistic or an energetic interpretation may be used for the same phenomenon. For example, in questioning perceptions of equilibrium:

I: What does equilibrium mean to you?

K: That you have reactions going in opposite directions, the reaction will proceed until the forward reaction is equal to the opposing reaction due to the adjustment of the concentrations of the reacting substances.

[TR 11: lines 134-138 category E]

This mechanistic explanation (forward and backward reactions) is in contrast with the following energetic approach:

Q: ---- if we have species A plus B going to species C plus D, and then an equilibrium is set up between the tendency for A plus B to go to C plus D ---

I: --- What do you mean by 'the tendency'?

Q: The potential to go.

I: Chemical potential?

Q: Yes, chemical potential.

I: That's an energetic approach, isn't it?

Q: Yes, I would view it in terms of energy.

[TR 17: lines 333-344 category E]

7.3.9 An implicit distinction between a mechanistic, micro-
scale view and an energetic macro-scale view was given by participant U when discussing Kinetics:--

U: ---- If you have compound A sitting here, and compound B sitting here, if you mix the two together and a reaction occurs, then what you're doing is converting a system from higher to lower energy, presumably, because the tendency is for systems to 'roll downhill' in terms of energy and in energy levels.

[TR 21: lines 182-187 category K]

This same idea was rather more explicitly voiced by participant E:--

E: --- there's a case for putting thermodynamics separately because that rises above mechanism --- the fact that it's made of atoms doesn't matter as far as thermodynamics goes, so thermodynamics rises above it all.

[Tr 5 edit; lines 81-83 category K]

The most effective statement concerning a polarity between micro- and macro-effects was given by participant AA, also whilst talking about Kinetics:--

I: Well, you are a chemist, and if I say 'tell me what reaction Kinetics is all about' - w - what are we talking about?

AA: We're talking about two, erm two different views of the world, we're talking about a view of the world, erm, which is on the macroscopic scale, which is what happens when you take substances and, er, cause them to react - er - and by whatever appropriate means you investigate how changes in erm such initial properties as, as concentrations, your solutions or pressures of your gases or whatever it might be influence the observable behaviour of the reaction. And then you have a totally separate world - erm - a world of the imagination on the microscopic molecular level in which you envisage molecules reacting with each other and you construct various theories to explain how the model that, that you are operating, would be interpreted in terms of the bulk behaviours of matter. And finally you try and link those together. You try to relate the observable behaviour of the bulk properties of matter to the mechanistic behaviour of your molecules reacting under whichever particular model be it a - erm - a billiard ball collision - erm - transition state theory model or whatever, erm, that you have constructed to relate the macroscopic to the microscopic.

[TR 27: lines 338-357 category K] original emphasis.
7.3.10 The 'two worlds' that AA presents are offered in terms of a difference between 'reality' and 'imagination' - the observed and the theoretical. To some extent I accept the link between macro-effects and observables, micro-effects and theoretical models. However, as has already been encountered (7.3.4, p124) molecular modelling is for some chemists far more 'realistic' than mathematical modelling (treatments of observables). It is not my intention here to discuss the question of 'realism', and whether mathematical modelling is any more or less 'real' than molecular modelling, as it would appear to be the case for the interviewees. It is an interesting thought, however, that neither is closer to 'reality' than empirical observation allows. I believe that the statements within the data show that macro-effects are related most closely to energy considerations (thermodynamics), whilst micro-effects are manifest mainly in mechanistic explanations. I therefore postulate a second perceptual polarity, involving two fuzzy sets, and which might be represented thus:

![Diagram](diagram.png)

**Diagram 16: Postulate 2.**

7.3.11 Reference to 'energy' in chemical reactions was frequent in the data, in a series of contexts ranging from various forms of molecular energy (Kinetic, activation etc.), through to the overarching concepts of thermodynamics. Despite the fact that none of the key questions used at interview directly addressed thermodynamics, a significant number of participants [14 out of 36, or 38.9%] introduced it. In nearly all these
cases, thermodynamics was seen to be very closely related to equilibria, and almost remote from Kinetics. For example, participant S, when talking about equilibrium, said:

S: --- you're looking at the relationship between thermodynamic processes and kinetic processes which is very important; in equilibrium you're concentrating on the thermodynamics and what is feasible ---

[TR 19 edit; lines 46-49 category C]

and participant U said:

U: --- I suppose you end up with the fact that if you have an equilibrium process, you have a mixture of units which are in thermodynamic balance ---

[Tr 21 edit; lines 58-60 category E]

and:

U: Well, I suppose we use thermodynamics to describe energetic processes and - therefore to understand equilibrium.

I: But not to understand -

U: (interrupting) Kinetics, no!

[Tr 21 edit; lines 104-106 category C]

Participant E also showed this same distinction between thermodynamics and kinetics, whilst relating it closely to equilibria, in the passage already quoted in 6·3·2.

7·3·12 Others were more cautious about such a clear distinction, as instanced by participant I (in this case, 'I' not referring to 'interviewer'):

I: --- once I've said yes to thermodynamics --- it has an influence on it, but I wouldn't say it was a fundamental factor with respect to equilibrium.

[Tr 10 edit; lines 142-143 category E]
This cautionary note was echoed by participant P:-

P: ---although I am sure one could apply the principles of equilibrium thermodynamically to it [a chemical reaction], in practice you have to be very careful --- you can make some awful mistakes of great simplicity by not recognising the mechanism of loss of material from the 'match' ---

[TR 16 edit; lines 51-58 category E]

Several participants made clear how they saw the relationship between equilibrium, kinetics and thermodynamics. For example:-

Y: --- if you have a reaction which, er, goes to equilibrium, then the position of that equilibrium is controlled by the thermodynamic argument --- however the rate at which those products are obtained is determined by kinetic arguments so, er, kinetics and thermodynamics really are two sides of the same coin.

[TR 25: lines 124-131 category C]

and:-

AA: --- so the position of equilibrium depends on the free energy difference between the starting materials and the end products, but the rate at which it is attained - and that's going back now to kinetics - is the activation energy --- so, that is now tying kinetics up with thermodynamics to bring me into equilibrium reactions.

[TR 27: lines 291-299 category C, original emphasis]

Only one participant indicated any really strong and direct link between kinetics and equilibrium:-

K: Well, yes indeed, since in fact the kinetics are of fundamental importance in the equilibrium reactions in many cases.

[Tr 11 edit; lines 33-34]

7·3·13 The major impression gained from reading these transcripts and edits, is that kinetics and thermodynamics form two separate areas of study, with equilibrium being subsumed by thermodynamics. It is not my intention here to enter into a Gagne-style concept hierarchy analysis [see Gagne (1977) since I am dealing with perceptions of the concepts
more than epistemology. That such perceptions might well be termed personal epistemologies, is a point to which I shall return in 7.4.1. What is my intention is to suggest that the evidence within the data shows a polarisation between kinetics and thermodynamics (to include equilibrium). It is on this basis that I wish to bring into my arguments a third postulate, a perceptual polarity relating to the focal concepts themselves. Since my key questions have only addressed 'equilibrium' I shall continue to use that term, in polarity with kinetics (again as fuzzy sets). Diagramatically, this can be expressed as:-

\[ \text{Kinetics} \rightleftharpoons \text{Equilibrium} \]

**DIAGRAM 17: Postulate 3.**

7.4 Perceptual space model.

7.4.1 The adoption of fuzzy set notions for the three pairs of characteristics elicited from the data, implies the possibility of varying degrees of overlap between the individual sets in a pair, and between pairs. The use of strongly bounded poles would not only limit such overlap, but would also not reflect the varying perceptions encountered in the data. I suggest that strongly defined poles would reflect an autocratic epistemology relating to the focal concepts. This may well be the case for 'academic science', the 'received version' of chemical knowledge. In this study however, I am dealing with personal epistemologies, or as I would prefer, personal perceptions (I am not certain that many, if any, of the research participants had rationalised their ideas sufficiently to warrant the term personal epistemology). Personal perceptions, by definition, must be to some degree idiosyncratic. Only
when there is an element of congruence in people's thinking, can one claim that their ideas 'overlap'. The three postulated perceptual polarities represent, I suggest, a degree of congruence associated with the participants' thinking about particular characteristics of the focal concepts.

7.4.2 These perceptual polarities may be seen as three dimensions relating to the focal concepts - the dimensions of size (macro-micro systems), of numeration (qualitative - quantitative approaches) and of conceptualization (kinetics - equilibrium). This multi-dimensional quality of the focal concepts may be represented diagramatically (Diagram 18):

**Diagram 18: Focal concept dimensions.**
The choice of orthogonal axes in relating the three postulated polarities derives from the use of fuzzy sets. Each of the six of the identified fuzzy sets can conceivably shade into any of the other five, irrespective of pairing, to some degree. The most effective way of representing this would be as an octahedral arrangement of the fuzzy sets, and this demands orthogonal axial directions (Diagram 19):-

DIAGRAM 19: Inter-relationship of fuzzy sets.
The choice of spheres to represent each fuzzy set is totally arbitrary, and a matter of pictorial convenience. I think it would be wrong to assume these fuzzy sets had any particular, regular or even static basic 'shape', either for individuals or for groups, though on the evidence of the research data it is possible to suggest a localised centre for each group of ideas.

7.4.3 Such an octahedral arrangement may now be seen as occupying a perceptual space based on the three postulated dimensions. This can be approximated to a volume whose dimensions will depend on the size and shape of the fuzzy sets. Without further information or evidence of these sizes and shapes, I intend to generalise this situation and suggest that the perceptual space is notionally seen to be a sphere of radius sufficient to enclose the octahedron of fuzzy sets (Diagram 20). This generalised perceptual space model will, for individuals, be context-dependent - an issue discussed in 7.5.3 (et seq).

Diagram 20: Generalised perceptual space model.
The perceptual space model generated in this way is an abstraction from the perceptions recorded through interview. To see how this relates to individual's perceptions, it is interesting to speculate how individual's notions may 'occupy' the perceptual volume.

7.5 Personal understandings.
7.5.1 At this point I wish to return to the thinking modes described in 7.2.3. The characteristics of the Tn and Tp thinking modes were given in outline in Table 10, p 90, and are repeated here for clarity:

<table>
<thead>
<tr>
<th>Tn</th>
<th>Tp</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Kinetics and equilibria seen as separate, almost isolated areas.</td>
<td>2. Kinetics and equilibria seen to be fundamentally related areas.</td>
</tr>
<tr>
<td>3. Energetic/mathematical mode.</td>
<td>3. Molecular/mechanistic mode.</td>
</tr>
<tr>
<td>4. Intellectual elegance rated highly.</td>
<td>4. Practical application rated highly.</td>
</tr>
</tbody>
</table>

Whilst these descriptions reflect the evidence in the data, they do not allow an easy correlation with the perceptual space model. The characteristics of both Tn and Tp may be restated, however, to accommodate a more 'fuzzy' characteristic, whilst remaining within the conceptual framework.

(see next page)
7.5.2 Such a restatement, which I believe is still justified in terms of the data, indicates points of contact with two of the perceptual polarities. The Tn mode shows congruence with the quantitative (mathematical modelling) and macro-system (energetic explanations) fuzzy poles. The Tp mode shows congruence with the qualitative (molecular modelling) and micro-systems (mechanistic explanations) fuzzy poles. It is possible therefore to suggest that each thinking mode is focussed on a different part of the perceptual space. This can be represented diagrammatically as in Diagram 21 (p139) though it should be stressed that the planar interface between the Tn and Tp volumes is a matter solely of diagrammatic convenience. In adopting the fuzzy set principle, this interface should more properly be seen as a gradual change from Tn to Tp, or even a zone of 'co-existence' - and it will be remembered that some

<table>
<thead>
<tr>
<th>Tn</th>
<th>Tp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noetic thinking</td>
<td>Pragmatic thinking</td>
</tr>
<tr>
<td>Concentration on quantitative aspects</td>
<td>Concentration on qualitative aspects</td>
</tr>
<tr>
<td>Move away from molecular/pictorial thinking</td>
<td>development of molecular/pictorial thinking</td>
</tr>
<tr>
<td>Mathematical algorithms</td>
<td>Basis for a better understanding of methods of quantification and their value for, and extension to, macro-systems.</td>
</tr>
<tr>
<td>Precise description involving thermodynamic explanations, of macro-systems, providing high quality computational ability, and high predictive capability.</td>
<td>Mechanistic explanations of molecular behaviour which can be predictive in qualitative terms at a micro-level.</td>
</tr>
</tbody>
</table>
evidence exists for such a complementary situation.

7.5.3 Using the speculative scenario developed in Diagram 21 it is possible to predict that an individual who solely uses Tn thinking would have a perception of the focal concepts which was developed from a macro-system (energetic explanations) and quantitative (mathematical modelling) approach, with little emphasis being given to mechanistic explanations and molecular
modelling. Conversely, an individual solely using Tp thinking would emphasise mechanistic explanations and molecular modelling at the expense of energetic explanations and mathematical modelling. In this theoretical situation it is being taken that both the focal concepts are being perceived with the same thinking mode. Put another way, the 'plane' separating Tn and Tp in Diagram 21 is vertical, and inclusive of the kinetic/equilibrium axis. If such a situation was evident among the research sample, then the assumptions being made here - namely, that the thinking mode used:

a) provides occupancy of perceptual space

and b) provides occupancy of a restricted volume of perceptual space

may receive credibility.

7.5.4 A review of the thinking modes used by all the research participants, for each of the focal concepts, revealed that two (A, Q) used Tn almost exclusively for both kinetics and equilibrium, whilst four (I, K, M, P) used Tp almost exclusively with both the concepts. The sort of statements made by A for example, were 'I would want to develop some quantitative expression which related rate to factors such as concentration...' (kinetics), and 'equilibrium studies tend to be engendered by thermodynamics' [TR 1 edit; lines 30 and 69] - both Tn generated statements. Participant M used Tp generated statements such as 'well, it's A plus B reacting to give C' (kinetics) and 'I visualise that as being essentially the same, I mean all reactions are in principle reversible' (equilibrium). It would be wrong to give the impression that participants A and Q only used Tn, whilst participants I, K, M, P only used Tp. The fuzzy set characteristics of their perceptions were apparent in 'lapses' into the alternative mode or a combination of both. However, their prime perceptual characteristics fitted reasonably well with the speculative scenario represented in Diagram 21.
Other scenarios are also feasible, depending on where the interface between Tn and Tp falls within perceptual space, or even whether an interface exists at all. Diagram 22 provides further scenarios in diagrammatic form:

**Diagram 22: Occupancy Scenarios**
A further review of the thinking modes used by the participants revealed that five (D, E, S, T, X) exhibited perceptions which could be described by Diagram 22(a), one (L) by diagram 22(b), whilst none fitted 22(c). Other situations did exist, however; for example:-

<table>
<thead>
<tr>
<th>Participant</th>
<th>Kinetics</th>
<th>Equilibrium</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Tn/Tp</td>
<td>Tp</td>
</tr>
<tr>
<td>N</td>
<td>Tn/Tp</td>
<td>Tp</td>
</tr>
<tr>
<td>O</td>
<td>Tn/Tp</td>
<td>Tp</td>
</tr>
<tr>
<td>R</td>
<td>Tn/Tp</td>
<td>Tp</td>
</tr>
<tr>
<td>V</td>
<td>Tn/Tp</td>
<td>Tn</td>
</tr>
<tr>
<td>AA</td>
<td>Tn/Tp</td>
<td>Tn</td>
</tr>
<tr>
<td>F</td>
<td>Tn</td>
<td>Tn/Tp</td>
</tr>
<tr>
<td>J</td>
<td>Tn</td>
<td>Tn/Tp</td>
</tr>
<tr>
<td>Y</td>
<td>Tn</td>
<td>Tn/Tp</td>
</tr>
<tr>
<td>Z</td>
<td>Tp</td>
<td>Tp/Tn</td>
</tr>
</tbody>
</table>

In such cases, the diagrammatical representation would require a non-planar interface; for example, for participant B:-

**DIAGRAM 23: Conceptual space with non-planar interface.**
It would be far too simplistic to accept these diagrammatic representations as 'maps' of each individual's perceptions of the focal concepts. Apart from the fact that a far larger research sample would be required to provide significant numbers within each scenario, before more than tentative insights can be drawn, the nature of the scenarios themselves must be considered. It cannot be wise to attempt rigorous definitions from 'fuzzy' models. The purpose of sketching out these scenarios, and attempting to link them with the way participants have represented their perceptions, is pictorial, not definitive. In this sense, the scenarios are illustrative of any argument that the thinking mode used provides occupancy of perceptual space; the extent of occupancy equates broadly with an individual's understanding of the focal concepts. In an ideal situation, an individual would 'fill' the whole perceptual space with both thinking modes. In cases where partial, perhaps fragmented occupancy occurs, understanding is partial and fragmented. Assuming that my argument is accepted, the questions arise as to why only partial occupancy occurs, what effect this has, and what may be done to improve the quality of occupancy.

Within the data, there are clues as to why partial occupancy occurs, leading to partial understanding. Further, various comments indicate what effect this may have for the individual. Both these points will be discussed more fully in Chapter 10. It may not have escaped the reader's attention that so far no comment from the 'student' group of participants has been included. This has been largely due to poor quality of the ideas expressed concerning the focal concepts. It is my belief that this is a result of poor 'occupancy factors', and the following rather longer extract, is a good example of this. Three postgraduate chemists on a Postgraduate Certificate in Education course are talking:

I: ... what do really think are the main ideas that are - concepts if you like - that are within reaction kinetics, and what does the
chemist use reaction kinetics for?

W1: (inaudible).

I: This is an open question so you can negotiate the ideas between yourselves if you like - I don't mind.

W3: Determining the speed of a reaction.

W2: Yes. (inaudible).

W3: That's right.

W2: How you can alter the rate of reaction.


W2: And like in the food industry and things like this - yes.

I: So reaction pathways.

W3: Mm!

W2: The slow - the slow - well I suppose (inaudible)

W3: - and the most economical - pathway.

I: Anything to add to that (to W1)?

W1: No - I agree with most of that (laughter) - very diplomatic!

I: Previously, you've all mentioned mechanisms - is that important?

W2: You've got to look at the mechanisms before you can, sort of, work out --

I: The pathways?

W2: Yes - and then how you're going to affect them - how you're going to slow them down or - speed them up.

I: Do you get involved in catalysis to any great extent?

W2: (pause) Could do!

I: You - it doesn't ring bells? That-is it where you came into contact with things like catalysis?

W1: Well, came - yes - came into contact with it -

W2: Yes.

W1: - in kinetics in catalysis. Very important in biochemistry
obviously - erm -

I: O.K. Well let's switch from that and ask the same thing with regard to chemical equilibrium - what would you say is the main concept behind - or the concepts involved in that, and what's the main value of it to the chemist? (long pause)

W1: Uh hm!

W3: Yes!

(further pause)

W3: See, you don't tend to think about these things when you're in your degree course!

I: Why not?

W1: Well - it's the way it's put over. No - equilibrium, I think my main concept is the - erm - having the knowledge to actually predict you know what would actually happen, whether a reaction is likely to occur and so on - and - in what direction it will proceed - that's part of it anyway! Er -

W3: Where you attain equilibrium.

I: What is equilibrium?

W3: It's sort of ions in equal concentration with a solution or a solid (laughter).

W2: You can see we haven't done much in chemical equilibrium! It's not as -

W3: It hasn't stuck!

W2: - I can remember kinetics - not very well, but - I could talk more, much more about kinetics say than I could about equilibrium.

Whilst the extract speaks for itself, to be fair to participants W1, W2 and W3, the rest of the interview was much more articulate, and contained much useful information on other points. At this juncture however, to compare the articulation of higher education teachers, and industrial practitioners (whose comments have formed the basis of the arguments in this chapter) with that of recent graduates, may well be very significant. I believe this has much to do with the long-standing schism of
theory and practice in education, a matter discussed in 8.4.4. It also relates to consideration of the third question arising from the perceptual space model, 'what may be done to improve the quality of occupancy?' - (or put another way, how does a 'student' become a 'practitioner' in terms of coherence of understanding?) - undertaken in Chapter 10.
Chapter Eight

Relevance in education.

In which the concept of relevance is discussed, and applied to the special case of chemical education.

8.1 Mismatch?
8.2 The nature of the problem
8.3 A triadic model of relevance
8.4 Decision environments
8.5 Relevance limits
CHAPTER EIGHT.

8. RELEVANCE IN CHEMICAL EDUCATION.

'The world is not a fixed, solid array of objects, out there, for it cannot fully be separated from our perception of it. It shifts under our gaze it interacts with us, and the knowledge that it yields has to be interpreted by us. There is no way of exchanging information that does not demand an act of judgement.'

Bronowski (1976) p364

8.1 Mismatch?

8.1.1 As described in 7.1.4, two major sub-sets of statement categories were discernable in the data from analysis. Subset 2 indicated considerable concern with the effectiveness of chemical education courses in higher education, and 19 out of the 24 transcripts which had clear statements in this area, contained pejorative comment (ie.79.0%). Effectiveness, of course, is a matter of judgement and thus highly subjective. However, many of the comments contained within those 24 transcripts addressed very similar criticisms; these were grouped in two main areas:

a) a lack of relationship between chemical knowledge presented in physical chemistry courses and how that knowledge is applied in practice.

b) teaching methods.

A comment exemplifying both the above, and which is typical of many, comes from participant Q. Whilst clearly enjoying a little hyperbole, Q makes the points clearly:--

Q: --- the overall feeling that I got from university courses was that there was the chemistry department - very much, erm, theoretical to an excessive point --- what would happen is, you used to go into the lectures and there used to be about, I don't know, 100 people in
the lecture and the guy would get out his chalk and then he would produce these equations and these differentials of equations --- then there was the inorganic chemistry lectures as well, which again was, erm, if you learned you know like the periodic table --- like organic chemistry, if you learned the behaviour of these particular groups of alcohols and ketones etcetera, then you would pass the exam. --- you know you used to be really impressed by the guy that could come out and produce these thousands of equations on the board, but what use they were - in fact I never realised until I started working!

[Tr 17: lines 111-145]

There is some indication here of an element of mismatch along a 'knowledge acquisition - knowledge utilization' dimension. It is this polarity that will form the basis of discussion in this chapter. The questions of teaching methods will be dealt with later (Chapter 10).

8.1.2 In contrast with claims of 'irrelevance' made during interview, is the image projected by course Prospecti.
For example:-

'Chemistry has been rightly called the 'central science', and it prepares you for a variety of careers in industry ---'[B.Sc. Chem. Hons.].

University of East Anglia, 1984/85 Prospectus p20.

The university offers a B.Sc. in Applied Chemistry which is 'bolstered by the addition of matter especially relevant to anyone whose career is likely to be on the manufacturing side of chemical industry.'

University of Kent, 1984/85 Prospectus p C18.

The B.Sc.[Chem. Hons.] course '--- provides a balanced and critical appreciation of theory and practice --- together with instruction in the principles of chemical technology --- [and includes a study of] chemical operations on an industrial scale.'

Bradford University, 1984/85 Prospectus p 91.

The B.Sc.[Chem. Technology] '--- is of particular use to those seeking employment in the various areas of chemical manufacturing industry as opposed to purely scientific or academic research.'

Brighton Polytechnic, 1984/85 Prospectus p 102.
8·1·3 These examples were culled from a selection of 15 University and Polytechnic Prospecti, chosen at random, and are generally representative of the sentiments expressed in all. Whilst being cautious about the extent to which one may read inferences into publicity statements, I feel confident in suggesting that:

a) many chemistry courses in higher education have as one major aim, a vocational utility.

b) such statements raise expectations in the minds of potential undergraduates concerning that vocational utility.

Despite the caution offered above, I believe there is also a 'second level' of inference that can be drawn from such prospectus statements. I find it interesting to note, for example, that Bradford University B.Sc. courses offered a 'balanced and critical appreciation of theory' but only 'instruction' in chemical technology. Could this be a value judgement on the relative merits of theory and practice? Further, the University of Kent suggest that the 'addition of matter' (whatever that may mean) to their courses renders them 'especialiy relevant' (my emphasis). It could be argued that behind these statements lies a world of academic control of knowledge which by simple processing ('instruction', or 'addition of matter') produces vocational relevance. In view of the transcript evidence, it would seem that either my inference concerning 'simple processing' is non-substantive, or the vocational relevance achieved does not match the expectations raised, a point to which I shall return (Chapter 9).

8·2 The nature of the problem.

8·2·1 What is educational relevance? Why is one thing more relevant than another in an educational process? According to the Oxford Dictionary of Etymology (1966), the word 'relevant' is probably of legal origin, and was not in common use in England before 1800. In derivation, it seems to stem from the mediaeval word 'relevans', related to the Latin verb 'relevare'
(to lighten, or relieve, involving the notion of helping) [Chambers Twentieth Century Dictionary (1983)]. Websters Third International Dictionary (1961) suggests that a thing is relevant when it has a connection, especially a logical connection, with a matter under consideration. A commonly recurring dictionary definition of relevance would read something like:-

Relevance: the fact of being related to the matter in hand. Roget's Thesaurus (1980)

This seems much like commonsense, but is not a particularly helpful definition for educational purposes. We need to know more than the definition gives. For example:-

* What is being related to the matter in hand?
* What is the matter in hand?
* In whose hands is it?
* Why is it being related?
* What is the nature of the relationship?

Relevance, therefore, at this general level is a multi-faceted factor, and its application to the field of education therefore requires further inspection.

8·2·2 Peddiwell (1939) in his satirical observations on 'the curriculum', raised questions concerning the relevance of education to societal needs. In his book 'The Saber-tooth Curriculum', he portrays the problems associated with the conservative teaching of skills which were rapidly becoming irrelevant as the conditions for the survival of the community changed. Such a picture of education losing touch with the needs of society is perhaps of even greater cautionary significance in today's fast changing world. However, it is only part of the picture since his tale involves the relevance of education. We must also consider relevance in education.

8·2·3 In discussing relevance - 'that thumb-worn symbol in the modern debate about the relation of education to man and
society' - Jerome Bruner (1974) notes two meanings of the word:

'The first is that what is taught should have some bearing on the grievous problems facing the world, the solutions of which may affect our survival as a species. This is social relevance. Then there is personal relevance. What is taught should be self-rewarding by some existential criteria of being 'real' or 'exciting' or 'meaningful'. The two kinds of relevance are not necessarily the same, alas.'

Bruner's identification of social and personal relevance form linked aspects of relevance for education. Social relevance relates to the relevance of education, personal relevance relates to relevance in education. This conjunction is expressed clearly by Bruner thus:

'Relevance in either of its senses depends upon what you know that permits you to move towards goals you care about. It is this kind of 'means-ends' knowledge that brings into single focus the two kinds of relevance, personal and social. It is then that we bring knowledge and conviction together ---'

One problem with such an analysis of the use of 'relevance' in an educational context is that it remains a broad generalisation. The relevance of education (relevant education) can embrace some wide-ranging alternatives. Withey (1975) has expressed this clearly:

'To some it [relevant education] will be the long-sought-after formula by which 'equality of opportunity' can be made meaningful, namely to provide for each student a programme that is relevant to him. To the 'child-centred' educationist and the progressive the principle of making classroom activities relevant to the child will be highly congenial. Parents, with their feet on the ground and their eyes on their child's employment prospects, or concerned perhaps at his apparent ineducability, might feel that if only the schooling could be more relevant to the child all might after all be well. Politicians, administrators, and economists may feel more assured if the educational programme offered in the nation's schools can be described as being relevant because this has a ring of practicality about it, and seems a better return for one's vote and one's money.'
However, a great benefit of Bruner's assessment is the notion of bringing 'knowledge and commitment together to produce something that is ' 'real' or 'exciting' or 'meaningful' '. The relevance of education, by implication, involves the learner who should see some relevance in education. In this way the learner, through personal commitment to acceptable educational goals can produce learning which is qualitatively different from skill and knowledge acquisition alone. The tapping of internal motivation can result in an 'affective commitment' which is well expressed in the words of the eminent physicist Isidore Rabi, quoted in Bernstein (1979):

'We don't teach our students enough of the intellectual content of experiments - their novelty and their capacity for opening new fields. If you follow a theorist, you come in and say, 'Now what shall I do?' and then you do it, and come back and say, 'What have I done?' I don't know why people work that way. My own view is that you take these things personally. You do an experiment because your own philosophy makes you want to know the result. It's too hard, and life is too short, to spend your time doing something because someone else has said it's important. You must feel the thing yourself - feel that it will change your outlook and your way of life. You must bring it back to the human condition, the human expression - much closer to what the artist is supposed to feel.'

p 87

8·2·5 Withey (1975) looked at the usage of the word relevance in his attempt to analyse its value in an educational context. He isolated two qualitatively different uses. On the one hand, we have the case where A is clearly pertinent to B; a direct, obvious and logical relationship which is readily accepted without argument. This use, which he terms 'propositional', when extended to education, generally relates to content or organisation (or both). On the other hand, we have a usage of 'relevance' in which it is possible to argue for or against the suitability or acceptability of A in relation to B. Withey calls this the 'evaluative relevance'. The implication of evaluative relevance is that criteria for judgement must be required, and hence justifications are involved. I believe this forms the basis of a clear distinction between relevant
education, which largely involves propositional usage, and educational relevance which primarily involves evaluative usage. There is a parallel here to be drawn with educational aims and objectives. We may consider the aims of an educational process as being obvious and uncontroversial. The objectives of courses within that process will define strategies and tactics for achieving those aims, and this is a far more controversial matter. In similar vein, chemical education in the modern industrial/technological age may be seen as relevant education; whether the processes of such chemical education have any educational relevance may well be a qualitatively different argument.

8.2.6 Withey's ideas are, to my mind, much more useful in attempting to understand relevance in an educational context, particularly in terms of relevant education and educational relevance. It may be taken as almost axiomatic, for example, that a knowledge of oxygen is required when trying to understand combustion, an instance of propositional relevance. We might, however, consider whether a knowledge of the electronic configuration of oxygen is necessary for an understanding of combustion. Presumably one criterion involved in deciding upon the suitability of introducing electron configurations would be the level of understanding deemed necessary. Evaluative relevance is thus embedded in a 'decision environment', which will itself be dependent on the various values, assumptions and justifications held by those who have to make such decisions. Personal and group perspectives will therefore be highly significant in determining what is educationally relevant. Also decision making skills become important, a point to which I will return in Chapter 10.

8.2.7 Where propositional relevance is involved, it would seem likely that differences between individual's or group's 'decision environments' are minimal, or to put it another way, there will be high congruence between perspectives. The notion
of relevance thus becomes (apparently) unproblematic:

'The question of relevance (restricted to a limited sociological relevance - that is, what is particularly useful and important to an individual in our society now) is somewhat easier to resolve.---

One of the main effects of considering relevance as a criterion for selecting for the curriculum will be for schools to avoid treating knowledge in an entirely abstract and theoretical way, but to relate it to the real everyday world.'

Lawson (1973) p 155

Here, there is an assumed propositional characteristic in the relevance discussed. A similar usage permeates much of the literature relating to chemical education. [see, for example, Bishop (1977), Kolb and Taylor (1980), Haensel (1982)].

8.2.8 Evaluative relevance, however, is somewhat more problematic, as Knamiller (1984) has pointed out. In discussing the problems associated with attempts to make science education relevant in developing countries, Knamiller talks of the 'relevance dilemma' in which relevant education means different things to different people. A particular approach to organising and operating science education may be seen by the 'outside observer' as a direct assault on poverty and unemployment. To the 'inside consumer' it may be taken as the only available means of improving personal living standards. These two views need not be compatible, and can even be mutually counter-productive. A student rush to get on the 'science band-wagon' could lead to economic difficulties within the educational system and poor quality output, with neither the 'outside observer' nor the 'inside consumer' having their expectations met. This draws attention to the need to understand the views and expectations of those who are involved in a relevant education process, in order that educational relevance may be explicit. Without such explicit understanding there is a real danger that one view (from perhaps one group) may predominate, and produce pseudo-relevance [Mayhew and Ford (1971)].
example:

'students are willing to put up with considerable drudgery and not a little nonsense in science classes because scientists have convinced them that drudgery and nonsense are necessary for something the students ultimately want.'

p 167

8.2.8 This general sentiment was echoed in the interview data as exemplified by participant L:

L: --- at university your head is absolutely swimming with equations --- how to invent a matrix, and all sorts of daft things like that help you pass exams. And I say, 'all sorts of daft' advisedly, in that the exams are, well -- even now, the best method you've got of testing what somebody knows --- but the difficulty of passing exams has got no relation to the actual difficulty of doing a job in industry. Obviously you need to pass the exams, but the relevance shifts quite significantly after that certain date.

Pseudo-relevance may easily be confused with propositional relevance in highly authoritarian situations, such as examination dominated courses. The 'true' relevance may thus be revealed at a later time.

8.2.9 Whilst deliberately avoiding a deep philosophical discussion of the meaning of relevance, since that, in my view, would not be germane to the purpose of this inquiry, I have tried to argue that:--

a) there is a distinction to be drawn between relevant education and educational relevance. The former is often grounded in a propositional form of relevance that is largely uncontroversial through social convention, tradition or belief. The latter involves an evaluative form of relevance that requires decisions by groups or individuals, based on various assumptions values and justifications.

b) evaluative relevance should require explicit statements
concerning the nature of that relevance, so that discrepancies between differing perspectives can be accommodated. Otherwise situations such as 'relevance dilemma', and 'pseudo-relevance' can introduce disharmony.

8·3 A triadic model of educational relevance.

8·3·1 I would suggest that propositional relevance is largely involved in the construction of courses, and thus becomes the professional preserve of the educator. As Jevons (1969) suggested:—

'educators are probably well advised to focus their attention on the things with which they have most direct contact --- . The more immediately relevant factors to consider fall into three broad classes - those relating to the subject, to the students and to their prospective careers, respectively.

So the ideal educator, the paragon of all educational virtues, combines an easy mastery of his subject with a profound understanding of his students and a keen awareness of their career prospects. He has to arrive at some kind of synoptic view of all these in deciding what and how to teach.

As can be seen, there is really only one decision environment in this model, that of the educator.

8·3·2 It is thus the educator's professional and personal judgement that is evaluating the relevance of both course
content and structure for the student (personal) and a career (impersonal). It is then open to the student to accept or reject such 'given' relevance. The employer who provides the career, and the practitioner who builds the career seem to have no part to play in constructing educational relevance. Whether the educational relevance given by the educators to such courses is propositional or evaluative, it must operate on at least two levels:

a) personal relevance, ie. whether or not the individual sees merit in what he is being asked to do in terms of personal objectives.

b) instrumental relevance, ie. whether or not the course, its organisation, its content and teaching methods are seen to have merit in terms of its aims - whether they be either explicit or implicit.

Jevons' model not only concentrates on only one party to an educational process, it takes no regard of personal and instrumental relevance. This I believe is a recipe for pseudo-relevance, producing propositional relevance where evaluative relevance should exist.

8.3.3 To avoid the shortcomings of Jevons' monadic model, I am proposing a triadic model which I am confining to the field of evaluative relevance. The evaluative characteristic thus implies that chemical educational relevance will depend upon whose perspective is involved in making decisions about it. Such perspectives will differ for a variety of reasons dependent on the values, judgements etc., each incorporates. In contrast to Jevons' monadic model, I suggest that three main groups (acting either in concert, or as individuals) will have distinctive justifications for chemical educational relevance:

a) Chemical educators; by whom I mean those teachers who assume a professional role of introducing others to the knowledge and processes of chemistry in an educational context.

b) Chemical practitioners; by whom I mean those who assume
a professional role of applying chemical knowledge and processes in an industrial or commercial context.
c) Learners; by whom I mean those students who are endeavouring to master the knowledge and processes of chemistry for whatever reason, within an educational institution.

Each of these groups will work within its own decision environment, and have views on educational relevance which will involve both personal relevance and instrumental relevance. In accepting Bruner's notion that relevance in either of its senses depends on 'what you know that permits you to move towards goals that you care about' (quoted on p 152), then instrumental and personal relevance together produce optimal conditions for educational relevance. This can be represented diagrammatically (see p 160).

8.4 Decision environments.
8.4.1 That there are differing visions of relevance is indicated in earlier sections of this chapter (8.1) in which an apparent mismatch along a knowledge acquisition - knowledge utilisation dimension was discussed. The stated aims of higher education as stressed through publicity literature did not seem to match the experience of those who undertook the courses. This would indicate that different factors are given priority in the decision environments of educators and practitioners.

8.4.2 There are some very significant articles in the literature discussing the importance of the focal concepts (kinetics and equilibrium) within chemical education. Ashmore (1965) wrote that:

'much more emphasis is being paid to rates of reaction in industrial chemistry. Many pre-war processes were based on the attainment of equilibrium conditions and paid little attention to kinetics.'

p 160

Jezowska-Trzebiatowska (1975) argued for the inclusion of
DIAGRAM 24: Triadic model of educational relevance.
industrial chemistry in undergraduate courses, to be:
'directly connected with thermodynamics, kinetics and other fields
of chemistry.'

p 35

Later McGarvey and Knipe (1980) claimed that:
'a feature of modern introductory courses in chemistry is the
importance given to the study of reaction rates and mechanisms. This
is a recognition of the role that kinetics and mechanisms play in the
understanding of chemistry.'

p 155

There is a shift of emphasis in these quotations, from the
importance of the focal concepts within industry, to their
inclusion in undergraduate courses being justified on theoretical
grounds. This is not, I suggest, either accidental or an
artefact of selection from journal articles.

8·4·3 If one refers back to say, the 1950's, then discussion
of reaction rate and chemical equilibrium was frequently
approached through Guldeberg and Waage's Law of Mass Action
(originally propounded in 1879). In simplified form, this
approach followed the argument that, for a reversible reaction:

\[ A + B \neq C + D \]

then applying the Law of Mass Action:

\[ \text{Rate} = K' [A][B] \quad \text{(Rate Law)} \]

and

\[ \text{Rate} = K'' [C][D] \]

at equilibrium \[ \text{Rate} = \text{Rate} \]

Hence

\[ K_{eq} = \frac{K'' [C][D]}{K' [A][B]} \quad \text{(Equilibrium Law)} \]
Equilibrium was thus expressed as a balance of competing rates [see for example Edelson (1975)]. Experimental evidence suggests that few chemical reactions follow this simple stoichiometric derivation, infrequently following the equation so directly. The obvious experimental fact of the equilibrium condition is constancy of concentration; however the relationship between those equilibrium concentrations and the stoichiometry is often far from clear. Ashmore (1965) noted that:

"Students should be discouraged from learning an outdated law which is all too often presented as if it applied to all reactions"

p 160

Wright (1965) suggested that:

"-- a sound relation of the Equilibrium Law is being 'deduced' from unsound premises, and a false conception may in consequence be implanted in the minds of those taught."

p 15

By rejecting the 'traditional' approach, Ashmore claimed that the equilibrium expression:

"-- can then be derived by rigorous application of the laws of thermodynamics without any consideration of the rate approach to equilibrium or of equal opposing rates at equilibrium."

p 161

8.4.4 This genuine concern that teaching should be based on 'sound premises' seems to have had two distinct side effects, both of which depend strongly on epistemological justifications:

a) equilibrium studies have become subsumed into chemical thermodynamics, as a special case of a wider appraisal of the energetic characteristics of reactions.

b) Kinetics have become 'refined' to a high degree, in attempts to unlock reaction mechanisms; the refinement leading to complex mathematical modelling of reactions.

Perhaps this latter point is in response to Koenig(1965)
'-- equilibrium laws that were general and exact are deducable from principles of thermodynamics --- the same laws would be deducable also from principles of kinetics, if known with sufficient generality and exactness.'

The result, it would seem, has been what might be called an 'epistemological schism', in which kinetics are treated separately from equilibrium and thermodynamics. As Chen and Sjoberg (1980) have remarked:

'The differences between thermodynamics and kinetics are emphasized in every physical chemistry textbook.'

8.4.5 The schism is however not just on a 'topic' basis, since thermodynamic reasoning is based on:

'-- the ideas of physics and mathematics rather than on those of chemistry; and on macroscopic physics and pure mathematics at that. The physical content is that of a theory expressible in its entirety in non-mathematical terms; and the mathematical background is concerned more with a knowledge of what is integration than with the evaluation of integrals.'

Wright (1974) p 9

Kinetics on the other hand:

'-- is concerned with the reaction mechanism, i.e., the sequence of steps by which a chemical reaction proceeds, the rates of these steps, and the factors, like nature of reactants, concentration, temperature, and catalysis, which affect the rate.'

Mickey (1980) p 659
(original emphasis)

The effect of this approach to kinetics has been the generation of increasingly complex mechanisms, as the complexity of the systems under study grew. The difficulties involved in solving the mathematical differential equations also grew. By 1975, Edelson was commenting:
'The mathematics involved is so highly specialised as to be of limited interest while the solutions are often so complex that they allow little insight to be gained into the interrelationship of the various component steps of the mechanisms. Furthermore they encourage the investigator to force a proposed mechanism into a format for which solutions are available rather than to allow chemical considerations to predominate.'

p 642

8.4.6 Chemical education thus appears to reflect a major concern for theoretical precision, and the logical statements involved in structuring knowledge. Mathematical modelling seems to play a key role in this concern, bringing with it an abstraction from the 'reality' of interacting molecules. This point is clearly made by Wright (1974), when discussing the teaching of thermodynamics in the secondary school:

'Thermodynamics does not possess the virtue, occasionally attributed to it, of providing a suitable underlying theme for a unified and integrated treatment of the whole of chemistry. It has nothing to say on the structural aspects of chemistry, and little on the kinetics and mechanistic aspects.

As it does not involve particular molecular models (since the equations are deducible by purely macroscopic arguments involving no models at all) thermodynamics is a subject peculiarly unsuited to elementary teaching. It exemplifies the importance of non-pictorial theory in physical science - a topic almost certainly best reserved for teaching in universities.'

p 10 (my emphasis)

Thermodynamics is valued for its 'non-pictorial theory'; kinetics seems to be the preserve of 'highly specialised mathematics'. Molecular modelling thus becomes of secondary importance. We are in the domain of noetic thinking, that:

'could well be seen as a result of the strong orientation of British university chemistry courses towards the 'pure', theoretical side.'

Kempa (1985)
(private communication)
It would seem that the 'decision environment' for higher education has thus lead to a strong emphasis on content.

8.4.7 In discussing 'chemistry courses and the chemist in industry', Freemantle (1975) suggests that a typical analysis of a chemistry course would be:

---

**The first step is a breakdown into organic, inorganic and physical chemistry:**

'Yet the student cannot swallow any branch of chemistry all at once, and so the subject matter is broken down into items such as 'the Arrhenius equation', and 'the third law'. Once this stage is reached the subject matter is collected in the form of a syllabus; the solution to the problem 'how can we present chemistry to students?' is the breakdown into isolated topics. The answer to the question 'What chemistry is being isolated taught?' is in the collection of topics, the resynthesised syllabus.'

---

In contrast Freemantle suggests that in industry and elsewhere where chemistry is being professionally practised:

'-- it is necessary to combine an analytical and a synthetic approach
This process can be illustrated thus:

As a result the recognition of such analytical and synthetic processes may be more important than the components or content of courses. This analytic-synthetic process is, it is suggested, 'essential to the work of the qualified chemist in industry'.

8.4.8 This differentiation between 'theory' and 'practice', or perhaps 'pure' and 'applied' chemistry has been expressed clearly by Hughes (1975). In discussing the influences affecting secondary school chemistry curricula during the curriculum revisions of the 1960's and early 1970's:

'The curricula produced replaced trivial, outdated content with contemporary modern knowledge and changed the learning approach from one of amassing factual information towards developing an understanding of the principles of chemistry and of the processes for achieving scientific knowledge. The content moved towards physical chemistry and physics and thereby became more rigorous and more abstract. From the viewpoint of chemistry per se the courses were excellent.'

However, he continues his argument:

'In recent years there has been a growing awareness of the theoretical
bias and lack of technological or applied aspects in current chemistry curricula. Although isolated attempts to remedy this imbalance have been made over the years, it is only recently that the need to adapt content and methods to the present-day demands of society has, to any extent, been accepted.

That progress has been made is exemplified by a sprinkling of articles in journals of science and technological education and the widespread development of links between the major chemical industries and individual schools.'

That similar changes were being considered at the higher education level is also evident in the literature. For example, Jones (1969) investigated the views of professional scientists on the education of scientists in industry. Among the suggestions made for course design were:

1. the desirability of a period of industrial experience during industrial training.
2. the need for undergraduate course practical work to reflect the work scientists do in industry.
3. greater emphasis on the applications of science to industry.
4. the avoidance of creating a 'poor relationship' attitude to industrial science compared with 'academic research'.
5. greater contact between academics and industrialists.


One feature I find interesting about the literature relating to chemical education and chemical practice is that approaches to teaching chemistry are rarely under review. Content, syllabi, proportion of time given to other 'disciplines'
(economics, management, etc.) are frequently reviewed. This point is perhaps best exemplified by Stark, in the more recent (1983) Report on a seminar 'Developing Professional skills in Chemistry', held at the University of East Anglia. A view from industry was provided, in which he selected three areas in which skills were required:

A. Professional knowledge
B. Professional skills
C. Industry related skills.

'Professional knowledge' was elaborated in the report on one page of an eleven page Appendix, as shown in Table 19:

**Professional Knowledge.**

<table>
<thead>
<tr>
<th>CHEMISTRY</th>
<th>(facts/theories/principles/techniques ....)</th>
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<tbody>
<tr>
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<td>Different branches.*</td>
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<tr>
<td></td>
<td>organic</td>
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<tr>
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<td>inorganic</td>
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<td></td>
<td>organometallic</td>
</tr>
<tr>
<td></td>
<td>physical (including thermodynamics)</td>
</tr>
<tr>
<td></td>
<td>analytical, particularly modern techniques.</td>
</tr>
</tbody>
</table>

* understanding of other scientific disciplines.

e.g. Biochemistry/biology
Physics
Electronics
Computing
Mathematics
Engineering and Chemical Engineering.

from Developing Professional Skills (1983)
p 12: abridged.

TABLE 19: **Professional Knowledge.**
This may be recognised as the basis of a 'standard' undergraduate course. There was no attempt to analyse the chemistry content more deeply for educational relevance. This is compatible with my impression, gained from the literature, that chemistry course content is one of the 'given' features of preparation for professional practice. Freemantle's 'analytic-synthetic process' may exist within this given framework - there seems no reason why it should not - but the evidence from the interview data suggests that it does not. Since the 'practitioner' and 'student' group of interviewees span a period from the 1940's through to the 1980's in higher educational experience, it would seem that much has been discussed to minimal effect!

8.4.10 The views contained in the interview data showing concern for educational relevance reflect clearly the predominance of a theoretical aspect. Participant C, talking about the focal concepts said:

C: ---- If you knew you were going to use these things when you get into industry, or even doing post-doctoral or just graduate research, then I think you would take far more interest in them - if they were presented in the realistic context with what they could be used for and not just a series of numbers, you know, deriving a formula at the end.

(TR 3: lines 180-186)
Category R

This lack of interest due to the lack of a realistic context was echoed by participant S when talking about theoretical chemistry:

S: I could not really get much relevance out of it - it seemed too unrelated to chemistry as a practical subject --- unless I can see the practical significance, I find it difficult to appreciate why it should be there really!

(TR 19: lines 103-114)
Category R

The concern with the 'realistic context', the 'practical
The 'mismatch' between educational approach and practical need was given a slightly different flavour by participant P:

P: It's one thing you do quickly learn from industry away from a chemistry course at university, you know --- the old story; •••. the old story; there, you get 9/10 for getting the method right - bo-bom! And with me, you don't get anything for getting the method right - you get 0/10 for getting the answer wrong!

[TR 16: lines 426-431] category R. original emphasis

All the above are chemical practitioners, of ages ranging from 26-45.

8.4.11 The educator's viewpoint has been equally clearly expressed. For example, from participant U:

U: --- but you're teaching a discipline. Not only is it interesting for a start, one should know how things work if you're going to be working in the area. But you can - and you often will - carry forward some of those ideas, and you will use them later whether you think about it or not, and I suppose that if one --- is learning chemistry at the degree level you might not be interested in some aspects, but you should know something about them.

[TR 21: lines 386-394] category T original emphasis.

And, from participant AA:

AA: I think we've gone through a phase at all levels --- in which
we have started very much from the hypothetical, the conceptually very
difficult, the microscopic world of atoms and molecules, and, sort
of, occasionally you reach the surface enough to say 'Oh, incidentally,
you know, there's something called the Haber process which relates to
thermodynamics and to chemical equilibrium'--- I can see why there
was a need to get away from the totallycataloguing, descriptive type
of chemistry, but it does seem to me --- that we've gone right
overboard in the opposite direction. The descriptive chemistry is
limited, and where it appears, it is not related to the chemistry of
the real material world so much as to the chemistry of particular
things that happen to be in bottles on the shelf.

[TR 27: lines 612-637]
category R.

Both U and AA are currently teaching physical chemistry to
undergraduates and postgraduates. A 'recent postgraduate'
response to the 'mismatch' clearly implicates teaching
 technique as a major factor (it should be remembered that this
was a group interview):

I: To what extent was the work you did tied to theoreticalexplanation
as opposed to saying how useful this is in practice ---?

W2: No, not in kinetics anyway.

W3: It was very theoretical. Well it was very biased towardsthe
theory, but we did get some idea as to application.

W2: I found that with all the courses, really, what you were first
saying. We never had time to sit down and think it through, 'cos we
were in such a - you know, get this done, exams at the end of each
term. We knew that it was going to be all the theory, and this maths---

W1: Yes, but there is time, I mean, that's just the fault of the
course -

W2: You think so?

W1: Yes, there is time - it's approach.

W3: Yes, it's approach.

[TR 23: lines 513-530]
category T.

8.4.12 Since proposing a triadic model of education (Diagram
24, p160) based on a general analysis of the meaning and
usage of the word relevance, I have argued that:-
a) There is evidence in the literature of a bias towards a noetic perspective in the teaching of the focal concepts at a higher education level, resulting in abstract, non-pictorial theorising, with a strong mathematical component.
b) There is evidence that industrial practice requires an 'analytic-synthetic process' for use in solving 'real' problems.
c) Where increased industrial relevance has been suggested, there is rarely any attempt to do other than add to, or substitute new material in, 'standard' chemistry courses.
d) Research data would indicate weak educational relevance in courses which are strongly biased towards mathematical abstraction and theorising, with a consequent loss of 'reality'.

I have also suggested that this is a result of a separation between theory and practice, often seen as a distinction between 'pure' and 'applied' chemistry. If my arguments are accepted, then there would seem to be little congruence between the 'relevance perspective' of the educator, compared with that of the practitioner; due in the main to somewhat different 'decision environments'. One major factor in this difference as related to the focal concepts of this inquiry (ie. a special case of the general model) would appear to be a strong bias towards a noetic mode by educators. I am suggesting here that the educational experience provided for the learner may condition 'thinking for understanding' in a limiting way - that is, emphasis of the Tn mode, perhaps at the expense of the Tp mode (see 8.4.5/6). The strong dissatisfaction with this bias by chemical practitioners suggests that the use of both Tn and Tp modes are important in practice, with deficient thinking strategies possibly being remedied through work experience. The effectiveness of courses seems in part to depend on the extent of chemical 'realism' identified by the student, in the work being undertaken, a point discussed further in Chapter 10. I believe this to indicate dissonance between personal and
instrumental relevance within the relevance model, and in the last section of this chapter, I will suggest the root cause for this dissonance.

8.5 Relevance limits.

8.5.1 I have so far concentrated on the educator and the practitioner in my argument. The reasons for this have been clarified in 7.5.7, but for the present I wish to continue looking at these two groups. This particular inquiry can only briefly inspect the components of the various decision environments in my model; a detailed consideration could well form the basis of an inquiry of its own. However, from my inspection of the literature, and the analysis of interview data, the perceived mismatch between some of the proclaimed aims of higher education and the perceived value of the courses designed to meet those aims does seem to have substance. It should be remembered at this point that I am concerned with perceptions of educational relevance. It must be clearly acknowledged that higher education courses in chemistry have wider aims and purposes than pure vocationalism. [See for example, Holliday et al (1973), Brock and Meadows (1977), Leach (1978), Cotrell A (1978), Kornhauser (1979), Johnstone et al (1981)]. However, I suggest that the practitioner's bias for rating educational relevance will be largely related to value for professional practice. This is not, to my mind, the same as vocationalism, which is a much more highly focussed objective. 'Professional practice' may well entail many of the wider aims of higher education in chemistry.

8.5.2 On the basis of my survey and analysis, I would suggest that one significant difference between the 'educator' and 'practitioner' decision environments relates to the control and use of chemical knowledge and the thinking and understanding this engenders. I have indicated (8.4.12) my belief that educators value a noetic approach to the focal concepts. This results from a high regard for the unifying power of a
thermodynamic approach to kinetics and equilibrium, and the high precision obtainable through mathematical modelling. Chemical practitioners, on the other hand, seem to find this abstraction introduces an element of 'chemical unreality'. This is well exemplified by two extracts from the interview with participant N:

N: (talking about kinetics) ... Yes, I keep seeing it in terms of equations which I think is possibly not the right way of looking at it - an equation with square brackets and rate constants and things like that in, which is possibly rather an artificial way of looking at it ---.

[TR 14: lines 194-197]
category K.

N: Well, I suppose it ties up with this thing about the discrepancy between theory and practice. It's all very well to look at equations on a piece of paper and say 'these represent what is actually occurring in there', but there seems to be some sort of discrepancy between looking at something on a piece of paper and actually what's going on in your 'reacting pot' as it were --- I have memories of just learning things written on pieces of paper and trying to cram in as much as possible --- without actually thinking about what is actually meant in real terms, in terms of the actual reaction itself---

[TR 14: lines 220-236]
category RC, original emphasis.

8.5.3 The need for greater 'chemical reality' was expressed by others also, For example, participant H when asked her preference in using mathematical as opposed to molecular modelling with the focal concepts, replied:

H: Personally, molecular. I think molecular is easier to actually see.

I: By 'see' do you mean 'imagine'?

H: Yes, yes ... understand.

[TR 8 edit, lines 152-154]
category RC, original emphasis.

The fact that molecular modelling introduced greater 'reality', and hence better understanding was a frequent comment among those who raised this matter (8 of 10). There were also several (19)
instances throughout the transcripts of the need for pictorial (diagrammatic) thinking to aid explanation and memory. Together with molecular modelling, the use of reaction profile diagrams, analogies with 'energy hills', and so forth are clues to a need for pictorial representation which Wright (1974) specifically rejects (see p 164). Molecular modelling and pictorial thinking are indicative of a pragmatic approach to the focal concepts.

8.5.4 To see how important the ability to use Tn or Tp (or a mixture Tn/Tp) thinking modes might be in the two groups' decision environments, and hence the effect this might have on educational relevance, a list was made of the thinking modes used by each participant when talking about the focal concepts. Table 19 (see p 176) shows this occurrence, broken down into the two groups (educators, practitioners) and in terms of kinetics and equilibrium. Since group sizes were not identical, the number of occurrences of Tn, Tn/Tp or Tp for each group were totalled and converted to percentages. These were then plotted on a diagram, using a notional axis of Tn ---- Tn/Tp --- Tp, as if the Tn and Tp modes formed the limits of a continuum. The result is given in Diagram 27 (p 177). Whilst being careful about how much may be read into such a quantification exercise, I think it is reasonable to suggest that the higher proportion of Tp thinking among practitioners is significant. It is significant for two reasons: firstly, it is at the expense of both Tn and Tn/Tp (in statistical terms); secondly, if my premise about the higher value placed on Tn in higher education is valid, the shift to Tp is all the more important - one must assume that the practitioners started out 'clothed' as it were in Tn bias. An immediate inference is that professional practice also has a thinking mode bias, in this case toward Tp. On the assumption that one must know something before applying it, then it is possible to argue that knowledge acquisition through higher education courses does not provide an important ingredient of the professional practice scene. This may well
<table>
<thead>
<tr>
<th>Educator group</th>
<th>Kin</th>
<th>Eq.</th>
<th>Practitioner group</th>
<th>Kin.</th>
<th>Eq.</th>
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<tbody>
<tr>
<td>TR1</td>
<td>Tn</td>
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<td>7</td>
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<td>20</td>
<td>Tp</td>
<td>Tn</td>
</tr>
</tbody>
</table>

N= 10  
No of instances= 20

Tn -- 9 of 20 = 45.0%  
Tn/Tp -- 7 of 20 = 35.0%  
Tp -- 4 of 20 = 20.0%

N= 16  
No of instances= 32

Tn -- 19 of 32 = 34.4%  
Tn/Tp -- 60 of 32 = 18.8%  
Tp -- 15 of 32 = 46.8%

TABLE 19: Tn, Tn/Tp, Tp frequencies.
DIAGRAM 27: Plot of $T_n$, $T_n/T_p$, $T_p$ frequencies.
be a limiting factor in evaluating educational relevance.

8.5.5 This might be represented in terms of diagrammatic 'scenarios'. Accepting the postulate that the focal concept 'zone' entails two modes of thinking (Tn, Tp) and that perspectives of educational relevance seem to relate to a knowledge-application dimension, a generalised relevance perspective can be envisaged thus: (Diagram 28).

![Diagram 28: Generalised relevance perspectives.](image)

Particular relevance perspectives may now be represented by drawing in 'limits' derived from a person or group context and thinking modes. For example, a person (X) whose sole preoccupation with the focal concepts was the structure and development of chemical knowledge, and who predominantly used the noetic mode of thinking, only the area within the limit drawn in Diagram 29 would carry significant relevance.

![Diagram 29: Relevance limit for person (X).](image)
Alternatively, a person (Y) who was solely concerned with the application of the focal concepts and who predominantly used the pragmatic mode of thinking, would find the most significant relevance in the area delimited in Diagram 30:

![Diagram 30: Relevance limit for person (Y).]

8.5.6 This idea can now be extended to incorporate the quantification exercise described in 8.5.4. A rough 'plot' of the percentages for the thinking modes would give the following relevance limit for the 'educator' group (Diagram 31):

![Diagram 31: Relevance limit for 'educator' group.]

For the 'practitioner' group, I suggest the relevance limit would look something like the following (Diagram 32):

![Diagram 32: Relevance limit for 'practitioner' group.]
The implication made here, and not unfairly I believe, is that the educators are more 'knowledge orientated' than 'application orientated', with the converse for practitioners. It would be unwise to use these relevance limit diagrams for much more than pictorial representation of ideas. However, it is possible to speculate on an extension of these ideas.

8·5·7 Diagrams 29 and 30 presented theoretical relevance limits for two persons (X) and (Y), who might be seen as extreme examples of the educator and practitioner group theoretical limits respectively. To obtain the optimal conditions for educational relevance (8·3·2) then there should be a high degree of congruence between the 'relevances' of the three groups in the triadic model. Such a degree of congruence, allowing for natural 'group bias' due to professional occupation might be represented thus (Diagram 33):

![Diagram 33: Optimal congruence of perspective limits.](image)

To achieve this degree of congruence would require
a) higher personal and instrumental relevance for a noetic approach, from practitioners.
b) higher personal and instrumental relevance for a pragmatic approach, from educators.
Both these points relate to a 'knowledge acquisition' orientation. Put more simply, it indicates a need to change attitudes and methodology with regard to the teaching and learning of the focal concepts. Educational relevance may now be seen to be
not just a question of appropriate content; it requires content that may be used to foster appropriate thinking modes in an appropriate context. The practitioner has moved through the higher education phase, and must rely on work experience, if there are deficiencies in this respect. The learner, however, is in the 'knowledge acquisition through higher education' phase attempting to meet the optimal relevance condition. The implications for the 'learner' group having its own specific decision environment, and how these ideas on educational relevance may be related to an understanding of the focal concepts using the perceptual space model, will be discussed in Chapter 10. But first, the confirmatory questionnaire must be introduced and discussed.

* * *
Chapter Nine

Research Questionnaire.

In which the construction and use of a confirmatory questionnaire is described, and the implications of the recorded responses discussed.

9.1 Construction
9.2 Distribution
9.3 Analysis
9.4 Inferences
9.5 Summary
9. RESEARCH QUESTIONNAIRE.

'This is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning.'

Sir Winston Churchill (1942)
(speech at Mansion House)

* * *

9.1 Construction.

9.1.1 The need for a confirmatory triangulation has already been discussed (4.2.4). The choice of a questionnaire method seemed appropriate. In contrast with the interviews, research participants would be given an opportunity to respond free from any 'personal interaction' effects. It also offered me the opportunity to seek clarification, as well as confirmation, of the interview data. The importance of being clear in one's mind about the purpose of a questionnaire, before attempting a design, has been strongly recognised in the literature. In particular, if statistical analysis is to be involved, the nature of the statistics (inferential or descriptive) must be decided. Various design decisions are therefore required to ensure data of an appropriate quality are obtained. In the case of this questionnaire, many of these decisions were dictated by the context of its operation. For example:--

a) being a confirmatory questionnaire, inferential statistical analysis was not essential; this simplified both overall questionnaire and individual question design. (see 9.3.2)

b) the type of question involved would have to reveal individuals' attitudes and perceptions; scaled attitude questions thus seemed most appropriate, based on the semantic differential principle.

* 'Confirmatory' is here being used in the sense given in 4.21 - 'concern with some better understood social phenomenon'; it should be contrasted with 'exploratory' inquiry.
c) the source of the questions was defined by the interview analysis to be confirmed.

The major decisions being faced in the construction of this questionnaire were thus reduced to the areas of detailed content and distribution. The eventual question design and questionnaire format were strongly influenced by the extremely helpful advice given by Youngman (1978).

9.1.2 In deciding on the detailed content, four points in particular appeared to need consideration:-

a) should the questionnaire attempt to address either 'gaps' in interview analysis, or significant factors arising from it, or both?
b) to what extent could any further information be derived relating to the perceptual space model?
c) a major feature appearing during the analysis concerned a lack of 'chemical reality' concerning perspectives on the focal concepts; could this be inspected further through the questionnaire?
d) could the questionnaire provide deeper insights into the decision environments of the triadic model of relevance?

The first of these questions - a general principle relating to design - pointed to the need to include both 'gaps' and significances. Of the other three more specific points, it was thought that the perceptual space model could best be checked by constructing questions relating to its three basic postulates. The question of 'chemical reality' demanded an 'open' question in order not to constrain personal viewpoints. In attempting to probe the decision environments, it was decided to ask questions relating to personal perceptions of undergraduate courses, and their design. Since it was not the purpose of the questionnaire to analyse the focal concepts, nor to assess participants' knowledge of them, it was decided not to question them directly. It was thought necessary however to include an opportunity for participants to express
<table>
<thead>
<tr>
<th>Factor</th>
<th>Description</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Personal attitudes to focal concepts</td>
<td>19</td>
<td>65.5</td>
</tr>
<tr>
<td>B</td>
<td>Textbooks</td>
<td>2</td>
<td>6.9</td>
</tr>
<tr>
<td>C</td>
<td>Relationship between focal concepts</td>
<td>29</td>
<td>100.0</td>
</tr>
<tr>
<td>E</td>
<td>Perspective on equilibrium</td>
<td>26</td>
<td>89.7</td>
</tr>
<tr>
<td>E1</td>
<td>Effect of interview</td>
<td>3</td>
<td>10.3</td>
</tr>
<tr>
<td>F</td>
<td>Importance of focal concepts</td>
<td>25</td>
<td>86.2</td>
</tr>
<tr>
<td>H</td>
<td>Personal response to higher education</td>
<td>24</td>
<td>82.8</td>
</tr>
<tr>
<td>I</td>
<td>Industry related experience</td>
<td>7</td>
<td>24.1</td>
</tr>
<tr>
<td>K</td>
<td>Perspective on kinetics</td>
<td>27</td>
<td>93.1</td>
</tr>
<tr>
<td>L</td>
<td>Influence on learning</td>
<td>13</td>
<td>44.8</td>
</tr>
<tr>
<td>M</td>
<td>Mathematics related factors</td>
<td>20</td>
<td>69.0</td>
</tr>
<tr>
<td>N</td>
<td>Nature of chemical reaction</td>
<td>1</td>
<td>3.4</td>
</tr>
<tr>
<td>P</td>
<td>Personal philosophy of science</td>
<td>2</td>
<td>6.9</td>
</tr>
<tr>
<td>R</td>
<td>Relevance of courses</td>
<td>24</td>
<td>82.8</td>
</tr>
<tr>
<td>RC</td>
<td>'Realism' in chemistry</td>
<td>10</td>
<td>34.5</td>
</tr>
<tr>
<td>T</td>
<td>Teaching approaches in undergraduate chemistry</td>
<td>28</td>
<td>97.0</td>
</tr>
<tr>
<td>U</td>
<td>Choice of undergraduate course</td>
<td>4</td>
<td>13.8</td>
</tr>
</tbody>
</table>

N=29

Graph of rank order

N=29

**TABLE 20:** Percentage response of factors from analysis.
their ideas about the focal concepts themselves, by including open questions to this effect. Because the main purpose of the questionnaire was to check on and help elaborate individuals' perceptions, a direct approach to 'content definition', though included, was not overstressed. This was done by setting out my personal meaning for physical chemistry and asking for structured comment from anyone who disagreed with it. The questionnaire thus included a mixture of 'scaled attitude' and 'open' questions.

9.1.3 For the basis of the questions, the frequency of appearance of the analysis factors was consulted (see Table 15 on p111). The transcripts were then revisited, to ensure no other significant points were omitted. The results of this process are given in Table 20 (p185), as a percentage response from the 29 transcripts, ignoring any sub-factors at this stage. The need to contain the length of the questionnaire meant that only the most frequently occurring factors could be considered. It was therefore decided to operate a 'cut-off' of 60.0%, below which the factors would not be included. This was partly arbitrary, partly a result of a significant drop in frequency between factors M (69.0%) and L (44.8%). Since the interviews had involved direct questioning on the focal concepts, and it was not the intention to perform a concept analysis (9.1.2), factors C, K and E were no longer considered as a basis for questions. The remaining factors of 60.0% or greater occurrence (A, F, H, M, R, T) were then reviewed to consider the importance of sub-categories. The results of this further survey were:

1. **Factor A:** Personal attitudes to the focal concepts.
   Broadly separate into 'liked' (A1) and 'not liked' (A2).

<table>
<thead>
<tr>
<th></th>
<th>A1</th>
<th>A2</th>
<th>No comment</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>7</td>
<td>12</td>
<td>10</td>
<td>29</td>
</tr>
<tr>
<td>% (of 29)</td>
<td>24·1</td>
<td>41·4</td>
<td>34·5</td>
<td>100</td>
</tr>
</tbody>
</table>

N=29 (number of transcripts)
Of the 12 'not liked' comments, all expressed concern over mathematics and over-abstraction. There is some specific comment about theoretical chemistry not being 'real'.

2. Factor F: Importance of the focal concepts.

<table>
<thead>
<tr>
<th>Comment</th>
<th>No comment</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td>% (of 29)</td>
<td>86·2</td>
<td>13·8</td>
</tr>
</tbody>
</table>

Of the 25 comments:-
14 (56·0% of 25) stressed the importance of the focal concepts in industry.
11 (44·0% of 25) made it clear that the focal concepts were an important (if only background) feature of their work.

3. Factor H: Personal response to higher education.

<table>
<thead>
<tr>
<th>Comment</th>
<th>No comment</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>24</td>
<td>5</td>
</tr>
<tr>
<td>% (of 29)</td>
<td>82·8</td>
<td>17·2</td>
</tr>
</tbody>
</table>

Of the 24 comments:-
14 (58·3% of 24) said their undergraduate course was disliked/badly taught/had little relevance.
4 (16·7% of 24) said their undergraduate course was enjoyable/had some relevance.
6 (25·0% of 24) offered 'neutral' comment.

Broadly separable into M1: Mathematical barriers to learning/understanding
M2: Mathematics liked
M3: Mathematics not liked
Some participants commented under more than one sub-category, and hence the total number of comments exceeds the number of transcripts (29). Factor M was the only instance of non-exclusive sub-factors. This appears to be due to considerable overlap between those who did not like mathematics (M3) and those who found it difficult (M1). There were others, however, who whilst not averse to mathematics, also found it particularly difficult when related to the focal concepts. Several of these were comments on the degree of abstraction involved being a source of difficulty.

5. Factor R: Relevance of courses.

<table>
<thead>
<tr>
<th>Comment</th>
<th>No comment</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>24</td>
<td>5</td>
</tr>
<tr>
<td>% (of 29)</td>
<td>82.8</td>
<td>17.2</td>
</tr>
</tbody>
</table>

The 22 comments on relevance contained two main areas of criticism:-

i) no obvious utility value.

ii) lack of 'chemical reality', or relationship to the 'real world' of chemistry.

6. Factor T: Teaching approaches in undergraduate courses.

<table>
<thead>
<tr>
<th>Comment</th>
<th>No comment</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>26</td>
<td>3</td>
</tr>
<tr>
<td>% (of 29)</td>
<td>89.7</td>
<td>10.3</td>
</tr>
</tbody>
</table>

The high response rate here suggests considerable concern with
teaching techniques at undergraduate level related to the focal concepts. Comment was too general to sub-categorise, but factors identified elsewhere were reflected; eg.

i) too theoretical (abstract)

ii) too mathematical

iii) lacking in relationship with 'real world' problems.

Other significant points arising relate to:

i) highly didactic approaches

ii) teaching for examinations.

9.1.4 As a result of this whole exercise, it was decided to write questions to elicit information in the following areas:

i) the importance of mathematical/molecular modelling and qualitative/quantitative approaches in understanding the focal concepts.

ii) reaction to chemical education courses in higher education in general, and with specific reference to the focal concepts and mathematical aspects of learning them.

iii) personal perceptions and expectations of first degree courses.

iv) opinion relating to the design of physical chemistry first degree courses.

Questions were drafted using a 1 to 5 attitude scale concerning polar ideas relating to the specific issues being investigated. For example, in the case of the importance of mathematical modelling in understanding the focal concepts, three ideas seemed apparent in interview data:

a) utility value, both in practice and in descriptive power

b) ease of understanding

c) accuracy of the model in description and prediction of chemical phenomena.

This became translated in a question thus:
Mathematical modelling is:

Very useful  1  2  3  4  5  Not very useful

Very easy to understand  1  2  3  4  5  Not easy to understand

Highly accurate  1  2  3  4  5  Low accuracy

Participants were directed to circle the number which they thought most closely fitted their opinion of mathematical modelling in these three respects.

9.1.5 The draft questions were trialled among a group (four in total) of my teaching and research colleagues, and with two others, a secondary school teacher, and an industrialist. As a result of the very constructive criticism received, several changes were made. In particular these related to:

i) including thermodynamics as well as kinetics and equilibrium as separate areas for questioning.

ii) ensuring that 'the other side of the coin' was included, to avoid implicit bias; for example, the question 'Qualitative understanding is a prerequisite for quantitative understanding' should be balanced by asking whether 'Quantitative understanding is a prerequisite for qualitative understanding'.

The first point (above) was particularly significant. The structuring questions at interview had not directly addressed thermodynamics. However, it is very clear from the data that the close relationship between kinetics, equilibrium and thermodynamics influenced individuals' understanding of the focal concepts. That this point should have arisen again was a clear indication that the questionnaire required modification.

9.1.6 After modification, the draft questionnaire was shown to the 'triallists' for further comment, before production and distribution. The outline structure of the questionnaire is given below; the full questionnaire will be found in Appendix 6 (p A6 ).
Questionnaire: Outline structure.

Introduction. Purpose of questionnaire, and instructions. Personal definitions of important terminology. Space for participants' definitions.

Section A. Biographical details.

Section B. Conceptual areas of kinetics, equilibrium and thermodynamics; molecular/mathematical modelling and qualitative/quantitative understanding.

Section C. Chemical education in undergraduate courses. Personal perception of whole course, and of the focal concept components; perceptions of mathematical aspects; use of real chemical problems in teaching approaches.

Section D. Personal perceptions: expectations of undergraduate courses, and extent of meeting those expectations; notions of relevance in chemical education.

Section E. Perceptions of course design; course designers and their influence; content selection; chemical 'reality'.

The questions were coded by section to allow ease of analysis.

9.2 Distribution.

9.2.1 As Youngman (1978) has pointed out:

'No matter how meticulously the sampling procedures have been pursued, the researcher using questionnaires for data collection remains heavily dependent upon response rates. Since the best guarantee of efficient sampling is a high response rate, distribution and return arrangements become vital parts of the research design.'

p 27

The confirmatory nature of this questionnaire has meant few problems being encountered through poor response. The sample for the questionnaire was dictated by the interview programme, all those having been interviewed being invited to complete the questionnaire. The opportunity was taken to extend the sample beyond the interview participants, 15 others being included in the distribution. These 15 others were involved through the same processes outlined in 6.1.1, and again I am
indebted to my colleagues for their help and support. The distribution of these 15 'others' among the three participating groups was:

- Practitioners: 5
- Teachers: 3
- Students: 7

The total sample (interviewees plus 'others') to whom questionnaires were sent was:

- Practitioners: 20
- Teachers: 16
- Students: 14

9.2.2 The questionnaires were forwarded with a letter of explanation and return postage. In nearly all 'non-interview' cases, the questionnaires were delivered personally. This was thought advisable, in order to explain the background of my inquiry, and the purpose of the questionnaire. It may be a measure of the good relations built up with the participants, that postal returns were very prompt. The profile of response was:

![Diagram 34: Response profile for questionnaire.](image)
It can be seen from Diagram 34, that 37 of the 50 questionnaires had been returned within eight weeks of dispatch. A letter was sent to the remaining 13 'non-return' participants at this point, requesting a response. Within a further 4 weeks, only three further questionnaires were returned. This was taken to indicate that 'response saturation' had been achieved, and so the 'return' period was closed to allow analysis in detail. The final response rate was 40 from 50 questionnaires distributed, ie. 80%, and the numbers returned in each group were:

<table>
<thead>
<tr>
<th>Group</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practitioners</td>
<td>17</td>
<td>42.5%</td>
</tr>
<tr>
<td>Teachers</td>
<td>13</td>
<td>32.5%</td>
</tr>
<tr>
<td>Students</td>
<td>10</td>
<td>25.0%</td>
</tr>
</tbody>
</table>

This compares with the following group numbers for the total interview sample:

<table>
<thead>
<tr>
<th>Group</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practitioners</td>
<td>16</td>
<td>44.4%</td>
</tr>
<tr>
<td>Teachers</td>
<td>10</td>
<td>27.8%</td>
</tr>
<tr>
<td>Students</td>
<td>10</td>
<td>27.8%</td>
</tr>
</tbody>
</table>

The questionnaire sample thus gives a slightly better balance between 'teacher' and 'practitioner', though with no significant change in the proportion of students. It should be remembered at this point that the questionnaire sample includes non-interview personnel, in all three groups.

9.3 Analysis.

9.3.1 Analysis of the questionnaires involved three processes:

a) obtaining raw scores (coding)

b) processing the raw scores to provide useable information.

c) a review of responses to 'open' questions.

The first of these processes (coding) was quite straightforward, if tedious. The returned questionnaire booklets were separated into the three sub-groups involved. The number of responses for each attitude scale point was then tallied for each coded question. For example:

(see next page)
### TABLE 21: Score tally chart.

These were then converted to raw numerical scores. For example:

### TABLE 22: Numerical data chart.
With the three sub-groups tallied and converted to raw numerical scores, the numerical scores were added together to give the raw data for the whole sample. For example:

**Total sample:**

N=40

<table>
<thead>
<tr>
<th>Section B.</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Total response</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>6</td>
<td>14</td>
<td>12</td>
<td>6</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>B2</td>
<td>6</td>
<td>7</td>
<td>22</td>
<td>3</td>
<td>1</td>
<td>39</td>
</tr>
<tr>
<td>B3</td>
<td>0</td>
<td>2</td>
<td>19</td>
<td>14</td>
<td>4</td>
<td>39</td>
</tr>
<tr>
<td>B4</td>
<td>13</td>
<td>12</td>
<td>8</td>
<td>6</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>B5</td>
<td>2</td>
<td>5</td>
<td>19</td>
<td>12</td>
<td>1</td>
<td>39</td>
</tr>
<tr>
<td>B6</td>
<td>2</td>
<td>18</td>
<td>13</td>
<td>5</td>
<td>1</td>
<td>39</td>
</tr>
</tbody>
</table>

**TABLE 23: Full sample numerical data chart.**

It will be noted from Table 23 that the total number of responses for some questions is at variance with the number of participants. There were instances, almost entirely within the student sub-group, of non-response to certain items. This raised the question of the status of the numerical scores, an important issue from two points of view. In the first place, what should be done about unanswered items; in the second place, what effect would this have on any method of analysing the raw scores more deeply? It seemed highly probable that non-response was due to lack of understanding of either the question itself, or the concepts to which the item referred. There had been no comment about obscure questions either from trialling the questionnaire or from contact with participants (some of
whom returned the booklets personally). It would seem safe, therefore, to assume that non-response was due to lack of understanding of the substance of the questions. This assumption is strengthened by the fact that the majority of non-responses occurred in section B of the questionnaire - the only section to be based directly on the focal concepts. It must also be significant that the majority non-response occurred among the student participants; this point will be referred to again (9.4.4).

9.3.2 Non-response also raised the possibility that each individual participant could be interpreting the rating scale idiosyncratically. If we take for example, Item B1:

<table>
<thead>
<tr>
<th>In chemical kinetics</th>
<th>molecular modelling is:</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1 Very useful</td>
<td>1 2 3 4 5 Not useful</td>
</tr>
</tbody>
</table>

not only can interpretations of 'very useful/not useful' vary, but also assessment of the meaning of the scale points can differ. It would be unwise, therefore to assume a linear relationship between the numbers 1—5, or to assume that 1 and 5 represent exactly the same poles of a bi-polar construct in each individual case. This does not invalidate the questionnaire if the data are to be used for totally descriptive purposes. Any attempt to draw statistically significant inferences from such crude data would seem to be both unwise and unreliable. Had such inferential statistical treatment been required, the questions would have had to be framed rather differently, much less freedom of interpretation being given. At the design stage, advice had been taken on the appropriateness or otherwise of statistical analysis for the purposes of this questionnaire. It is not accidental, therefore, that the data generated are open to limited treatment.
9.3.3 A search of the literature [e.g. Siegal (1956), Nunnally (1975)] suggested that the most appropriate methods of analysis would be:

a) construction of frequency histograms, which could provide a visual check on significance.
b) statistical tests of significance involving the computation of median scores, for comparison either by inspection or the use of quartiles to give an idea of score distribution around the median.
c) chi-square analysis, which could test the degree to which the distribution of responses throughout a table differs from a chance pattern.
d) more sophisticated statistical procedures which would enable a search for significant variations between groups (e.g. Kruskal-Wallis one-way analysis of variance).

The latter of these options was rejected on the basis that the test construction did not (and was not intended to) lend itself to significant correlations to any great extent. This decision was to a large extent vindicated when chi-square analysis was trialled. It was obvious at this stage that within the groups, many of the attitude categories had too few responses to make the tests reliable. There seemed little point, therefore, in seeking correlations between groups on such evidence. Frequency histograms were drawn for one group of questionnaire participants. Visual inspection did not provide significances in which one might have confidence - neither could one be sure that significances were not being overlooked. Calculation of medians did little to improve the situation, and many elements of the data involved had too few responses to enable an effective use of quartiles.

9.3.4 It was therefore decided to recode the data into three rather than five categories. This was done by assuming that category 3 represented those who had no significant view in either direction of the polar differential. It was then
assumed that all those on one side of the middle category showed a trend in their thinking towards that end of the scale. Categories 1 & 2, and 4 & 5, were thus added together. The recoded data, now indicating trends in thinking, is exemplified by Table 24:

### Total sample.  

<table>
<thead>
<tr>
<th></th>
<th>1+2</th>
<th>3</th>
<th>4+5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>20</td>
<td>12</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td>B2</td>
<td>13</td>
<td>22</td>
<td>4</td>
<td>39</td>
</tr>
<tr>
<td>B3</td>
<td>2</td>
<td>19</td>
<td>18</td>
<td>39</td>
</tr>
<tr>
<td>B4</td>
<td>25</td>
<td>8</td>
<td>7</td>
<td>40</td>
</tr>
<tr>
<td>B5</td>
<td>7</td>
<td>19</td>
<td>13</td>
<td>39</td>
</tr>
<tr>
<td>B6</td>
<td>20</td>
<td>13</td>
<td>6</td>
<td>39</td>
</tr>
</tbody>
</table>

**TABLE 24: Recoded numerical data chart.**

These recoded frequencies were then converted to row-percentages (Youngman 1978) and plotted as linear percentage bar charts, as shown in Table 25 and Diagram 35:

### Total sample.

<table>
<thead>
<tr>
<th></th>
<th>1+2</th>
<th>3</th>
<th>4+5</th>
<th>% of</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>50.0</td>
<td>30.0</td>
<td>20.0</td>
<td>40</td>
</tr>
<tr>
<td>B2</td>
<td>33.3</td>
<td>56.4</td>
<td>10.3</td>
<td>39</td>
</tr>
<tr>
<td>B3</td>
<td>5.2</td>
<td>48.7</td>
<td>46.1</td>
<td>39</td>
</tr>
<tr>
<td>B4</td>
<td>62.5</td>
<td>20.0</td>
<td>17.5</td>
<td>40</td>
</tr>
<tr>
<td>B5</td>
<td>17.9</td>
<td>48.8</td>
<td>33.3</td>
<td>39</td>
</tr>
<tr>
<td>B6</td>
<td>51.3</td>
<td>33.3</td>
<td>15.4</td>
<td>39</td>
</tr>
</tbody>
</table>

**TABLE 25: Row-percentages.**
This process has advantages in making allowance for the small variations in total number of responses per item, showing the proportion of 'neutral' responses and allowing an easily read data display technique to be used. For example, it is relatively easy to see from Diagram 35 that:

- a) at least one-third of the participants thought that molecular modelling in kinetics was useful, easy to understand, but not very accurate.
- b) half the sample thought that mathematical modelling in kinetics was useful and accurate, whilst approximately one-third found it difficult to understand.
- c) in each case, quite a significant proportion expressed no particular view.

One weakness of using the linear bar chart is that it is not easy to make comparisons between the trends in each
group with either the total sample, or with other related questions. A further phase of manipulation was thus undertaken in an attempt to highlight any significant differences. For each related group of questions, the row percentages for the left and right hand columns of each sub-group table were collated (ignoring the middle columns in each case), as exemplified in Table 26:

Kinetics Percentages:

<table>
<thead>
<tr>
<th>Molecular modelling:</th>
<th>Practitioner(P)</th>
<th>Educators(E)</th>
<th>Students(S)</th>
<th>Total sample(T)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes(Y)</td>
<td>No(N)</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>B1 useful</td>
<td>41·2</td>
<td>17·6</td>
<td>61·5</td>
<td>23·1</td>
</tr>
<tr>
<td>B2 easy</td>
<td>29·4</td>
<td>5·9</td>
<td>46·2</td>
<td>7·7</td>
</tr>
<tr>
<td>B3 accurate</td>
<td>5·9</td>
<td>32·3</td>
<td>0·0</td>
<td>53·8</td>
</tr>
</tbody>
</table>

(17) (13) (10) (10)

N.B. Figure in brackets beneath table = N; this applies to all the percentages unless shown otherwise.

TABLE 26: Sample of collated row percentages.

9·3·6 The collated row percentages were then used to produce PEST profiles, ie. comparative diagrams of the trends for the three sub-groups [Practitioners(P), Educators(E), Students(S)] and the total sample(T), as shown in Diagram 36:

DIAGRAM 36: Sample PEST profile.
Whilst this does not indicate the order of those who have made no specific response, it does give a visual measure of the trend of thinking relative to the middle choice on the original attitude scale. This technique has elicited some useful information, when comparing the overall trend (total sample) with trends in the sub-groups. For example, Diagram 37 - the PEST profiles for questions B 10 and B 11, shows very clearly how the overall trend masks significant differences in the trends for the P and S groups:—

DIAGRAM 37: PEST profiles for questions B 10 and B 11.

9.3.8 The full implications of this data analysis are discussed in the next section, and the complete data tables are contained in Appendix 7, pA7. In view of the fact that the application of
chi-square analysis and inspections of medians provided no improvement on the above process, in seeking significant trends, I believe that for my purposes, the method is both reasonable and adequate.

9.4 Inferences.
9.4.1 Only three of the forty members of the sample provided personal definitions of the focal concepts. An opportunity, via open questions, had been provided for participants to disagree with, or comment on, my statement that physical chemistry 'broadly equates with chemical kinetics, chemical equilibrium and chemical thermodynamics' (Questionnaire, p 2). Participant 10, in the Practitioner(P) group, gave the following definitions:

Code

X1: Chemical kinetics. The study of the rate at which chemical reactions occur.
X2: Chemical equilibrium. The extent to which a 'reversible' chemical reaction can be said to be shifted towards 'reactants' and 'products'.
X3: Chemical thermodynamics. Study of the physical mechanisms of chemical reactions with respect to energy considerations.

(Participant P10, p 2)

Participant 48 in the Educator(E) group who had not been interviewed, gave the following:

Code

X1: Chemical kinetics. Concerned with rates of reactions. Describes conditions of the individual steps of a reaction ie. reaction mechanisms.
X3: Chemical thermodynamics. The branch of chemistry which deals with energy transformations, predicting whether a chemical reaction may take place and to what extent under certain conditions - use of properties such as temperature, pressure and volume of a system. Concerned with initial and final conditions (unlike
(Participant E48, p 2)
words in [] my own.

Participant E20, added an explanatory comment:

I disagree with 1 [my definition of physical chemistry], as it should include a study of spectoscopy and electronic structure.

Code

X1: Chemical kinetics. A study of the rate at which reactions achieve equilibrium, and their detailed mechanisms.
X2: Chemical equilibrium. A study of the quantities of reactants and products present at infinite time.
X3: Chemical thermodynamics. A description of chemical equilibria in terms of energy and entropy factors as well as the application of statistical mechanics to describe chemical equilibria.

( Participant E20, p 2)
words in [] my own.

This is quoted in full since I believe they provide some confirmation of Postulate 2 (7·3·10) of the perceptual space model, a point discussed further in 9·5. Each of these participants is, in their own way, using both macro- and micro-system approaches in their descriptions as they involve energetic and mechanistic arguments in their definitions. It is not my purpose here to either comment on or judge the accuracy of their definitions.

9·4·2 The age profiles (Diagram 37, p204) for the participants derived from Section A of the questionnaire show that the Educator(E) group contained a large proportion (69·2% of 13) of its numbers in the 36-45 age group. As might be expected there was a preponderance of members in the 18-25 age range for the Student(S) group (60·0% of 10). The Practitioner(P) group contained a much more even spread over the first three age ranges (18-25, 26-35, 36-45). Of the total participation, only four members (10·0% of 40) were in the 46-55 age group.
<table>
<thead>
<tr>
<th>Age group</th>
<th>18-25(1)</th>
<th>26-35(2)</th>
<th>36-45(3)</th>
<th>46-55(4)</th>
<th>56-65(5)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practitioners</td>
<td>4</td>
<td>6</td>
<td>3</td>
<td>4</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>Educators</td>
<td>0</td>
<td>1</td>
<td>9</td>
<td>3</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>Students</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
<td>10</td>
<td>13</td>
<td>7</td>
<td>0</td>
<td>40</td>
</tr>
</tbody>
</table>

**DIAGRAM 37: Age profiles for questionnaire.**
The span of experience of higher education thus covers a period from the mid 1950's through to the 1980's, with the bulk of experience being post 1960. Although the sample is too small to make generalisations, it is striking that the bulk of the E group are in the mid-period of professional life, and hence are at some distance from initial graduation. One or both of two effects could follow from this. Firstly, there is an obvious 'generation gap' in comparison with the S group; secondly, the E group's own experience of higher education could be 'dated', and hence out-of-step with current needs and practice. Throughout the following discussion of the questionnaire data, I shall refer to the practitioners as the P-group, the educators as E-group and the students as S-group. The total sample will be referred to as the T-group. It must be remembered however that the population size (N) of each group is not identical. Hence in quoting percentages in the text, N values will be given in brackets, eg., 15.0% (13), which should be read 15.0% of 13.

9.4.3 Section B of the questionnaire referred to the focal concepts, firstly enquiring whether molecular and mathematical modelling were seen to be:

a) very useful or not useful
b) easy to understand or not easy to understand
c) very accurate or not very accurate.

Table 27 (see p 206 ) summarises the main points emerging for the whole group (T).

The trend is thus for molecular modelling to be seen as useful but not very accurate, for kinetics and equilibrium, with an indication that it is easy to understand. Mathematical modelling in kinetics and equilibrium is seen to be both useful and accurate, but not very easy to understand. Thermodynamics is not seen as amenable to molecular modelling, and thus is seen to be very much the province of mathematical modelling.
<table>
<thead>
<tr>
<th></th>
<th>Molecular modelling. %</th>
<th>Mathematical modelling. %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Kinetics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B1-6</td>
<td>useful 50.0</td>
<td>useful 62.5</td>
</tr>
<tr>
<td></td>
<td>not very useful 46.2</td>
<td>accurate 51.3</td>
</tr>
<tr>
<td></td>
<td>easy to understand 33.3</td>
<td>not easy to understand 33.3</td>
</tr>
<tr>
<td><strong>Equilibrium</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B7-12</td>
<td>useful 37.5</td>
<td>useful 51.3</td>
</tr>
<tr>
<td></td>
<td>not very accurate 52.8</td>
<td>accurate 40.5</td>
</tr>
<tr>
<td></td>
<td>not easy to understand</td>
<td>not easy to understand</td>
</tr>
<tr>
<td><strong>Thermodynamics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B13-18</td>
<td>not useful 40.0</td>
<td>useful 70.3</td>
</tr>
<tr>
<td></td>
<td>not very accurate 51.4</td>
<td>accurate 56.8</td>
</tr>
<tr>
<td></td>
<td>not easy to understand</td>
<td></td>
</tr>
</tbody>
</table>

N=40

**TABLE 27: T-group responses; B1 to B18.**

A further look at the PEST profiles indicates that the S-group in particular found difficulty with mathematical modelling in kinetics [66.9% (9)], and half of them were not sure of its usefulness [50.0% (10)]. Another interesting difference of opinion is between the P-group who saw mathematical modelling in equilibrium as useful [76.5% (17)], and the S-group who did not have a strong opinion [66.6% (9) 'neutral' response]. Further, the S-group found mathematical modelling in equilibrium difficult to understand [75.0% (9)], a view not shared to anything like the same extent by the P- and E- groups. Since the P-group found mathematical modelling in equilibrium useful [76.5% (17)], a view not shared to the same extent by the E-group [46.2% (13)] and hardly at all by the S-group [11.1% (9)],
one wonders about the possibility of perceptions being ameliorated through use of the concepts. This point is strengthened by a similar effect in perceptions of the usefulness of mathematical modelling in thermodynamics \( P - 88.2\% \ (17); E - 76.9\% \ (13); S - 14.3\% \ (17) \). In fact, a small majority of those making other than a neutral response in the S-group, thought mathematical modelling not very useful in thermodynamics \( 28.6\% \ (7) \).

9.4.4 Section B also inquired into perceptions of the value of qualitative versus quantitative approaches to the focal concepts. As Postulate 1 of the perceptual space model, this is closely related to molecular/mathematical modelling (see 7.3.6). In response to the question 'which of these two approaches do you consider important for understanding these concepts?', the T-group response was (Table 28):

<table>
<thead>
<tr>
<th></th>
<th>Qualitative %</th>
<th>Quantitative %</th>
</tr>
</thead>
<tbody>
<tr>
<td>B20 Kinetics</td>
<td>25.0</td>
<td>50.0</td>
</tr>
<tr>
<td>B21 Equilibrium</td>
<td>40.0</td>
<td>22.5</td>
</tr>
<tr>
<td>B22 Thermodynamics</td>
<td>30.0</td>
<td>45.0</td>
</tr>
</tbody>
</table>

\( N=40 \)

**TABLE 28: T-group responses; B20 to B22.**

The most significant point here arises in connection with kinetics and equilibrium. The PEST profiles show that it is the S-group who predominantly prefer a qualitative approach in equilibrium \( 50.0\% \ (10) \) compared with E and P. This trend is also reflected in connection with kinetics, though to a lesser extent, where the P-group preference for a quantitative approach predominates \( 64.7\% \ (17) \). Table 29 summarises the
T-group responses for the remaining questions in Section B:

<table>
<thead>
<tr>
<th>Question</th>
<th>Agree</th>
<th>Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>B23 Qual/Quant. approaches inseparable</td>
<td>43.6 (39)</td>
<td>35.9 (39)</td>
</tr>
<tr>
<td>B24 Qual. prerequisite for quant.</td>
<td>72.5</td>
<td>15.0</td>
</tr>
<tr>
<td>B25 Quant. prerequisite for qual.</td>
<td>12.5</td>
<td>72.5</td>
</tr>
<tr>
<td>B26 Qual. more elementary than quant.</td>
<td>62.5</td>
<td>15.0</td>
</tr>
<tr>
<td>B27 Qual. gives more 'realism'</td>
<td>47.5</td>
<td>25.0</td>
</tr>
<tr>
<td>B28 Quant. gives more 'realism'</td>
<td>17.9</td>
<td>48.7</td>
</tr>
<tr>
<td>B29 Qual. less abstract than quant.</td>
<td>50.0</td>
<td>30.0</td>
</tr>
</tbody>
</table>

N=40

TABLE 29: T-group responses: B22 to B29.

One can infer from this that the two approaches form a continuum in keeping with Postulate 1 of the perceptual space model (7.3.6). Full understanding seems most likely if one begins with a qualitative approach, which has the qualities of being less abstract and more 'realistic' in chemical terms. Reference to the PEST profiles would indicate that the E-group were more prepared to separate qualitative from quantitative approaches [53.8% (13)] than the P- and S-groups. This is an interesting point, since there may be a correlation here with thinking modes (Tn or Tp). A more qualitative approach would be appropriate for Tp mode thinking, whilst a quantitative approach would be appropriate for Tn mode (see 7.5.1). It is possible, therefore that this E-group view reflects a particular concern with Tn modal thinking. A further point of interest lies in the strong S-group view that qualitative approaches are less abstract [80.0% (10)] in comparison with E- and P-group opinion, which is more or less evenly divided on this point. This could be a result of resistance to mathematical
explanations, but it may also relate to the feeling, expressed at interview, that molecular modelling has more 'chemical reality' - a point of particular importance to those learning chemistry.

9.4.5 Before leaving Section B, one very significant factor must be touched on. The response rate for the S-group varied between 5 and 10 for the group of 10. Of the 22 questions directly related to the focal concepts, only 5 had a 100% response rate. The section on thermodynamics was particularly badly dealt with, with responses from between 5 and 7 of the group of 10. The more general areas dealing with qualitative and quantitative approaches brought a 100% response rate (820 -29). The other groups showed no similar trait anywhere within the questionnaire. There is evidence in the student group-interview transcripts to suggest that the focal concepts were hardly retained at all after graduation (see 7.5.7), with bad teaching being given as the main reason. Whatever the reason - and this will be discussed further in Chapter 10 - the same poor understanding and memory factors appear very clearly in the S-group's response to the questionnaire.

9.4.6 Section C was designed to check participants' perceptions of their undergraduate course, firstly in total and then with respect to the focal concepts. Table 30 (see p210 ) summarises the responses for the undergraduate course in total. As can be seen, the majority [71.8% (39)] enjoyed the total course, a sizeable proportion [35.9% (39)] did not find it difficult, and a majority found it interesting [66.7% (39)]. The courses seemed to match the expectations of many [48.7% (39)]. Whilst nearly half felt the courses were examination success orientated [48.8% (39)], almost two-thirds felt their courses were not vocationally orientated [61.5% (39)]. About half felt their course had intentionally promoted understanding
Examination of the PEST profiles does not reveal any major shift in opinion between the groups, though the trend appears to be that the P-group were most conscious of any examination orientation, whilst a small but not insignificant group of the S-group did find their course vocationally orientated [33·3% (9)], and/or did not intentionally promote chemical understanding [33·3% (9)].

<table>
<thead>
<tr>
<th></th>
<th>Agree %</th>
<th>Disagree %</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1 enjoyable</td>
<td>71·8</td>
<td>7·7</td>
</tr>
<tr>
<td>C2 difficult</td>
<td>12·8</td>
<td>35·9</td>
</tr>
<tr>
<td>C3 interesting</td>
<td>66·7</td>
<td>15·4</td>
</tr>
<tr>
<td>C4 matching expectations</td>
<td>48·7</td>
<td>23·1</td>
</tr>
<tr>
<td>C5 exam success oriented</td>
<td>48·8</td>
<td>25·6</td>
</tr>
<tr>
<td>C6 vocationally oriented</td>
<td>15·4</td>
<td>61·5</td>
</tr>
<tr>
<td>C7 promoted chemical understanding</td>
<td>51·3</td>
<td>15·4</td>
</tr>
</tbody>
</table>

(N=39)

This rather agreeable picture changed dramatically when the same factors were related to the focal concepts. Of the T-group, nearly half did not enjoy kinetics [43·6% (39)] or thermodynamics [41·1% (39)]. Over one-third found them difficult [kinetics: 35·9% (39); thermodynamics: 43·6% (39)]. More than half found this part of their course very mathematical [kinetics: 52·6% (38); thermodynamics: 66·7% (39)]. Perhaps even more significantly no-one [ie. 0·0% (40)] found any vocational orientation in their kinetics and thermodynamic courses, whilst the great majority [61·6% (39)] found none in
equilibrium. It is worth reflecting at this point that many higher education institutions make strong claims about the vocational value of their courses (see 8.1.2) and that the focal concepts are of extreme importance in chemical industrial practice. Some further interesting points emerge when the PEST profiles are inspected. For example, the relatively small T-group proportions finding that the focal concepts proved useful in their work [kinetics: 41.1% (39); thermodynamics: 35.9% (39); equilibrium: 43.6% (39)], masks a higher proportion of the S-group not finding the focal concepts useful [kinetics: 66.7% (9); thermodynamics: 66.7% (9); equilibrium: 66.7% (9)]. With their limited work experience in mind, I would suggest that the S-group's view here is coloured more by the lack of vocational relevance projected during the course, than anything else. In general, also, it is the S-group that found the courses rather mathematical [kinetics: 62.5% (8); thermodynamics: 77.8% (9); equilibrium: 55.6% (9)] though significant proportions of E- and P- group shared this view [ie. 40.0% or above].

9.4.8 The influence of mathematics formed the basis of several other questions in Section C (C35-43). Table 31 outlines the responses for the T-group when asked their views on the mathematical aspects of the focal concepts:

<table>
<thead>
<tr>
<th></th>
<th>Agree %</th>
<th>Disagree %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Kinetics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>enjoyable</td>
<td>38.5</td>
<td>41.0</td>
</tr>
<tr>
<td>easy</td>
<td>33.3</td>
<td>28.2</td>
</tr>
<tr>
<td>interesting</td>
<td>41.0</td>
<td>35.9</td>
</tr>
<tr>
<td><strong>Equilibrium</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>enjoyable</td>
<td>33.3</td>
<td>33.3</td>
</tr>
<tr>
<td>easy</td>
<td>23.0</td>
<td>30.8</td>
</tr>
<tr>
<td>interesting</td>
<td>35.9</td>
<td>43.6</td>
</tr>
<tr>
<td><strong>Thermodynamics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>enjoyable</td>
<td>30.8</td>
<td>46.2</td>
</tr>
<tr>
<td>easy</td>
<td>10.3</td>
<td>41.0</td>
</tr>
<tr>
<td>interesting</td>
<td>33.3</td>
<td>46.2</td>
</tr>
</tbody>
</table>

(N=39)

TABLE 31: T-group responses C35 - C43.
There is little of significance in these figures except for the fact that a significant number found the mathematical aspects of thermodynamics difficult compared with those who found it easy [41.0% (39) cf 10.3% (39)]. It is when the PEST profiles are considered that some underlying significances are revealed. A higher proportion of the S-group disliked the mathematics associated with kinetics, than enjoyed it [55.5% (9) cf 33.3% (9)]. A majority of the P-group found the mathematics of kinetics interesting [52.9% (17)], whilst more of the E-group disliked the mathematical aspect than liked it [38.5% (13) cf 23.1% (13)]. The S-group did not find the mathematical aspects of equilibrium easy either [66.7% (9) cf 11.1% (9)]. Nearly two-thirds of the E-group [61.5% (13)] found the mathematical aspects of thermodynamics lacking in interest. It is difficult to find evidence for any explanation of these differences, but I suspect the educators' lack of enthusiasm may have some bearing on students' difficulties. The use of these concepts in day-to-day work routines may well have improved practitioners' appreciation of mathematical aspects.

9.4.9 The final part of Section C sought participants' views on some general points about physical chemistry courses and their experience of them. The T-group was evenly divided upon whether mathematics should only be used as a tool to solve problems [43.6% (39) cf 43.6% (39)]. There was quite strong disagreement with the statement that physical chemistry should be taught by specialists who are actively researching in the area [63.2% (38)], but strong agreement with it being taught by lecturers with a wide understanding of the area [73.7% (38)]. There was even stronger agreement that physical chemistry should be clearly related to experimental work designed to help concept understanding [78.9% (39)]. This latter point was particularly strongly supported by the S-group [100.0% (9)]. Experience of higher education showed that nearly half met
with mathematics being used mainly as a tool to solve problems [46·2% (39)], and over half found it used mainly to model chemical phenomena [51·3% (39)]. A majority found that the focal concepts were not closely related to real chemical problems or situations [kinetics: 51·3% (39); equilibrium: 46·2% (39); thermodynamics: 59·0% (39)]. The PEST profiles reveal that a large proportion of the S-group found mathematics used mainly to model chemical phenomena [77·8% (9)]. The E-group found little 'real problem solving' in kinetics [69·2% (13)], equilibrium [46·2% (13)], or thermodynamics [84·6% (13)] in their courses, in contrast to the S- and P-groups whose experience in this area was fairly evenly divided. It is interesting to speculate whether this is a product of the differing age profiles of the groups. If so, it could indicate that more recent courses are involving more 'real-problem' aspects than previously.

9·4·10 Section D tackled personal perceptions of first degree courses. This section produced easily the most strongly polarised comment. Table 32 outlines the T-group responses relating to the expectations participants had of their undergraduate courses:

<table>
<thead>
<tr>
<th>Expectations</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1 useful in terms of employment</td>
<td>82·5</td>
<td>2·5</td>
</tr>
<tr>
<td>D2 stimulating an understanding of chemistry</td>
<td>85·0</td>
<td>2·5</td>
</tr>
<tr>
<td>D3 valuable for professional status</td>
<td>70·0</td>
<td>10·0</td>
</tr>
<tr>
<td>D4 efficient means of gaining knowledge</td>
<td>72·5</td>
<td>0·0</td>
</tr>
<tr>
<td>D5 simply a mechanism for a degree</td>
<td>17·5</td>
<td>77·5</td>
</tr>
<tr>
<td>D6 giving personal development</td>
<td>69·3</td>
<td>12·8</td>
</tr>
</tbody>
</table>

(39) (39)

TABLE 32: T-group responses D1 to D6.
An open question (D7) was provided to allow participants to list any other expectations they had. Only three others emerged:

a) that the course should be demanding, but with adequate tutorial support (S-group).

b) that the course should have meaningful practical work (S-group).

c) that the course should indicate new and exciting research areas.

From the PEST profiles, it was clear that there were no significant differences in expectation between the groups. When responding to being asked whether these expectations had been fulfilled, the first - usefulness for employment - seems to have been met [85·0% (40)]. Slightly fewer found their course as stimulating as expected [62·5% (40) cf 85·0% (40)]. The major failure in expectation appears to be with the S-group, whose 90·0% (10) initial rating dropped to 40·0% (10). A similar, but smaller, shortfall also occurs with the E- and P- groups, indicating an element of disillusionment with higher education. This may perhaps relate to the mismatch between an expectation of courses as an efficient means of gaining knowledge [72·5% (40)], and the realisation of that expectation [50·0% (40)], the main groups affected being P and S [from 88·2% (40) to 52·9% (40) and 50·0% (10) to 20·0% (10) respectively]. The low expectation of degree courses simply being a mechanism for obtaining a degree also changed. For the E- and S- groups, some degree courses must have been simply a degree producing mechanism because the ratings dropped from 69·2% (13) to 38·5% (13) for the E-group, and from 80·0% (10) to 50·0% (10) for the S-group. In general terms the other expectations appear to have been largely fulfilled.

9·4·11 When asked about course design (Section E), there was
again strongly polarised comment. There was minimal support for school teachers being involved in higher education course design, mainly from the S-group [44.4% (9)], but the E-group had a clear view against [53.8% (13)]. All three groups strongly supported the involvement of higher education teachers [P: 88.2% (17); E: 92.3% (13); S: 100.0% (10)]. The involvement of industrial chemists was also strongly supported, particularly by the S-group [100.0% (10)] and P group [82.4% (17)], but somewhat less so by the E-group [61.5% (13)]. A small majority gave low priority to student involvement [T: 30.8% (40)]. This overall comment masks a small S-group support for student involvement [20.0% (10) with 80.0% (10) neutral comment] contrasting with a sizeable E-group showing low priority [46.2% (13)]. It is clear from further responses that higher education teachers and industrial chemists should have a strong influence over course design [85.0% (40) and 67.5% (40) respectively]. It is notable that, of the E-group, 92.3% (13) [7.7% (13) neutral response] gave priority to higher education teachers having strong influence over course design; only 46.2% (13) offered the same opportunity to industrial chemists. It is also interesting to note that the T-group's 60.0% (40) 'vote' giving low priority to students having influence over course design was strongly supported by the S-group [70.0% (10)]. Table 33 provides a summary of the responses to a series of criteria suitable for helping with the selection of content in higher education physical chemistry courses:

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Priority</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>E11 important concepts in chemical education</td>
<td>87.5</td>
<td>0.0</td>
</tr>
<tr>
<td>E12 importance in industry</td>
<td>85.0</td>
<td>0.0</td>
</tr>
<tr>
<td>E13 ease of quantification</td>
<td>10.0</td>
<td>52.5</td>
</tr>
<tr>
<td>E14 ease of examination</td>
<td>2.6(39)</td>
<td>78.9(39)</td>
</tr>
<tr>
<td>E15 good practical possibilities</td>
<td>65.0</td>
<td>7.5</td>
</tr>
<tr>
<td>E16 good examples of application</td>
<td>65.0</td>
<td>12.5</td>
</tr>
<tr>
<td>E17 elegance of theoretical explanation</td>
<td>17.5</td>
<td>47.5</td>
</tr>
<tr>
<td>E18 high student interest potential</td>
<td>67.5</td>
<td>5.0</td>
</tr>
<tr>
<td>E19 essential for future research capability</td>
<td>45.0</td>
<td>15.0</td>
</tr>
</tbody>
</table>

(N=40)

TABLE 33: T-group responses: E11 to E19.
9.4.12 Inspection of the PEST profiles elicits two interesting points. Whereas a high proportion of the P-group [64.7% (17)] and E-group [53.8% (13)] gave low priority to 'ease of quantification' as a criterion, as many of the S-group gave it high priority as low priority [30.0% (10) and 30.0% (10) respectively]. This is a fascinating contrast with the claims that physical chemistry courses are too highly mathematicised, made during interview. In accepting the integrity of such recorded comment, I can find no explanation for such an apparent contradiction. A second point arises in connection with the criterion 'good practical possibilities'. The T-group 65.0% (40) response giving it high priority, disguises an interesting difference between the groups. Both P and S give this criterion high priority [76.5% (17) and 100.0% (10) respectively]. However, the E-group gave a 23.1% (17) response giving good practical possibilities high priority, and a 23.1% (17) giving it low priority. This is at variance with the E-group response to the statement that 'physical chemistry should be clearly related to experimental work which is designed to help concept understanding' (see 9.4.9). 76.9% (13) of the E-group supported this statement, yet somehow do not give strong support to a criterion of 'good practical possibilities' in the selection of content. Again, I can find no explanation for such an apparent contradiction.

9.4.13 A review of responses to the open questions showed that three particular questions had sponsored keen interest. Table 34 shows the total response pattern (see p217). The 72.5% (40) response on B19 related to personal perceptions of how the focal concepts were inter-related. Two very clear issues emerged here:—

a) whether the concepts were linked or separate.

b) whether the concepts were discussed in mechanistic or energetic terms.
TABLE 34: Response pattern for open questions.

It was not found possible to quantify, in any meaningful way, the occurrence of these two issues, since there appeared to be a spectrum of opinion in each case. However, some examples will make clear the presence of these polarities. The linking of the concepts was obvious to participant 47:

These are all very interrelated ie.:
1. The kinetics of a reaction is dependent upon how thermodynamically positive it is.
2. Consideration of the thermodynamics of an equilibrium or a reaction often explains phenomena that would otherwise be difficult to understand.

[questionnaire P47, p 5]

Others were rather more direct in their assertion:

All are mathematical.

[questionnaire P25, p 5]
I usually lump all these together - the physics of chemistry from which you can formulate theories.

[questionnaire S30, p 5]

Totally - it is impossible to talk of anyone in isolation.

[questionnaire E21, p 5]

At the other end of the spectrum were comments such as:

I don't make any distinction between equilibrium and thermodynamics, kinetics uses concepts of thermodynamics and statistical mechanics, but it is a separate study.

[questionnaire E22, p 5]

Equilibrium and thermodynamics ultimately; kinetics less related.

[E40, p 5]

I see equilibrium and thermodynamics as being close together, whereas kinetics not so.

[E48, p 5]

Not one of the 'separatists' occurred outside the E-group, a point which may have some significance. This schism does however confirm the conclusion drawn from interview data, which formed the basis of Postulate 3 of the perceptual space model.

9.4.14 The macro-micro system (energetic-mechanistic) dimension, already noted in 9.4.1, also can be seen in responses to item B12. For example:

Reaction kinetics (ie. rate and probability of reaction) are determined by the thermodynamics - the energy levels of the various species involved - and the outside constraints applied. Equilibrium is the state reached when the energy of the system has been allowed to distribute itself.

[questionnaire P09, p 5]
Participant 9 is here clearly recognising the energetic dimension on the macro scale ('outside constraints'), and at the same time acknowledging the micro-system ('the various species involved'). Participant 38 is more mechanistically oriented:

All need to be considered to establish a reaction mechanism.

[questionnaire S38, p5]

Whilst participant 24 has an energy bias:

Chemical eq\textsuperscript{m} - position determined by thermodynamics as system moves to lowest energy position (\(\Delta G=0\)). Kinetics indicates rate at which a reaction moves, thermodynamics determining the height of activation barrier. Catalysis enables height of activation barrier to be altered. Position of C.E. cannot be altered (at fixed T and P).

[questionnaire P24, p 5]

There is, I believe, clear confirmation here of Postulate 2 of the perceptual space model, suggesting a macro-micro dimension to perceptions of the focal concepts.

9.4.15 There were two other sets of responses to open questions, having particular significance:

a) D14 criteria for selection of D15 course content 85.0% (40)

b) E20 interpretation of 'chemical reality' 85.0% (40)

Each of these will be discussed in the next chapter, together with other comment on the effectiveness of chemical higher education.

9.5 Summary.

9.5.1 The main issues arising from the interview data have been:
a) polarities in the perceptions of the focal concepts relating mechanistic/energetic explanations, molecular/mathematical modelling and a kinetics/equilibrium (thermodynamics) schism. These three dimensions formed the basis of the perceptual space model (7.4).
b) evidence of two modes of thinking concerning the focal concepts (Tn; Tp) which formed the basis of a thinking strategy model (7.2).
c) differing perspectives on the importance of the focal concepts for three groups of people - Practitioners, Educators and Students, which are a cornerstone of the triadic model of educational relevance with respect to these concepts (8.3).

9.5.2 I believe that the evidence from the questionnaire supports and confirms these three assertions in the following manner:

a) Responses to X 1,2,3 and B 19 support the presence of a mechanistic/energetic dimension (Postulate 2) and a kinetics/equilibrium (thermodynamics) schism (Postulate 3).
b) Responses to items B 1 to B 29 indicate support for a molecular/mathematical modelling dimension (Postulate 1) in view of the general ease with which responses were made - except in one notable instance, that of the S-group, who (on evidence from Section C) find mathematical modelling difficult.
c) Responses to items B 1 - 29 also support the thinking strategy model, with clear evidence of Tn and Tp modes of thinking. These are also displayed in responses to the open question B 19.
d) The PEST profiles have frequently revealed significant differences between the views of the three groups. This I believe to be an indication of the individual 'decision environments' experienced by each group, though clearly
Diagram 38: Interrelationships of the elicited models.
these may overlap.

9.5.3 On the basis of the trends shown in the questionnaire data, I feel confident that a reasonable measure of credibility has been obtained for the ideas generated by the interview data. It is now possible to link these ideas and models together in an overall flow-chart (Diagram 38, p221). The perceptual space (7.4) which is variably occupied dependent upon relevance limits and thinking strategies (7.2 and 8.4) is embedded in the decision environments which influence an individual’s perception of both personal and instrumental relevance. The extent to which the focal concepts are thus fully understood will depend on an interplay of all these factors, and the extent to which personal learning occurs. This is in some measure an interplay between psychological and epistemological factors. These points will be developed further in Chapter 10, particularly with regard to personal learning.

* * * *
Chapter Ten

Retrospect and prospect.

In which the processes and products of the inquiry are reviewed, and the implications for chemical education assessed.

10.1 Methodology
10.2 Confirmation
10.3 Research questions
10.4 Implications
10.5 Summary
CHAPTER TEN.

10. RETROSPECT AND PROSPECT.

'Wisdom teaches that our knowledge will be secure only if we really love our search for it.'


10·1 Methodology.

10·1·1 I have already suggested that any 'systematic self-critical inquiry' is a journey (Preface and 3·1·4) and that whilst having some idea where this particular journey began, I was uncertain where it might end (1·1). The experience of conducting this inquiry gives me to understand that there is no real 'end'. There is need however for a halt during which one reviews the road taken and surveys possible ways forward. If this can be done from a sound 'vantage point' the chances of finding effective ways forward are increased. Analogy, if pushed too far, can enter the realms of fantasy. Nevertheless, I think I can claim with some justice that I have reached such a vantage point on my journey.

10·1·2 The choice of a case-study methodology (4·2·3) has proved well suited to both the hybrid character of the field of the inquiry (3·1·5) and to the complex character of the concept of relevance. A major strength of the naturalistic paradigm is its flexibility in progressively focussing on significant aspects of multivariate situations. The use of an interview technique backed up by a confirmatory questionnaire, and intensive date analysis has, I believe, proved both effective and credible. In a research field of 'subjective reality' this approach has corroborated the five axioms of naturalistic study (3·4·3), through allowing an improved
understanding of the context of educational relevance through description of individuals' perceptions of their educational experience.

10·1·3 The absence of any clear definition of complex concepts such as relevance, leaves the way open for individual or group interests to generate hidden nuances beneath an apparently concensus meaning. This can lead to situations such as the 'relevance dilemma', and 'pseudo-relevance' (8·2·8). Any inquiry in an area having these characteristics must provide an understanding of the views people have of their world from their particular situation. Personal construct psychology has provided a strong theoretical framework for this study for this very reason. As Pope (1982) has pointed out:

'For Kelly, a successful communication between people depended not so much on commonality of construct systems, but on the extent to which people 'construe the construct system of the other' - ie. have some empathy and understanding of someone else's construct whilst not necessarily holding the same construct oneself.'

p8 (my emphasis).

This refers not only to the relationship between researcher and participants, but also indicates a need to be aware of differing personal constructs among the participants. Further, constructivism has considerable congruence with contemporary philosophies of science, providing a bridge between science and education (3·4·8). The assertion that knowledge is personally constructed has important implications for learning and understanding, a point discussed further in 10·4·3.

10·1·4 One particular danger in naturalistic research is an unrecognised interference from 'black-market understandings' (5·5·3). Insights gained by the researcher through involvement in interview may be unique and unavailable to others. Such insights may also be coloured by the researcher's own attitudes
and values etc. There is no direct methodological technique of which I am aware to eliminate this difficulty — short of the research audience being present at the time of interview, a clear impracticability! Indirect methods have thus been used in this inquiry to reduce this effect and improve the accountability of interpretation:

a) an open statement of my own commitments as educator and researcher (Chapters 1 and 2).

b) regular negotiation of data and data editing (selection) with the participants.

c) the use of the participants' negotiated statements as far as possible in developing the argument.

10.1.5 Four criteria may be used to check the 'trustworthiness' of naturalistic inquiry (4.1.3):

1. Credibility
2. Confirmability
3. Dependability
4. Transferability.

Of these, two (credibility and confirmability) I believe to have been clearly met through the processes outlined in 10.1.4, and through the questionnaire (Chapter 9). The criterion of dependability requires closer inspection. In terms of methodology I think the criterion has been satisfied, since every attempt has been made to describe the research process in detail. Repetition of the process should present no difficulties. Whether the outcomes would be replicated is in my view debatable. Replicability is based on axioms more germane to rationalistic inquiry (4.1.2). There is, however, an element of stability in the findings of this inquiry which suggests similar ideas might emerge.

Transferability is difficult to judge. Again as case-study methodology, the processes of this study could be applied to perceptions of other conceptual areas. Whether the models generated in this inquiry would either inform or emerge from such other studies could only be determined by further research.
In view of the deliberate restriction of this study to particular conceptual areas, I would resist any attempt at direct transferability. I am critical of these last two criteria in so far as they may be interpreted as placing demands on naturalistic study which axiomatically it should not encompass.

10.1.6 A particular problem posed in this inquiry has been that of sampling. Chemical practice embraces an enormously wide range of activities, and only a large sample could provide coverage of a majority of these. The main thrust of the study has been concerned with perceptions of relevance based on experience of higher education. The size of the final sample was determined largely by 'theoretical saturation' [Agar (1980)], ie. further interviews produced no new data. It should be remembered that the opportunity to extend the sample was taken when the questionnaire was distributed (9.2.1). A total of 51 participants have been involved in the inquiry. In only one case has limited role-specificity produced any comment:

My opinions as expressed in the answers to the above questions relate to my experiences as a chemical engineer not as a chemist - a chemist I am not.

(questionnaire P 08, p10)
original emphasis.

This, I suggest, says more of this participant's perception of his role, than about sampling and sample size. It does however indicate that further related studies designed to elicit practitioner role-perceptions and their importance for education could be very valuable.

10.2 Confirmation.
10.2.1 The premises made at the start of this inquiry concerning the importance of the focal concepts appear to have been confirmed (2.6). Two comments from an open question in the questionnaire make this clear, and are good examples of the views expressed at interview also:
From my personal experience I find that this area of chemistry is probably the most important topic in industrial process applications.

(questionnaire P69, p12)

In many respects physical chemistry is the basis of all chemistry and is therefore important in chemical education as a whole. Chemical education in itself should be relevant to the needs of industry.

(questionnaire E21, p12)

10.2.2 The mismatch between expectation and educational experience (8.1) also appears to have been confirmed, with particular respect to the focal concepts. From questionnaire evidence 85% (40) of those participating expected their degree courses to be useful for employment, whereas only 5.1% (39) found any vocational orientation in any aspect of the teaching of the focal concepts. There is no significant variation in this pattern between the practitioner, educator or student groups. Of the focal concepts, kinetics and thermodynamics appeared not to have any vocational orientation at all (PEST profiles C6, C14, C23 and C32).

10.2.3 Seminar comment obtained after the IP interviews (6.4.3) seems also to have received confirmation. The remodelling of thinking strategies (7.2) has facilitated a mechanism for describing personal understanding of the focal concepts (7.5). That the two thinking modes might form a sequential development of understanding is partly supported by the agreement of 72.5% (40) of the questionnaire participants that a qualitative (largely Tp) understanding of the focal concepts is prerequisite to a quantitative (largely Tn) understanding. This is further supported by the agreement of 62.5% (39) of the T-group that a qualitative understanding is more elementary. Evidence for differing 'value bases' for use of the thinking modes is seen in the higher incidence of Tp mode usage among practitioners compared with educators (8.4.4). The suggested relationship between mathematical difficulties
and a content/process dimension has some support in both interview and questionnaire data. However, this would appear to involve a more complex issue relating to 'chemical reality' (discussed in 10.4.15). There has been no supporting evidence of qualitative differences between graduate and higher-graduate participation. There has been some comment from practitioners that 'high flying academics' do not make the most adaptable employees, a point taken up in 10.5.2.

10.3 Research Questions.

10.3.1 The research questions (2.9) forming the basis of the study are:

a) Is it possible to characterise educational relevance?

b) What makes concept learning to be of greatest practical/vocational value?

c) What is required to make chemical education courses of optimum relevance?

I want now to discuss these in turn, apply directly the ideas developed in this inquiry, namely:

a) thinking modes

b) perceptual space and personal understanding

c) the relevance model

before moving to a discussion of the implications.

10.3.2 Is it possible to characterise educational relevance in chemical education? My answer, in the light of the experience of the inquiry, must be a qualified 'Yes'. The caveat involved is the concern already expressed over transferability (10.1.5). My answer is thus in two parts, the general and the specific. The general characteristics are given in Table 35 (p.230). Failure to recognise the evaluative nature of educational relevance may lead to pseudo-relevance, in which the perspective of a person or group of persons is taken for granted, and becomes on the surface indistinguishable from propositional relevance. This may not provide difficulty unless the integrity of such pseudo-relevance is called into question, perhaps as
a result of failure to match stated objectives, or through individuals' unfulfilled expectations. A lack of understanding of the various perspectives involved and their associated decision environments, must reduce the ability to be evaluative. Non-recognition of the importance of each of the operational modes will severely limit successful evaluation of educational relevance, whether the various perspectives have been considered or not. Education has for too long wanted for mechanisms to link theory and practice in a meaningful way. Unless pseudo-relevance is avoided one such mechanism may well not operate. These general characteristics of educational relevance must therefore have enormous significance for the professional activities of the educator.

<table>
<thead>
<tr>
<th>Educational relevance is:--</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Evaluative</td>
</tr>
<tr>
<td>2. A multi-perspective concept</td>
</tr>
<tr>
<td>3. Related to 'decision environments'</td>
</tr>
<tr>
<td>4. An important mechanism linking knowledge and its application</td>
</tr>
<tr>
<td>5. Dependant upon two operational modes:</td>
</tr>
<tr>
<td>a) instrumental</td>
</tr>
<tr>
<td>b) personal</td>
</tr>
</tbody>
</table>

TABLE 35: General characteristics of educational relevance in chemical education.

10·3·3 Specifically related to the focal concepts, educational relevance carries a further characteristic (Table 36, p231). Implicit in this sixth characteristic is that high occupancy of perceptual space is consonant with high understanding of the concepts themselves and vice-versa (7·5·6). Further, since this relates to the ability of the individual to operate with particular thinking modes, it is personal learning which
is important, i.e. understanding rather than acquisition. The additional characteristic must, therefore, be of great significance in course design and selection of teaching techniques on the one hand, and student engagement with the teaching/learning process on the other.

For chemical kinetics and equilibrium,

**educational relevance is:-**

1. Evaluative
2. A multi-perspective concept
3. Related to decision environments
4. An important mechanism linking knowledge and its application
5. Dependent upon two operational modes:
   a) instrumental
   b) personal
6. A function of the individual's ability to use the appropriate thinking modes to gain maximal occupancy of perceptual space.

<table>
<thead>
<tr>
<th>TABLE 36: Characteristics of educational relevance for the focal concepts.</th>
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</table>

10.3.4 What makes concept learning to be of the greatest practical/vocational value? 'Practical/vocational value' implies that concept learning must have as one of its aims 'application' or 'utility'. Concepts are not very useful nor easily applied unless well understand. Thus at one level, the answer to this question must be 'learning for understanding'. Applying the ideas generated by this study, this would require maximal occupation of perceptual space (provided that it is the focal concepts that are involved). Maximal occupation would require meaningful mastery of the thinking modes. This is, however, still not the full answer, since practical application and vocational utility often require an analytic/synthetic process
requiring flexible and integrative thinking. Tight boundaries around concept learning may lead to isolated pockets of knowledge, whether with understanding or not, which inhibits creative thinking. Concept learning for understanding should thus be lodged within a context which includes the needs of practical application and vocational utility. Thus the learning environment should be cognizant of relevance perspectives. A major implication of this is that the practitioner, educator and learner should all appreciate that knowledge must be supported by application and application supported by knowledge. In operational terms, this should influence course design and the facilitation of personal learning.

10.3.5 What is required to make chemical education courses of optimum relevance? One must inevitably face the supplementary questions 'relevance for what?' and 'relevance for whom'? These questions strike right to the heart of the model of relevances, since judgement of relevance will depend upon the characteristics of an individual's 'decision environment'. Any requirements for improving the relevance of chemical education courses must thus relate to such 'subjective reality'. This is a broad issue, and any attempt to produce generalised solutions would be a move towards pseudo-relevance. I propose therefore to seek answers (not just an answer) to this third question and its supplementaries, in the discussion that follows.

10.4 Implications.
10.4.1 In recent years educational relevance has become almost a pass-word for innovation, being used to justify, promote and pressure educational change. For example, in 1983, Government Command Paper Nº 8836, 'Teaching Quality' gave as one criterion for accrediting teacher education courses the 'recent substantial, and relevant teaching experience' of the staff. In 1985, the Department of Education and Science listed relevance among the ten principles on which policy is based for the practice of science education in the 5-16 age range. Also in 1985 the
Secretary of State for Education wrote to the University Grants Committee suggesting that a higher proportion of students should be studying 'subjects of vocational relevance'. Pressures such as these are, I believe, associated with a wave of vocationalism that has been moving through science education at all levels. This is part and parcel of an increasing demand for education to produce some economic return for the community, through higher employment and higher employability. In an educational context, relevance has become a key issue.

10.4.2 As has previously been suggested, educational relevance involves an evaluative usage (8.2.5). To operationalise educational relevance effectively requires an analysis of those factors which will allow both instrumental and personal relevance to be mutually supportive. The ideal situation, in the context of the focal concepts, would be where the relevance limits of the educator and practitioner were largely congruent (8.4.7). The learner has thus to be put in a position to develop towards such an ideal. The characterisation given to educational relevance by this study thus has major implications in the following areas:

a) development of processes and techniques for student learning which enhance personal and instrumental relevance.
b) staff development in chemical education, where analytical and evaluative skills in an educational context are implied.

These will now be discussed more fully.

10.4.3 Student learning: One factor apparent during this study has been the ease with which the focal concepts have been discussed when what might be termed 'personalised cognition' had taken place. Several strategies for this personalisation were noted:

a) searching for 'patterns':

H: I think if you can see a pattern, then you can get an understanding of what's going on ---

[TR 8; lines 80-81]
b) using 'themes':
   A: You can use energetics as a thread on which you can hang virtually all chemistry.
   [Tr 1; lines 263-264]

c) seeing 'chemical realism':
   WI: --- it's easier to understand from my viewpoint - describing it in a molecular manner --- much easier to relate to a molecular viewpoint than energy states which is --- nebulous. I think it's just too vague, nothing actually concrete to lock onto there.
   [TR 23; lines 455-461]

d) linking theoretical and practical learning:
   F: Yes, of course, every practical example makes teaching better --- it sets imagination going and you can visualise things.
   [TR 6; lines 501-503]

These factors seem to produce an internalisation or personal construction during learning which enhanced understanding. Considerable naturalistic research has been done in the area of student learning, using qualitative methods and rigorous analysis of interview data. Some important outcomes of this research are summarised in Table 37:

<table>
<thead>
<tr>
<th>Experience of learning</th>
<th>Full understanding</th>
<th>Partial understanding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Referential approach</td>
<td>Deep processing</td>
<td>Surface processing</td>
</tr>
<tr>
<td>Organisational approach</td>
<td>Holistic approach</td>
<td>Atomistic approach</td>
</tr>
<tr>
<td>Strategy</td>
<td>Meaning orientation</td>
<td>Reproducing orientation</td>
</tr>
<tr>
<td>Style</td>
<td>Comprehension learning</td>
<td>Operation learning</td>
</tr>
<tr>
<td>Motivation</td>
<td>Intrinsic</td>
<td>Extrinsic</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Premise: Personal construction of knowledge is characteristic of full understanding.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>Referential approach</td>
</tr>
<tr>
<td>Organisational approach</td>
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<tr>
<td>Strategy</td>
</tr>
<tr>
<td>Style</td>
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<tr>
<td>Motivation</td>
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</table>

TABLE 37: Summary of research into student learning.
These inquiries were undertaken within a personal construct framework and hence the premise made is that personal construction of knowledge is a necessary requirement for full understanding in learning. Such full understanding would appear to be achieved through a certain specific attitude to learning. This appears to require an ability and personal willingness to search for meaning embedded in an integrative context [A useful review of research into student learning is given by Ramsden (1985)].

10.4.4 These findings may be related to my argument that full understanding equates with optimal occupation of perceptual space, and that such occupation may be limited by the extent of perceived personal and instrumental relevance. For a student to develop such optimal occupation, experience of education should foster full understanding, and not partial understanding. Within the data, there are clues indicating why such partial understanding may occur (7.5.7). Although the following examples are taken from the student group, similar comments are found throughout the interviews:—

BB1: A lot was not actually relevant; we did projectiles in physics, and that didn't mean much for Food Science [the main subject of the degree].

[TR 29; lines 80-81]

BB2: --- it was easy to learn rote fashion and get good marks.

[TR 29; line 99]

BB3: Organic lectures were terrible. Organic chemists must be the most boring people on earth with little arrows going everywhere ---

[TR 29; lines 136-138]

BB1: In our physical chemistry course we split up our course into different sections so when you finished one you went on to something else straightaway - they weren't related. It's just that the lecturers had a timetable for you and that was it.

[TR 29; lines 265-269]
These, I suggest, are all instances of situations likely to induce partial understanding, i.e. surface processing ('easy to learn by rote'); an atomistic approach ('we split up our courses'); a reproducing orientation ('little arrows going everywhere'); operation learning ('doing organic practicals when we were doing kinetics'); and extrinsic motivation ('a lot was not actually relevant').

10.4.5 This rather pejorative scene changes significantly when student involvement occurs, or when the perceived relevance is high. For example, the following discourse occurred in one group interview (TR 29):-

W2: Yes, I must admit it is approach, because the six months I spent in Sweden - completely different approach.

I: Is that so? What happened there?

W2: It was - we were taught.

I: Mm - hm! What do you mean by taught?

W2: Well, we were taught rather than lectured at.

I: A lot of English universities would say it's exactly what they're doing!

[Wi: (in background) It's a waste of time going to university].

W3: No, no - there's no discussion.

W2: No, no - like this chap Stefan, used to lecture us. He used to come in and, I mean we got on really well with him, we'd have a chat about things and -

W1: Thought provoking -

W2: Yes, yes -

W1: They actually make you do some work -

W2: Yes, yes -
Another student emphasised the point about relevance very clearly, in talking about her experience in comparison with others:

BB1: Two lecturers had been in industry and brought their experience in with them and integrated that into their lecturing which was very, very good – so we had a rough idea of what to expect before actually going out into the big wide world. So that was a good idea! Whereas talking to some people who had just done straight chemistry they were taught by people who'd been at university for years and years and couldn't remember what the outside world was like and it was literally just writing a whole mass of things on the board and not relating it to anything. It was just stuck there!

When asked what gave relevance to chemistry courses, the student group produced suggestions which may be summarised thus:

a) something you can use;
b) something you can see the importance of;
c) something you can see it is worth learning;
d) a particular piece of theory which can be useful;
e) an ability to apply knowledge.

The comment was also made that 'it makes it easier to remember things as well, if they've got some sort of application' [TR 29].

Taken all together, this evidence suggests to me that far more attention needs to be paid not only to personal relevance for students, but also to their perceptions of instrumental relevance. Higher education should endeavour to produce those conditions which foster full understanding, namely:

a) teaching techniques which demand a deep approach, and comprehension learning in a holistic context.
b) a realistic linkage between theoretical knowledge and
its application through the development of application skills.

10.4.7 In suggesting the above, I am not specifically or deliberately intending to support a vocational approach. It must not be assumed that the sole aim of higher education is to train people for employment. My arguments are intended to suggest ways of improving understanding through learning. This may or may not have a vocational connotation. What has become clear to me through this study is that understanding is fostered through seeing the relevance of application - or, put another way, knowledge seems more relevant if it is 'application oriented'. This is subtly different from the current swing from content to process in science education. What I am suggesting is that process skills are used to help understand content. This is the full import of the fourth characteristic of educational relevance in chemical education (Table 35). The process skills which seem to be important as far as the focal concepts are concerned are the thinking modes elicited in this study. These are necessary to produce an understanding which enables a person to combine 'an analytical and synthetic approach to work situations, problems and decisions' (8.4.7).

10.4.8 The enhanced relevance gained in this manner need not, and indeed should not, reflect only directly utilitarian ends. The professional practitioner also requires a developed intellect. This issue was not lost on some students; for example:-

BB1: What you were asking about just now about the relevance of university. It's just what [BB3] and I were saying at the beginning, taking the example about Schroedinger. Yes, fair enough, that doesn't have any useful application for industry or an outside job. But what it does do is it stretches your mind and it increases your knowledge. So, you don't just go to university to apply anything that you learn there to an outside world. You're also going to expand what knowledge that you have - so that's interesting. So there's a difference. You can't just have all - all relevance based courses.

[TR 29; lines 560-575]
original emphasis.
My point is made by the last comment. The main argument here is an appreciation of the implicit relevance of intellectual development for an individual. Explicit relevance is only given to vocational purposes. I believe chemical education would be much more effective if all the 'relevance values' were explicit - which leads me to the second area which I think this study may illuminate.

10.4.9 **Staff development in chemical education:** Throughout this study, teaching standards and course design in higher chemical education (as it relates to the focal concepts) have been heavily criticised. The following quotation is given, not for any judgemental reason, but because the participant concerned had not only worked in industry but researched and taught in American and European universities:

T: --- I must say, in all my experience of universities, I've never come across worse teaching than I've come across in Physical Departments - their attitude towards it - they're almost like a different breed of chemist. It's really put me off, everywhere I've been.

[TR 20; lines 394-397]

In a more general vein, Professor McKeachie, writing in the Foreword to Marton et al (1985), has noted that:

'Faculty members uniformly think of their courses as contributing to the development of thinking that is more analytical or critical. Yet in practice we often teach in ways that direct our students to rote memorization, and then blame the students for the fact that they have not achieved our objectives.

I have often said in lectures that professors frequently confuse difficulty of a test with high standards of educational value, and that it is easy to make a test difficult without making it a more effective measure of achievement. This book [The experience of learning] --- attacks the 'building blocks' conception of knowledge - that knowledge involves knowing more and more details of a particular discipline --- . Test questions are made
more difficult as they become more and more peripheral to the phenomenon, or as they become narrower in scope, encompassing 'very specific details of an event or minor part of a phenomenon' --- Higher Education on the other hand is generally concerned with introducing conceptions of knowledge involving greater understanding and analytical ability.'

p viii.
Professor McKeachie's views are supported by many of the criticisms in the data: over-didactic courses; concentration on facts for examination; excessive abstraction due to over-specialisation (mainly through mathematical modelling); teachers who are too purist with their knowledge to involve practical applications.

10.4.10 This picture is comparable with Schon's (1983) description of one style of professional activity, that of 'Technical Rationality', in which:

'professional activity consists of instrumented problem solving made rigorous by the application of scientific theory and technique.'

p 21.
It is my contention that even if the 'technical rationality' style of professional activity is satisfactory for a research role, it is unsatisfactory for a teaching role. The other style of professional activity offered by Schon, the 'Reflection-in-action' style, seems to me, more valuable for teaching since it recognises:

'the complexity, uncertainty, uniqueness and value conflicts which are increasingly perceived as central to the world of professional practice.'

p 14.
Schon argues that many aspects of professional activity involve 'recognitions and judgements' which have been learned, internalised and then taken for granted. It is important for professional development to make these implicit factors
explicit, through a process of 'reflection-in-action'. An
important aspect here is that:
'when someone reflects-in-action, he becomes a researcher
in the practical context'.

p 68.

10.4.11 A move from the Technical Rational style to the
Reflection-in-Action style through staff development programmes
in chemical education would seem to be demanded by the
characterisation of educational relevance provided by this
study. The changes involved may not be easy, since by
implication, personal commitments are involved (see Table 38).

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<tr>
<th>Aspect</th>
<th>Technical Rational</th>
<th>Reflection - in - Action</th>
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<tbody>
<tr>
<td>Mode</td>
<td>Instrumental solution of standard problems</td>
<td>Inquiry in a practical context</td>
</tr>
<tr>
<td>Approach</td>
<td>Knowledge of discipline leading to</td>
<td>Framing of problems in conjunction with</td>
</tr>
<tr>
<td></td>
<td>Diagnostic procedures leading to</td>
<td>Drawing on experience in conjunction with</td>
</tr>
<tr>
<td></td>
<td>Performance of algorithms</td>
<td>Evolving experimentation</td>
</tr>
<tr>
<td>Commitments:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.Philosophy</td>
<td>Realist</td>
<td>Relativist</td>
</tr>
<tr>
<td>2.Psychology</td>
<td>Behaviourist</td>
<td>Constructivist</td>
</tr>
<tr>
<td>3.Sociology</td>
<td>Functionalist</td>
<td>Interpretative</td>
</tr>
</tbody>
</table>

[After SCHON, D. (1983)]

TABLE 38: Styles of professional activity.

That such staff development programmes are possible has been
shown by a collaborative development between the University of
Surrey and the Roehampton Institute to provide a Diploma/M.Sc
in the Practice of Science Education by distance learning, for
science educators of the 9-19 age range. It draws on the same
philosophical basis as Schon's 'Reflection-in-Action', with

course members being required to critically examine their current educational practice. It also views the educational enterprise from a constructivist standpoint [see for example: Gilbert and Horscroft (1985); Horscroft and Pope (1985); Horscroft, West and Denicolo (1986)]. Although the course is designed for pre-university teaching, its message is applicable to all science teaching. As the authors of Module A2 say to the course members:

'We have deliberately laid stress on helping you to reflect on your views on the teaching of science. From time to time we have set up dichotomies or ideal types. We do not assume that you will have placed yourself firmly in any such category, but we do hope that consideration of such typologies will have helped you sort out some of your personal values.

We have also emphasised the importance of interaction between student and teacher. --- we are advocating the need for reorganising the personhood within each individual and the necessity of taking this into consideration during the teaching process ---. We believe that rigorous reflection on the process of teaching, development of increased self awareness, a responsible and caring attitude towards students and work colleagues are vital elements related to competence. These skills are not automatic and are not 'once and for all' items to be learnt. The development of such competence is an on-going process and one that is essential in a changing environment. --- We have indicated that significant learning is likely to occur only if the 'facts' to be learned are construed by the learner as having personal relevance. Teachers need to be aware of the current perspectives of learners in order that experiences may be generated in which learners can reflect on their own views and recognise their role as theory builders.'

(Horscroft and Pope 1985, Study guide, p192)
The main benefit of such staff development would not, I think, rest at the level of improved teaching. The implication of being a reflective practitioner is that, through reflection on one's practice, research is undertaken on how one applies one's knowledge for a specific purpose. This linking of theory and practice would inevitably lead to inspection of several important features of chemical higher education, including:

a) the teaching/research contract: whether teaching and research are compatible, and if so in what way; if not, what are the implications for chemical education?

b) the identification and understanding of those skills demanded by industrial practice in chemistry; how these may be developed in the novice, with optimal educational relevance.

c) which organisational structures within chemical education will provide optimal educational relevance?

d) which are the most appropriate mechanisms for developing optimal relevance in chemical education courses?

Thus there is a dimension beyond lecture-room and laboratory performance. The whole learning environment is involved, from the Department through to the curriculum. Data evidence suggests that knowledge is best understood through practical application. In this respect, biochemistry is seen by students to be more relevant than pure chemistry. Does this imply that institutional organisation should follow 'application structures' rather than 'knowledge structures'? Certainly there is evidence that the ambience of academic departments influences student learning [Ramsden (1982)]. Who decides on what is taught in chemical education? Is the involvement of chemical industrialists on Advisory Panels more than just 'tokenism'? If not, are their relevance values the same as those of the academics? Prosser (1982) suggests that
undergraduate curricula are largely determined by academics' perception, because no effective means have been found for academics to understand and accept other perceptions.

10.4.14 Some evidence of differing views on the curriculum comes from the questionnaire. One open question (D14) asked which criteria were considered most or least important in selecting course content in chemistry. Table 39 (see p. 245) provides a summary of the responses. Two general factors are apparent: practitioners and students seem to concentrate on understanding, educators on knowledge; educators have no common factors of concern. This seems to be a poor recipe for curriculum development. The 'least important' factors certainly seem to point to a mismatch of relevance perceptions. I believe a clear case can be made for a major programme of staff development in chemical education on a 'reflection-in-action' principle supporting, and supported by, research into improving educational relevance.

10.4.15 One feature of the interview data that requires inspection is the obvious need for some participants to have 'concrete' (molecular) models to make chemical concepts 'real', and the difficulty found by these (and others) with the increasing abstraction of mathematical modelling (7.3.10). I find two aspects of this situation interesting. Firstly, molecular modelling is in practice an interpretation of mathematical relationships derived from observed data. In principle therefore neither is more 'real' than the other. That some find a 'concreteness' in molecular modelling which helps with understanding and imagination in preference to 'abstract' mathematical modelling, may parallel a situation found by Larkin (1982) between novices' and experts' mental
<table>
<thead>
<tr>
<th>Practitioner</th>
<th>Educator</th>
<th>Student</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practical situations related to industry (5)</td>
<td>Clear concepts (1)</td>
<td>Related to industry and real life (6)</td>
</tr>
<tr>
<td>Industrial problem solving (2)</td>
<td>Ease of quantification (1)</td>
<td>Solving problems (4)</td>
</tr>
<tr>
<td>Mental stimulation (2)</td>
<td>Relevance to 'life' (1)</td>
<td>Qualitative understanding first (2)</td>
</tr>
<tr>
<td>Integration of subjects (2)</td>
<td>Practical skills (1)</td>
<td>Co-ordination between subjects (1)</td>
</tr>
<tr>
<td>More understanding/less information (1)</td>
<td>Effective teaching (1)</td>
<td>Mental stimulation (1)</td>
</tr>
<tr>
<td>Less abstract, more real (1)</td>
<td>Links with industry (2)</td>
<td>Scope for personal development (1)</td>
</tr>
<tr>
<td>Students' expectations (1)</td>
<td>Good balance between sciences (1)</td>
<td>Other skills, e.g. essay writing (1)</td>
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| Theoretical and mathematical treatments (5) | Advanced topics of no educational use (1) | Theoretical and mathematical treatments (6) |
| Cramming with facts (4) | Wide range options (1) | Cramming facts (3) |
| Job market (1) | Examinations (1) | Exam orientation (2) |
| Exam results (1) | History of discoveries (1) | |

[Number of responses in brackets]

**TABLE 39: Criteria for content selection: responses to D14.**
models in physics. The novices' model was qualitative and limited; the experts' model became quantified and abstract. A better understanding of the situation in chemical education might be informative of the importance of modelling in conceptual development. Secondly, the need for 'chemical reality' may be evidence of 'conflict' between personally and socially constructed knowledge. Berger and Luckman (1967) suggest that the social distribution of knowledge entails a dichotomy through general and role-specific relevance. They also claim that role-specific knowledge will grow at a faster rate than generally relevant and accessible knowledge. As each role-specific subset increases in complexity it becomes more exclusive and inaccessible to outsiders. In this way disciplines and sub-sets of disciplines are generated. By comparison if we take a constructivist view, knowledge is constructed by the learner as an active sense-maker, this implies a distinction between private understanding and public knowledge. Learning involves the learner in constructing a private understanding of some part of public knowledge. It is tempting to suggest that if full understanding is to occur, then public and private 'knowledge' must be compatible. If only public knowledge (ie. concensus science) is acquired, personal relevance could be low. If only private knowledge exists then there may be little instrumental relevance. This whole area would seem a fruitful field for further research.

10.5 Summary.
10.5.1 Early on in this report, I remarked on being given an opportunity to "really learn some chemistry" when I first started teaching (1.4). What has become clear from experience gained in this research, is that this was the first occasion on which I recollect truly reconstructing formal knowledge for myself. My chemical education to that point had largely been 'algorithmic' and rote. This is perhaps a good example of the message that I hope will be taken from this report. Personal learning promotes understanding, flexibility and
creative thinking, in a major way. Algorithmic learning is constricting and of short duration. Educational relevance is a key factor in an individual's decision to engage in personal learning.

10.5.2 The tacit assumption that we all know what educational relevance is, and that we all mean the same thing by it should be rejected. The evidence that those outside education see the current processes as irrelevant is too compelling. Employers seem to prefer traits of adaptability and creative thinking to academic achievement. Participant J, an industrialist, made this clear:

J: --- a first class honours degree is not necessarily what you're looking for. The prime requirement that we have in our game is commonsense -- a pure academic is just a waste of time.

[TR 10; lines 98-104]

Peter Wilby (1986) reporting in the Sunday Times reinforces this point, as does the Standing Conference of Employers of Graduates (SCOEG, 1985) in its response to the green paper on the development of higher education into the 1990's:

' The employability of graduates is often assumed to be simply proportional to the 'relevance' of their degree subject and the level of their academic attainment. This is an oversimplification.'

(Appendix III, Introduction)

my emphasis.

10.5.3 What this study urges in the induction of students into chemical practice, is the production of courses that stress the application skills needed to use chemical knowledge in a range of practitioner-roles. Content is thus defined more by application than high-specialism; understanding given priority over unthinking knowledge acquisition; long term learning valued more than immediate academic performance. Three general recommendations follow, which it is believed
will enhance educational relevance:

1. That the relevance perspectives for all the interested parties in chemical education are recognised and their value bases equally respected.

2. Course design should accommodate both instrumental and personal relevance.

3. Mechanisms for consultation between industry and academia must rest on explicit values and assumptions for educational relevance.

10.5.4 The following suggestions for action towards achieving these recommendations follow (no particular order of priority):

a) learning situations should be developed in which thinking strategies are facilitated through personal learning.

b) application skills should form a major focus for course content, so that knowledge is encountered through practice, or through necessity, as part of an analytic/synthetic solution-finding process.

c) over-theoretical and abstract explanations which have minimal practical importance should be avoided until such time as a more qualitative understanding has provided a motivational base.

d) greater integration should be provided between conceptual areas, on themes relating to application, so that a more holistic understanding is possible.

e) a reflective and evaluative approach should be adopted in the teaching role in higher education, and linked with chemical education research.

f) staff development programmes in higher education should support and foster the above actions.

g) regular close co-operation with chemical practitioners at a 'working-level' rather than 'advisory-committee level' should be instituted.

10.5.5 Certain areas for further study are highlighted by
these recommendations and suggestions:–

A: Organisational issues:
1. The relationship between the teaching role and 'pure science' research in chemical education, and the 'parity of esteem' associated with the research function compared with the teaching function.
2. The suitability of organising teaching in higher chemical education using 'discipline-oriented' structures as opposed to 'application-oriented' structures. Is the traditional Chemistry Department out-moded?

B: Teaching/Learning issues:
1. The transferability of the models elicited in this study to other conceptual areas in chemistry.
2. The characteristics of role-perceptions among practitioners and their importance in designing courses in chemical education.
3. The phenomenon of 'chemical reality' relating to molecular modelling and its importance in developing an understanding of chemical concepts.
4. Detailed elicitation of the value bases associated with relevance perspectives, and their origin.

10.5.6 It is clear that moves in the direction of the above suggestions are occurring. At Roehampton Institute a new undergraduate course is under discussion which embodies many of the suggestions made above, and which it is hoped will combine enhanced educational relevance on a vocational as well as an academic front. Other universities also are meeting the pressure to change. As one Senior Lecturer in Physical Chemistry said during interview, pressure from industrial links had changed his teaching, through the introduction of 'richer' industrially-related material. On the positive side, this had put his courses 'in touch with the real world'; on the negative side, he regretted the lack of detailed depth required by the new courses. Academic standards had not
changed, but a different 'product' left the university (see Appendix 8 for a detailed excerpt).

10.5.6 Throughout this study I have felt rather like a mariner navigating between icebergs. What is seen is but a small proportion of what one suspects exists. I realise that the task I have undertaken is a complex and largely uncharted one, but my hope is that by 'holding a mirror to nature' the tips of the icebergs are visible, and some notion of the hidden substance revealed.

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APPENDIX 1.

A parable, written in 1983.

ISTICISM: the construction of a perspective.
watched by Don Horscroft.

There is a fable\(^1\) which retells something like this:-

'Xoat was a man wise beyond his years. In his creative moods, he would ponder upon the world as he saw it, assessing the why's and wherefore's it contained. His keen faculties enabled him to see into the world more deeply than most, and in consequence people listened to his words with respect. His views developed authority and status and his followers grew in number. Each of these was proud of his Xoatic affiliations, and used Xoatism as a formula for seeking answers to many questions. Being a Xoatist provoked acclaim and status. The world of Xoatism became warm, supportive and flourishing.

But, there were other wise men who also thought deeply, not only about their world but about Xoatism and its explanations. Soon, they found flaws in the Xoatic tenets, and they argued against the Xoatists. They cast around for and found other philosophers for comparison, and drew their conclusions.\(^2\) They found Xoatism inadequate and incomplete.

Among these other wise men was one Knustxoat by name.\(^3\) In his creative moods he pondered on the world as he saw it, and rejected Xoat's world as a mis-conception. He saw the Xoatic approach as restrictive; Xoatism did not provide adequate answers to his questions. In assessing the why's and wherefore's of his world, he used his keen faculties to look beyond Xoatism. In consequence, people listened to his words with respect, and his views developed authority and status.

In the debate comparing Xoatism with Knustxoatism, each side defended its position. As Xoatic literature blossomed, so did an opposing Knustxoatic literature. Attitudes hardened. To be a xoitist, to use Xoatic arguments, became either a positive force or a pejorative stance depending on one's viewpoint. Though both approaches revealed useful knowledge, out of the rigidly conformist thinking was constructed a limiting perspective.

An observer of this debate - Remulus, by name - was asked which was the most worthwhile; to be Xoatist or a Knustxoatist? In reply, he noted that Rome was surrounded by seven hills. From each, a view of the city could be enjoyed. It was true that the Palatinian view did not necessarily include all that could be seen in the Quirinalian view. Also, the
Capitolian view was particularly limited, due to the hill's height and immediate environment. To be Capitolian in outlook did not, therefore, give a good general picture of Rome as a city — though it was valuable for certain things. Perhaps one needed to embrace as many (if not all) the possible-to see the real Rome. It seemed to Remulus that identification with one viewpoint only, led to isticism — the adopting of a limiting perspective; the adherence to doctrine."

The fable, as you may guess, has no real ending. The problem facing the debaters is that of relinquishing the security of identity to be innovative, without over-indulging in new conformity. Yet, how much of that security is valid? The fable does not consider the focus of the view, the perfection of vision. And what of the birds-eye view? Is that necessarily better? Is the moral pointing out that, in the fascination of searching for a new justification, one must avoid the danger of adopting a narrow mental vision — ISTICISM?

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APPENDIX 2.

Excerpt from TR4, showing original transcript as marked during editing and the edited copy.

ORIGINAL:

47 D  well kinetics is is to do with rates [ee--ee it's to do with ehm how--] how quickly things react together [erm (pause) yeah (pause) er--]

47 I  what's the importance of knowing how quickly a reaction proceeds, would you say?

47 D  (Pause) well, when in the chemical industry it's very important [ee--er] if things don't go fast enough [erm you] you just don't have a process

50 I  so you're hinting at some sort of control?

50 D  well [there's a sort of a, there's a] there's a band of rates that's important. If things go too slowly, [your your] the economics of building a reactor to utilise that reaction are going to be [erm] no good. If they go too fast you may not even be able to control it - if it's explosive. [so it]

57 I  can you see whether - this very loose definition of kinetics is important in any other way [apart from saying 'yes that's a reaction that will be important to us you know that's a reaction] ?

57 D  [O.K. Yeah I] well, yes, actually understanding - [wh- if you've got the way the different components of a reaction mixture, th] - the order of reaction on the different components, and the way they influence the reaction, can tell you something about the [ex] actual pathway of the reaction
you mentioned the [word--er] phrase - order of reaction?

yes

are you happy to amplify on that, [oo]?

O.K. - yes - well if a if [um] you [oh my]
goodness - how you get to it - in, for a - well -
I mean the the sort of [--) going right back to the
beginning, there's first order and second order reactions
where, I mean, first order reactions [--) would be something
like [the 'er - uhm -] radioactive decay, where you have a
one component which [um] falls apart [laugh] era-

graphic description:

yes! - well! you tell me how it does it - obviously!!
(laughter) [um] or a second order reaction would involve
[--) (pause) wouldn't actually involve] two species
[--) reacting together to give something else, [so --]

*    *    *
EDIT:

D: — — — — — ... Kinetics is to do with rates, how quickly things react together ... (pause).

I: What's the importance of knowing how quickly a reaction proceeds, would you say?

D: (pause) ... Well, in the chemical industry it's very important ... if things don't go fast enough, you just don't have a process!

I: So, you're hinting at some sort of control?

D: Well ... there's a band of rates that's important. If things go too slowly, ... the economics of building a reactor to utilise that reaction are going to be no good. If they go too fast you may not even be able to control it - if it's explosive.

I: Can you see whether - this ... definition of kinetics is important in any other way?

D: Yes, actually understanding ... the order of reaction on the different components, and the way they influence the reaction, can tell you something about the - or - actual pathway of the reaction.

I: You mention the phrase 'order of reaction' ... are you happy to amplify on that?

D: ... going right back to the beginning, there's first order and second order reactions where, I mean, first order reactions would be something like ... radioactive decay, where you have one component which falls apart ... or a second order reaction would involve two species reacting together to give something else...
APPENDIX 3. Data-base from interview analysis.

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* clear statement                  P: practitioner
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APPENDIX 4: Transcript showing coding used during analysis.

I: Now, the first area I'd like you to look at is reaction kinetics. Now, what does that mean to you and what do you see to be the main ideas involved in that? ---

Q: I would judge reaction kinetics in terms of catalysts and behaviour of catalysts to perform the job that they're required to do, and how that varies with temperature and pressure. I suppose if somebody mentioned reaction kinetics I would immediately think of catalysts, and the behaviour of catalysts. But then there's, when I think about it as well, there's also the mathematical modelling of reactions and being able to model them be they 1st order, 2nd order, 3rd order reactions, being able to produce mathematical model that you can manipulate in order to understand or to have a good idea what's going to happen if you alter, sort of, variables involved. That's probably all.

I: you say your first thought is of catalysts -- why catalysts?

Q: Ah, because we come across a lot of catalysts -- my experience has been mostly on refineries and we're forever dealing with different catalysts, I mean, refining this and that and de-sulphurisation for cracking, moving certain things, adding certain things.

I: In what way does the catalyst relate to kinetics of a reaction?

Q: Because they're in reactors, that's why! I know that sounds very simple, it's because when you mention a reactor on a petroleum refinery, what's going to be in that reactor is a catalyst -- so when you think of reaction kinetics -- but, there I mean, you know -- a reaction is a reaction is something burning, you know, whereas, you know, everything about you is a reaction, but when we talk about reactors we talk about a catalyst container.
I: - - - What's the function of the catalyst in that case?

Q: - - it has a number of functions. It's to basically change - either to crack large molecules into small ones or to remove sulphur from the products, to produce certain types of molecules which you want to produce - you have platformer catalysts which upgrades petrol - basically just mucking about with molecules of the petroleum to optimise your products.

I: So, would you say that you're using a catalyst to help in the reorganisation of the molecule in some way?

Q: Oh, certainly! Yes.

I: That's the way you view it straight away?

Q: Yes, that's how I view it.

I: Would you be comfortable with my saying that the idea of a catalyst is to increase the activation energy?

Q: Oh, certainly, yes.

I: And would you think that's a better way of looking at it?

Q: (pause) - it depends how you want to look at it. It depends if you're trying to explain to somebody what's actually going on. I think my definition would be far more readily acceptable for somebody who wasn't aware of reaction kinetics, rather than your definition. If somebody asked me what do I do for a living, and I start explaining about I work in a refinery and we use a lot of catalysts, and if somebody - yes, somebody asked me 'What is a catalyst?' not so long ago - I can't think who it was - oh! it was a carpenter who was doing work for us - and if I said - - - a catalyst was something which decreased the activation energy between two things, right - he probably wouldn't be able to grasp that so readily as me saying 'something that allows a change to take place by bringing the two things into intimate contact with each other.'
I: Do you in your own work, ever have any recourse to using the more energetic explanation of reaction kinetics and catalysts?

Q: In my course of work, no --- I might do here. As I explained, I've only been here a short time. But again, on a refinery what happens is you have catalyst vendors and when a catalyst is needed for a particular process, then you will ask the vendor what size he wants us to design the reactor for, the speed that's going to go through, and the operating temperatures and pressures. So actually I don't get involved --- with setting the design parameters for operating a unit in which there's a catalyst. ---

I: --- can I ask you to do a similar thing for chemical equilibrium --- what are the main ideas you see involved in the area?

Q: Er - very dynamic situation, right?! Er which (laughs) - I view it in terms of mathematical models, you know ... these are good questions, aren't they! ... Basically, if we consider, say a component in a multi-component system --- let's say it's between its dew and its bubble point, then some of it will find its way into the vapour and some of it will find its way into the liquid. The stuff that's in the vapour will exert a certain presence and the stuff that's in the liquid will exert a certain pressure. And when these two pressures are equal, it's in chemical equilibrium.

I: That would be true in terms of the phases you're talking about?

Q: That's right, yes. That's how I'd view it, actually in terms of liquid and vapour phase. If you mention chemical equilibrium to me, yes, I'd immediately think of liquid/vapour phases. Because you see, again because we're designing distillation columns, then it's got a vital interest to us, the equilibrium between a liquid and a vapour --- because that's how you attain the purity of the substance, by stepwise changes in the equilibrium between the liquid and the vapour as you go up and down the column.
I: Now, in all that, you haven't actually related that closely to a chemical reaction.

Q: To a chemical reaction? (pause)

I: You talked about things moving -

Q: (interjecting) Right, yes, that's right! I can see what you're getting at, yes.

I: What do you think I'm getting at?

Q: -- how I view it now is, when you give me these sort of buzz words, it immediately means something to me 'cos we're using these concepts everyday, but it's a slightly different way, from the sort of engineering point of view - how to approach a problem - - - when you say 'equilibrium', right, I think 'Ah! Liquid/Vapour equilibrium, mate.' But now you've mentioned in terms of a reaction I think 'Oh, well, the equilibrium constant between - if we have species A plus B going to Species C plus D, and then an equilibrium is set up between the tendency for A plus B to go to C plus D, and then an equilibrium will be set up and the concentration of A is sufficient - er - when the concentration of A and B - - -

I: Talking about it is tricky! -- what do you mean by 'the tendency'?

Q: The potential to go --

I: Chemical potential?

Q: Yes, chemical potential from --

I: That's an energetic approach, is it?

Q: (with certainty) Yes! I would view it in terms of energy.

I: Is that your thermodynamic background?

Q: Yes, it is. I'd look upon it, having worked with thermodynamics for so long, I would tend to view most chemical happenings in terms of thermodynamics.
I: Do you think there's any way of explaining chemical equilibrium in molecular terms?

Q: (pause) Certainly -- when I was at school, and when I was at University, I was taught chemical equilibrium in molecular terms. You know, if I was to go to a book now, I could open it and say 'Ah! right, that's it!' But, to be quite honest, at the moment I'd be quite hard pushed to explain it in molecular terms.

I: -- Do you see any particular link between the field of reaction kinetics and equilibria?

Q: (pause) Well, there's certainly a link, yes, I mean it's all part of the, you know, chemical processes -- that's a good question, you see, because thermodynamics will tell you all about the equilibrium -- it will allow you to model a chemical system and tell you what equilibrium will be obtained, but it won't tell you anything about the rate that it will happen at, you know. So both those two things, I'd imagine, would go a long way to fully defining -- using both those disciplines would go a long way to defining the chemical system --

[ Interview interrupted briefly]

I: Did you explain yourself adequately on that, do you think?

Q: Yes. I think that one tells you what will happen eventually, and the other one tells you how quickly it's gonna happen.

I: If you think about teaching people chemistry for a moment, at undergraduate level -- would you think therefore, it would be sensible to teach these two areas fairly closely together?

Q: Certainly -- oh, certainly.

I: Because you see them as related?

Q: Yes certainly -- as I was saying before, the biggest problem which I found, and which people who were at school with me found, was that it
was taught as something quite magical, you know, it wasn't really [that] simple - which is getting away from the question you asked me!
Yes, I think it is - - - certainly essential to teach them both together.
I: - - - is there anything you want to ask me, - - - nothing else you want to add to what we've said?
Q: I think working in industry for so long is certainly - what am I trying to say? When I was at school, I did develop a really big interest in chemistry, you know, with every aspect of chemistry, every facet - - - but when you start working in a particular form you tend to, you know, it's no longer that enjoyable anymore, which is a real shame, because I found it really fascinating at school.
I: Any idea why that might happen?
Q: It's probably if a chap's very interested in cars and he becomes a mechanic, he soon gets pretty sick of cars (laughter), you know!

- Edit ends -

[Unedited transcripts were also similarly analysed; some further important statements were obtained this way]
APPENDIX 5

ANALYSIS CATEGORIES

This Appendix contains examples of interview statements which have been categorised according to the process described in 5.5, and as listed in Table 7 (p 77). Sub-factors are also shown, as listed in Table 16 (p 114). As far as possible, categories already quoted in the text have been avoided.

These excerpts have been clipped from raw transcript material so that some appreciation of the basic material can be gleaned.
1. CATEGORY A: Personal attitudes to the focal concepts and/or physical chemistry.
   (Number of instances - 19)

1.1 A1: Focal concepts 'liked'

TR3:

I: or chemical kinetics - goes by various names. Now - could you just sketch out what you see to be the main important ideas or concepts which are contained within that area of chemical concepts - er - er - of chemical kinetics?

C: Well - its an area which has never really interested me that is much. At university I did - I didn't - there's a book by Harris called Chemical Kinetics, which we bought and I read through, and -

I: Yes

C: and I used that to get through my degree to a certain extent. I did have to use it during my PhD when we were doing nitrene decompositions

I: Yep!

C: - had to find out whether it was a first or second order reaction,

I: Yes

C: and, um, we did some infra-red studies plotting to find out the rate constants and things like that, and that's the only real involvement I had w-with Chemical Kinetics. Uh, my view is that it's one of things at University, perhaps, that people aren't very interested in.

I: Whhm!

C: I don't know if you - you know, other people agree on this but its a very important aspect when you, when you come to doing you know, working somewhere like
H: But then - I also feel that I have a lot of problems in seeing earlier down in my chemistry - further down in my chemistry, that I feel probably, because I haven't recognised the patterns earlier I'd gone past the stage of recognising the patterns, and it became learning - for me - in inorganic. I also liked a lot of the physical - some of the complex maths left one a little bit cold (chuckle) -

T: Mm!

H: - most of the physical I enjoyed. I enjoyed the physical practicals - and - that sort of thing.

T: Right. O.K. Uhm. In that chemistry - sort of formal chemistry of yours - which topics interested you most?

K: I'd say physical chemistry.

T: Mm! Why was that? Any particular reason?

K: Because, er, I was able to, to structure the study better - er - er - organic chemistry and inorganic chemistry er appeared to be to a much greater extent er the absorption of a body of facts, whereas in physical chemistry I was able to relate it - er - to a greater extent to fundamental principles.
I: was there any particular part of your first degree that you very much liked?

R: Um - w', I obviously liked the chemistry, liked physical chemistry - um - and - um - I liked to some extent the physics and the applied mathematic - it was really just physics - theoretical physics.

I: Mm. What attracted you about those?

R: Erm - 'm, I suppose it was the - the, erm - well the great interest was, I - I - I suppose was the - in some of them was the - the attractiveness of some of the solutions to - erm - you know, situations as it were, and the neatness, I can't remember a lot of it now, but in fact the neatness of some of the proofs of - um - theories involved - sort of hypotheses and so on.

1.2 A2 : Focal concepts 'not liked'.

TR12

I: Good. Now, why did you say 'dread of& dread, thermodynamics'?

L: (laughs) Well it -it-it's a thing that - er - its diffic - I found - um as well as probably 99% of the other people who were there, difficult to grasp at first until you've sat down and looked at it in er in a logical fashion - and - from what I can gather talking to the students I come into contact with at Manchester and er at UMIST and Salford, it's still the same. Thermodynamics see - seems to be the - erm - the bogey-man although, once you've - once you cracked it y - you've cracked it.

I: Have you any idea why it's a bogey man?

L: I really don't - I, I've never --- I never really found out I mean, I always - I always managed to pass the exams. But it always seems - seems far more difficult than everything else. And, I, I honestly, I honestly don't know - it does seem - seem to be a - er - still a general trend, that it - its - (inaudible) maybe its a difficult subject to teach.
TR14

I: A neat distinction. O.K. Erm, Now, Which - 'K er let's do - reflect back on the area of chemistry as a whole. Which areas of chemistry interest you most?

N: (pause) er- I suppose organic chemistry, organic synthesis. Erm. Reaction pathways, perhaps, things like that. I was always less interested in (the ? physics of the solids) and also in theoretical chemistry, things like thermodynamics which I - - I always found difficult. A problem for a lot of other people, I know.

TR20

I: And are there any areas of chemistry that you find difficult or interesting or - -?

T: Chemistry as a whole you mean?

I: Mm! (assent)

T: Physical chemistry, yes. It's not my forte - and, organic chemistry I don't find any problem with, it's - (like being normal)?

I: What do you find difficult about physical chemistry?

T: Erm - I think mainly because I've never found it interesting, I've never seen it - er - perhaps it's the way its been taught. I've never really seen a use for all the things that I was taught. When I was doing my finals, we were having - erm courses in statistical thermodynamics and stuff like that - I couldn't see a use for it then. I still can't. Erm - particularly, it was very badly taught in that we were expected to regurgitate, for example in (ancient) purposes, complex mathematical do ( ?? ) erm and most of the people didn't have the mathematical background to really understand it, so - you had to memorise bits of it; and I could see the point of regurgitating a proof where half-way through it you had to memorise what a certain differential - or integration gave you - er - I just didn't ever see the point. And yet, the powers that he seemed to think it was important (inaudible) turned us on, it was almost like poetry as far as I'm concerned.
People learned it off by heart, churned it out - guaranteed get a 1st class Honours. That's not my way of doing something, you know, unless I can understand every single thing about it, I don't want to know, and it would have taken an awful lot of effort to actually go back and really understand the fundamental mathematics, to have really got to grips with statistical thermodynamics, and since I couldn't see any use for it, I didn't think it was worth my while doing that. Perhaps I suffered as a result. Other people who were prepared to put their pride behind them and learn the stuff off by heart, as a result did better in the exam. Erm - but they don't understand it any better than I did. At least I find some sort of satisfaction from that point of view.

I: Are there any parts of chemical knowledge you don't like, that you find very lacking in interest?

Z: Not that I don't like, erm - but, because I can't do them very well, I avoid - erm and this is quite often the physical chemistry side - the - erm, I have to go back and read my textbooks quite often at first year level or physical chemistry because I don't use it everyday and I forget it very easily, and I feel that I never really understood it from my own first year undergraduate level. I've never had to teach it - I mean, you learn by teaching it, and for that reason I've never really learned my physical chemistry.

undergraduate. Erm - I coped with it - you know - sort of enough to - er - to get a reasonable degree, but, erm, a lot of it was stuff which I, I really couldn't say I understood. I knew it well enough to, as I say, to pass the examinations, but that's a very different matter, and a lot of it of er is material that I've developed an understanding of since, particularly in the the borderline between physical and organic chemistry.
2. CATEGORY B: Influence of textbooks
(Number of instances - 2)

TR1

The trouble is of course, if you look in some textbooks then you find the statement that - erm - statements which do tend to separate them in the mind of the reader - statements such as 'thermodynamics' can ex - can suggest whether a reaction is feasible or not - er - but only kinetics can er indicate whether, if its feasible, it's likely to occur.' Sometimes I think that's a ...

..... once the ideas become fixed early on they then have trouble overcoming that block later on in the course.

3. CATEGORY C: Relationship between focal concepts
(Number of instances - 29)

3.1 C1: Focal concepts seen as linked

TR2

B: Well, I think the concept of . er . thermodynamics and . er .
going then into equilibria and into . er . kinetics, in other words the whole sort of lot of . er .what's normally grouped under physical chemistry .. I think the problem there with most people is that even in the first instance they very rarely see the use of it. It is not immediately obvious why it is absolutely vital that before you start on a piece of research that you must ensure that the thermodynamics are right (laugh), that the free energy changes make the reaction permissible and that the equilibrium will give you a reasonable chance of producing the material you want, and finally, the notes will tell you that you can produce it at such a rate that its commercially feasible.

Um ...

B: Um .. thats very much from the viewpoint of . er . of an industrial chemist--
I: Do you see any link between the two areas?

M: -- Erm -- -- (pause) -- -- Mm! -- -- well, yes, at a fundamental level, I mean, the same things are looked at -- The understanding of kinetics is seems to be fairly important to an understanding of equilibrium.

I: In what way?

M: Erm -- well just through the understanding of how reactions take place -- erm -- considering the effect of, again, things like heat on reactions -- you would need to understand most of the -- most of the kinetics work, I would have thought, to -- erm -- to make a decent fist of the -- equilibrium topics. Em -- connections -- -- erm.

I: Well let me ask you another question which might perhaps, um, help you.

Do you see any link between the ideas of chemical equilibrium and of reaction kinetics?

M: -- (Pause) -- Yes, I would have thought, er, very closely related --

I: And how would that relationship exist in your mind?

M: -- (pause) -- Well, er ... surely, you know, the equilibrium reaction is a, is a -- what it says, it's a ... a ... almost a static state of, of of a, of a chemical reaction, it's a point at which the reaction one way, and a possible potential reaction the other way erm are balanced -- are at equilibrium you know --

I: Yes.

M: So, er, the two are almost running parallel, er, --

I: Do you see any link between the areas of equilibrium and kinetics?

M: -- (Pause) -- Yes -- I, equilibrium is just a stage that's reached in a reaction -- or may be reached -- so it's all part of the same --

I: To you the two things are quite closely linked together?

M: Yes!

I: Can you see any reason why one might treat them separately?
TR13 (cont.)

M: (pause) I said - as I said, equilibrium is reached or - or maybe not in a lot of cases - it's just one particular time period in the phase of a reaction, so - - so they are inextricably linked.

L: Yes. y - you don't see any separation yourself - they're all part and parcel of the same area of chemistry?

M: Mm. Yes!

TR25

36 I: I: Are the ideas, that's kinetics and equilibrium, are they taught as inter-related ideas in this University?

36 JD: Y: Er, I think so, yes, but - yes I think that is fair to say, but I've been at other universities where they've been separated.

I: Mm - hm! Do you think that's sensible?

Y: Er - no, I wouldn't separate them. I don't think they should be separated. I was taught kinetics was in one box and thermodynamics was in another box and - er - I - it took me a long time to realise that they - er - the concepts are inter-related, although they are separate areas, clearly they are separate areas. There is an overlap region. er - we have a course which is called, I think - er - Liquids, Gases and Solids, and Entropy and Energy - another course - where - er - these ideas are all interrelated. And I don't lecture on that course, but I take tutorials on it.

3.2 C2 : Focal concepts seen as separated.

TR5 (a)

E: Well, at the end of the day the thermodynamics hasn't got anything to do with the kinetics really - - thermodynamically, thermodynamics only tells you erm what would - what the equilibrium situation if is assuming you've got all these reactions to occur. Er - its involved in a way from Kinetics.
TR5 (b)

E: (pause) I think there's a case for putting thermodynamics separately because that rises above mechanism an-er-er-helps there. And um-its a system-the fact that its made of atoms doesn't matter as far as thermodynamics goes-so thermodynamics rises above it all in a sense. And its-not that its not just the province of the chemist, of course-

TR7

I: Do you see any bridging ideas between the idea of chemical equilibrium and reaction kinetics?

G: No, I try to keep them quite separate.

I: Er-why do you do that?

G: (sighs) .. (pause) .. Right at the end I would bring them together - erm-I think as topics I treat them completely different to (one another?) - until they've got a good idea of what a rate equation is, until they've got a good idea of what - the equilibrium law - and perhaps - toward the end of their course I would, sort of, bring them together.

TR20: after being asked whether kinetics and equilibrium should be kept separate.

I: No - I think its not very logical - I think the two are connected. (pause) erm-I'd really have to think about it some more before I - committed myself on that. This is - we're talking about one of my absolute weaknesses - (laughter) - is physical chemistry - I think the two are connected. (pause) [erm-I'd really have to think about it some more Typographical repetition not on tape before I committed myself on that. This is - we're talking about one of my absolute weaknesses - (laughter) - is physical chemistry] - I'd have to - I'd have to really give it some more thought but is does - it does sound
illogical, just of the tope of my head.

I: Why do you say that it sounds illogical, what is it that makes you 'twitch', if I can put it like that?

T: Because they are connected - the two are related - so it seems silly to, erm - disconnect them.

TR14: showing 'oscillation'.

I: O.K. Erm - now do you see any link between reaction kinetics and chemical equilibrium?

N: (pause -- -- ) Er - I do - , well thinking about them no I've always regarded them as completely separate entities - um - o - obviously it's not like that. It - er - I mean, every - every reaction assuming it to be in equilibrium and therefore every reaction could be said to be proceeding at a - er - at a specific rate. So I - - I mean, with, with (?? run th ??) I suppose you're assuming that somethings starting and it's finishing rather than equilibrium in which you have something that's, that's carrying on all the time.

I: You said just then 'obviously it's not' - so what has, sort of, clicked in your mind to make you think the two might be linked?

N: Because, I suppose, - in real terms every reaction -i - if we - if we said every reaction that is in equilibrium also every reaction must have a rate of -- of which it occurs. So - erm - that you obviously can't be - can't be separated if you apply - er - both concepts to one reaction so therefore you can't - choose one over the other, so therefore they must - must be connected in some way. I've - er - just always been used to er - to considering them completely separately.

I: Why was that?

N: I suppose it was - uh! - it's - from a theoretical level you you're looking at any one particular concept at any one time.

I: Mm hmm!

N: I d - I don't recall considering both concepts at once.
4. CATEGORY E: Perspective on equilibrium.

(Number of instances - 26)

4.1 EI : Molecular model used

TR21

I: What is it an equilibrium between? or, of?

U: Well, I suppose that depends on, er, on the - whatever's in the system.

I mean, for instance, if we're looking at, for example, the tautomeric equilibrium, where you have, um, an enol and a keto-form, here you have, um, two molecular species which are different - and - in any, erm - thermodynamic equilibrium you have a mixture which is dependent upon the - I suppose the relative thermodynamic stabilities of the two. But the fact that one can change to the other - it can't therefore be at the same energy level can it?

I: Would you be able to distinguish er or between a thermodynamic equilibrium which is a balance of energy states as opposed to what you might call a molecular equilibrium, which will be a balance between two molecular species and therefore imply that rates of changing from one to the other and back again, are equal and opposite?

U: - - - They're on different, I think - - well, I don't think I can answer that question without probably sitting down and thinking about it.

I: When you first think about equilibrium, how do you think about it - do you think about it in terms of changes in molecules in one direction, being balanced by changes in molecules in an opposite direction, so that you get back to your starting point - or do you see it as a balance between two clear, distinct thermodynamic energy levels?

U: No - I probably think about it in terms of the change from one molecule to another.
I: Mm. You mentioned there equilibrium in terms of balanced rates -
Y: Right.
I: - is that a molecular or an energetic explanation?
Y: Er. Yes, we could - er - think about it in terms of a molecular
exploration where you've got a concentration of a particular species
expressed - er - on a molecular basis and the rate of a forward
reaction being the rate constant times the concentration, so it's really if you like a molecular explanation.

4.2 E2: Energy model used

TR1

A: The - ways of approaching equilibrium that I find - that I like through I'm not
sure the students always do - is to look at it in terms of competition between
different sets of energy levels - erm - but that's because one can then use
that as a basis for the introduction of statistical thermodynamics - and, I think that it's an area which could in fact be introduced much earlier in
courses - or an approach that could be introduced much earlier in courses,
than we tend to do.

TR4

I: how - how could you describe to me - what's the sort of main
area dealt with - main ideas covered by equilibrium studies -
D: uh hm! mm!
I: now what would you tell me there?
D: I tell you that - that was - um - - that is a
thermodynamic measurement, that will tell you - giv -
given you got (cough) number of components in a system and -
and their are roots for - relat - for converting them into
each other, that the equilibrium will be when they have actually reached the concentrations as, as the—erm, (det ?) governed by the thermodynamics.

I: Is that an equilibrium then in terms of energy, or in terms of concentration?

J: Ahm! (long pause) It must be an equilibrium in terms of energy, that the system as a whole has come to its lowest energy, and the energy that it's come to will define the actual concentrations of the components.

I: Good. Can I move from the kinetics area now towards the area of chemical equilibria and ask if you could sketch out what you see to be the main concepts that are involved in an area like that?

Y: Erm—well, you're looking at the Free Energy of the total free energy of the starting system compared to the total free energy of the finishing system—and you're really balancing the two together.

I: So it's a balance if free energies that you're thinking of, is it?

Y: Yes. I mean, when I actually think of it in my mind I see a line connected with a bump, or various bumps and another line at the bottom (overtalking).

I: A reaction profile.

Y: Yes, reaction profile, and looking at the various energies.
4.3 E3: Dynamic/static equilibrium discussed.

TR15

I: Mm-hm! -- Yea, that's right -- fair dues -- erm -- how would you yourself describe the concept of equilibrium as it's used in chemistry?

O: (pause) When you say something has reached its equilibrium -- erm -- you're assuming that -- no further reactions are actually occurring, and that you have got 40% of your products and still 60% of your starting materials -- 'nd -- it -- it will stay at that, that, those proportions unless you do something further to it to upset the equilibrium.

I: The reaction really stops then does it?

O: Er -- no it doesn't. I think things are still reacting but they're just going back and forth so that the overall proportions of each remain constant, but the reaction still -- er --

I: What do you mean by 'going back and forth'?

O: The -- e starting products react together to form -- sorry, the starting materials react together to form products, the products then react and go back to the starting materials.

TR16

I: I got myself a little lost there, I'll come back again to that. Erm, can I ask if -- you a similar thing now in the area of chemical equilibrium?

P: Mm -- (pause) -- I think that my idea of chemical equilibrium is when -- a reaction going one way is equal -- is -- i is equal to the reaction going the opposite way and that -- er -- you are into a stable situation in some way, where, a lot of funny things are happening, generally there's a flow that way and a flow this way and -- they are equal, and therefore
TR16 (cont.)

- there is - we come to a situation of no change - - Now, you know, that's not going mathematically into - you know - - expressions for - for Kp or partial (inaudible) or anything like that. But the idea that equilibrium is not a situation where nothing is happening, it is where what is happening is balanced - - where something's happening.

I: Now, y-you used the statement 'the situation of no change'. Would that strictly speaking be true?

P: No - sorry - the situation where changes cancel out if you like -

I: So it's apparently no change

P: Apparently no change - superficially in any case!

5. CATEGORY EI : Effect of interview.
   (Number of instances - 3).

TR1

A: I think it's a good ..... no I - I - I think it's a good idea actually. I mean because something that - this, I think this about - this is one of the - I won't say it's the first time, but there haven't been many times when I've actually had a conversation with anybody where we've looked at these sorts of things.

TR4

I: have stuck there! (laugh) Any comments you want to make on what we've talked about, anything further, any questions you'd like to ask me?
TR4 (cont.)

D: No - a - w - a comment I would make is that -
   er - is - is um - - related to the fact that I mean
   cos you - the / the questioning that um you dug up some
   old stuff which I, I mean I feel that I I'm still not
   thinking properly about, that - um - - 

I: Yep. I take your point -

D: I - I - I found

I: (talking over) I'm sorry to put you on the spot as it were

D: No, I I found, I have actually found it quite educational
   over the last half an hour but - I mean, I think things  
   have to be brought up

6. CATEGORY F: Importance of the focal concepts.
   (Number of instances - 23).

TR9

I: Ye-es. Um - O.K. Now, um, just two very short questions and then I'll
   leave you. How important do you think these two areas of chemistry are
   in the teaching of chemistry - would you rate them as a sort of 'key' area,
   or - fringe areas, or what?

D: Erm - - well I wou - I would have thought that they're I would've thought
   they're very, I'd've thought they are more important than many areas,
   because they do underline so much, erm - other chemistry, erm, including
   obviously the biological systems and - mm - applied aspects of chemistry
   - erm - and I'd've thought it would've been pretty - of interest to
   industrial - erm - ( ? ) - - as economics is so involved in in these two
   areas -
I: O.K., fine, uhm. Would you say that it was fairly obvious that
the areas of chemistry I've been talking about are important in
industrial chemistry?

J: They're obviously very important in industrial chemistry -
erm - possibly more in a production company -

I: Mm!

J: Where you - where people are having to change the operating conditions of that plant maybe to make a different range of products or something like that.

I: Mm!

J: And I would say that is very important. Erm. It's not quite so important, for the reason I've already explained, er i - in the contracting business, and - we are probably very similar to - mm - in many other contractors in that they all license processes. Now one other - only add one other difference, and many of, some of the big American Companies, some of the British ones for that matter, who design oil refineries, do their in-house design. We u - we used to have an office which did oil refinery design and there there no such th, there aren't many license processes, you literally do design an oil refinery just, really, distillation processes in most cases, from the textbooks - you know from published, er, papers and - and really from the textbooks. But oil refineries are not reactors - they're separation processes -

I: Oh yes!

J: - so, er - th, that is rather different. But I think you'll find that there're very few contractors who - who do design reaction - reactors, and go into the detailed calculation of reaction kinetics -

I: Yes.
TR10 (cont.)

J: - that comes from operating companies. Therefore an operating company such as an ICI or anyone else who is running plants, there the engineers coming out of university I think - will need a - or will apply, anyway, - far greater - to a far greater extent, the er - their knowledge of reaction kinetics, equilibrium, etc.

I: Mm. So, by implication then it's a fairly important point of any degree course in chemistry and chemical engineering?

J: I th - I would think it was a vital part, yes - I can't - I can't imagine a course without it. (laughter)

TR16

I: Right? O.K. I won't hold you much longer - more or less a couple of things I won't do. Erm - just one more general point: the area that we've been talking about, how important do you see that in terms of people who are practising in - in industry - chemists practising - whether they're chemical engineers or not?

P: Oh! of enormous interest - I'm sorry, of enormous importance. Erm - I - I'd put it in the - - er - - work, technical work that I've seen pass my nose during my working life here - erm, the concept of equilibrium is very important - very important indeed. And that, that - erm - you know, it covers everything that you see, certainly as an engineer, you know, as to what is happening in metallurgy, erm - to what is happening in gases and liquids and so on, but as it covers - as I say goes through metallurgy and everything - and the concept of - of equilibrium and er and er - and er - steady state (inaudible).
I: (Inaudible) Erm - would you therefore say that it was - equally important in terms of - the structure of chemical knowledge - if somebody was learning chemistry - needing to know these - erm - not just from the - from an industrial practice point of view, but from the point of view of having an understanding of chemistry?

P: - - - (pause) - - - - I don't quite know how to answer the question, for there are several - at what level of education it would be - -

I: I'm thinking very largely of undergraduate -

P: Oh, I don't think that an undergraduate would be much use without having some concept of the - er - of - - equilibrium, and if that was based on - erm - a concept of kinetics, that would be a very good basis for the concept of equilibrium. I can only - I can't imagine a chemistry graduate not knowing something about chemical equilibrium! - - - (inaudible).

7. CATEGORY H: Personal response to Higher Education
(Number of instances - 24)

TR6

E: I was disappointed with University actually!

I: were you?

E: mm! They just - they just lectured to you - - I, I thought it would be a place where you could discuss things with your lecturers and talk about (energy?) things as we used to do - we were encouraged to - we had a good chemistry teacher at school. Very small group, anyway, and - er- he was very keen on us asking questions and discussing things (tape side ends : continued side 2)

(tape count continuous)

I: - - - for that to get through

E: mm!
I: I should think that through now! yes --

E: yes, I mean -- even if you did have a point to discuss they'd
get quite shirty with you, as if you were trying to do this
down; or shut them up in some way. Mm. It was very bad. I was a
bit disappointed in it. I don't think it helped me as a person to
develop to go out to work in any way

TR12

I: Mm! Well, that's one of the areas you found difficult in the degree -
which bits of it did you like - particularly interest you?

L: Well, ... I, I I enjoyed all of it, you know, I .. I can say quite
truthfully that the, the four years at the University were probably the
best four years of my life so far - er - but discounting birth of
children, and things like that, but that's er on an entirely different plane.
Erm -- the, certainly, the, the the mathematics - um basically because it -
erm - for me it was easy erm - consequently, the, the s-, the allied subjects
that erm relied heavily on mathematical manipulation, like heat transfer
and radiation, and that, that kind of thing, came - came easily.
But I also enjoyed the - er - the organic chemistry - Erm --- essentially I,
I enjoyed everything. Even, even (laughs), the thermodynamics.

TR16

I: O.K. Um - can you remember, to any extent the structure of the chemistry
in that part?

P: It's - a long time ago. Erm, basically, it was half inorganic and half
organic and damn - all physical --

I: Mm - hm!

P: - a large part of both inorganic and organic was method of memory.
The majority of simple organic chemistry was "Learn it fellah; because
there ain't much logic!" The physical chemistry was totally childish,
I thought, and very badly presented, and it was only later in the chemical engineering course that physical chemistry started having some sort of real meaning, to me - at any rate. --
Fancy going to degree-level and having no real understanding of chemical potential, or Gibb's Free Energy - strikes me as being, you know, totally inadequate, upon reflection. But that's what happened!

X: You said that the, um, physical chemistry as presented in the Part I was somewhat inadequate - on what basis do you make that judgement?
R: Mainly because - from that time onwards, I've seen that physical chemistry - I had no idea at that time what it was all about, - that it was associated with energy - levels - that a lot of, lot of, lot of reaction - I had no idea that equilibria was associated with energy. There was no sort of there was no philosophical idea behind the physical chemistry, and I'm s - f - feel sure that some sort of philosophy - er - you know - what really are the laws of nature - could've formed a basis for that physical chemistry. I didn't do it at all well, it was just, you know, isolated little things like, you know, this is electro chemistry, what happens if you pass a current - erm - and that sort of thing.

8. CATEGORY I: Industry related experience
(Number of instances - 7)

TR1

X: And er - what was the work you were doing there?
R: I was a preparative organic chemist - probably one of the things that put me off organic chemistry (laugh in background) Er - m - I got quite frustrated there. The Chief Chemist regarded me as a - er - as a threat - though it didn't take me long to find out that I wouldn't have touched his job with a 35° barge-pole. Er - m .... we didn't hit it off, I mean things were so bad that
TR1 (cont.)
in the end I went and worked in a disused laboratory simply to get away from
him and erm also I still had a residual interest in chemistry - er - which in
..... an industrial company just can't afford to allow its employees to indulge.

TR17

I: You're quite happy with that? Nothing else you want to add to what
we've said?

Q: Erm - I think - erm - working in the industry for so long is certainly -
erm - - - what am I trying to say? When I was at school, I did develop
a really big interest in chemistry - er - you know, with every aspect of
chemistry, every facet (inaudible), but - er - at - when you start
working, when you start working in a particular form you tend to -you
know, it's no longer that enjoyable any more - erm - which is a real
shame, 'cos I found it really fascinating at school.

9. CATEGORY K: Perspective on kinetics
   (Number of instances - 27)

9.1 K1: Energy equations discussed; mathematical model used.

TR21

I: Erm, does that mean that you see the main driving characteristic of
kinetics as - an energetic feature?

U: W - er - I think, yes - I, I - - - I suppose one would!

I: Ah! But do you?!

U: Do I? (laughing) In the sense that I haven't really thought about it,
for a long while (laughter). I suppose yes. If if your taking - you - you
have compound A sitting here and compound B sitting here, if you erm mix
the two together and a reaction occurs, then - erm - what, what you're
doing is converting a system from a higher to a lower energy, presumably.

Because the tendency is for systems to erm to- to 'roll downhill' - in terms
of energy - and in, in, in energetic levels. I suppose Or, or - if
neg - our energies dec - decrea - decreasing our entropy is increasing.
Perhaps it should be fair to think of it in entropic terms!
Mmm! How would you define those things?

Well thermodynamics tells you what is possible, and kinetics tells you - erm how quickly it would happen - or slowly - er, and so kinetics goes into reaction mechanisms erm - - into - - so - how far does one want to go, then?

Well you take it as far as you -

Right -

- want to sketch it

Right, - Well, I mean, you've got the, er, I suppose you can say you've got the speed of reaction, and you relate that to, what is it - AC - EA/RT or KT, isn't it, - so A is the geometry factor, made up of two parts what ever they, the er - the erm - the chances of a molecule meeting molecules meeting, and the er orientation, I think those are the two parts, Er, and then, of course, the activation energy, and, er, - er - Boltzman constant and the temperature, so that that will tell you - er - so, obviously you can play around with the activation energy, by using catalysts and so on, and alter the speed of reaction. Erm - you can then, you could go into - there are various types of, er, of reactions - first order, second order, immolecular and bi-molecular - erm - ways of studying kinetics, erm, looking at volume changes - er - or for a very fast reaction - s - some sort of, er - relaxation method - stimulate the - erm - the reaction and then watch what happens - er - I suppose that would be about as far as my knowledge would run. (Laughter).

9:2 K2: Rate/order/mechanism : molecular model used.

I: a lot of it for a long time! Erm - could you sketch out for me erm what you consider to be the main ideas in what we loosely call reaction kinetics?

M: Mm. Well it's A + B reacting to give C.

I: That's how you see it is it?
TR13 (cont.)

M: That's right—well, that's the ideal situation. I should think but—especially in carbohydrates, I suppose, the situation is a good deal more complex.

I: So, it's just a question of whether they react or not is it?

M: Well, you must—consider all sorts of things like activation energies and intermediates (inaudible).

I: Mm. And what are they?

M: Well you get an impression of A + B coming together to—to interact in a—not a permanent sort of way—but orbital overlap and whatever—it might form some sort of a transition step which requires a certain amount of ent-energy—and—if there's sufficient energy there abundantly the reaction goes through to products—

I: Mm hm! You mentioned orbital overlap.

M: or whatever. S—

I: Yep, um—why did you bring that in?

M: Well, it's entirely electronic interaction.

I: So you're seeing this on an atomic level?

M: Yes! Yes, of course,——interaction of—

I: So you, you would say that

M: two discrete molecules, coming together, overcoming whatever repulsive forces, and then subsequently marriage of orbitals and electronic systems.

I: W—Would you accept that you're looking at it from a very mechanistic point of view?

M:—Yes! I would, yes.

TR19

I: So that's your general view of it, now what would you say are the main concepts involved in it?

S: Main concepts! Erm,—it seems to me it's a fundamental way of understanding what's going on in a chemical reaction by—by, er, trying to follow
TR19 (cont.)

every species, determine what, what - its a way of determining what intermediates and transition states are involved, er and therefore, really a way of looking at the interaction between molecules - er - -

L: So you see it very definitely as a - a molecular study?

S: Yes!

L: So, in that molecular study what factors or parameters would you be looking at?

S: Well, bond breaking, bond waking I suppose are the two - erm - - -

L: Right!

S: - er, and timing as well, as far as the time goes. Yes, the relative timing of the two aspects of bond-making and bond-breaking, But also, it's the interactions of - er - atoms, in their - spatial orientation, as it were (inaudible) source kinetic study.


TR25

I: the scene. Erm, I wonder if you could outline for me what you see to be the main ideas in chemical kinetics?

Y: Er - well, I think the - the first aspect of it is that - er - I would start off actually by not talking about kinetics specifically, but mentioning that - er - if you have a reaction which - er - goes to equilibrium, then the position of that equilibrium is controlled by thermodynamic arguments. Erm - there may be two possible end products, of which one product is more stable than the other, and if you wait an infinite amount of time then - er - you will get the most stable product. However, the rate at which those - er - products are obtained is determined by kinetic arguments, so - er - kinetics and
thermodynamics really are two sides of the same coin, so I would say that -
er - the K - er - kinetics tells you the rate at which equilibrium is
obtained and - er - thermodynamics tells you about the position of
that equilibrium. So, I think that's possibly the main thing I would
say first. Erm - - - the second thing is hard to pick on because there are a whole host of things which come to mind. Erm - it depends on
who I was talking to really for - which element I would emphasise.

10 CATEGORY L : Influences in learning
(Number of instances - 13)
10.1 L1: Symbols

Q: What you - you see, I'm - er - how, how I view it now is er when you
give me these, sort of, buzz words. I can think of - it immediately means
something to me 'cos I 'we - we're using these concepts everyday,
but its - its a slightly different way from the sort of engineering point
of view - how to approach a problem. Whereas, when I start talking -
when - you were mentioning - when you think of - when you say 'equilibrium',
right?, I think 'Ah! Liquid vapour equilibrium' - mate! But now
you've mentioned in terms of a reaction I think 'Oh, well the equilibrium
constant between, if we have species A plus B going to species C plus D,
and th - then an equilibrium is set up between the - er - - - tendency
for A plus B to go to C plus D, and then an equilibrium will be set up
and the concentration of A is er sufficient - er - when the
concentration of A and B -
I: Ok uhm! If I were to ask you - er - what the phrase reaction kinetics meant to you, what sort of response would you give me?

F: I think that would take me back to - 6th form at school where there's a picture of A and B with a little line above, an then, and the old arrow there from one to the other with the energy barrier in between - /335\n
TR22

I: So it's a balance if free energies that you're thinking of, is it? /395\n
V: Yes. I mean, when I actually think of it in my mind I see a line connected with a bump, or various bumps and another line at the bottom (overtalking).

I: -- a reaction profile.

V: Yes, reaction profile, and looking at the various energies. /400

10.3 L3: Equations

TR6

I: wh-no-why did reaction Kinetics come into your enzyme chemistry? /155\n
F: well, the Michaelis - Menten Equation, I think was the standard - your looking at the A going to B and the catalyst (?)

I: yes. So you see that in terms of an equation then?

F: yes very much so. Mm! Mm!

I: a mathematical equation?

F: mm!

I: you don't see it in terms of 'real chemistry' - molecules looking together an - er - that sort of thing?

F: not - not - my initial reaction no - mm!
TR14

A: Er - yes I keep seeing it in terms of equations which I think is possibly not the right way of looking at it - er - an equation with square brackets and rate constants, and things like that in, which - er - I think is possibly rather an artificial way of looking at it. The concept of reaction kinetics I suppose is - er - erm I suppose really it's just the way in which the - - the various factors, the various materials in one's reaction affects the rate of reaction.

11. CATEGORY M: Mathematics related factors
   (Number of instances - 20)
11.1 M1: Barriers to learning focal concepts.

TR1

A: (long pause) Having dev - having sort of developed the idea of the rate, then I would want to develop some quantitative expression which related rate to factors such as concentration and temperature - er which means that I'd want to get across fairly early on an equation like the Arrhenius Equation, er, but before one could do that one's therefore got to introduce the rate constant, er - and to get over the main hurdle which is the - presentation of a differential equation, whilst instilling the minimum amount of fear in the part of the recipients.

I: Uh-hum ..... so you're up against a mathematical barrier?

A: Yep! I find I'm always up against a mathematical barrier - err - in as much as you've only got to put 'd' something by dt on the board, and people's eyes start to go up towards the ceiling.
I know we - we did a lot of differential equations and (pause)

Is that why it was disastrous?

I think it probably was a fairly short course and I know we - we were expected to do an awful lot of different differential equations. It wasn't - the concepts didn't really seem to get over very clearly, it was a lot more emphasis on the - you know the techniques for solving differential equations, or - without - I don't (know), I think the basic idea of what it was all about seem to get lost in - in - in the sort of rush to get on to the 'doing' part of it. which - um - as - I, I mean, I think I do have a bit of a mental block ever since then.

Positive personal attitudes

did tend to be the organic areas. But after having taught organic here for about say 2 or 3 years, I went right off it. And I used to enjoy the thermodynamics, I - err, I suppose in a way it's all of those areas which have got mathematical associations that I still find both enjoyable and interesting.

Er - I think, I suppose it's rather - it's, er, - er - so it's such a novel - full of, novel concepts outside everyday life, er - and yet it's, er - produces solutions and er - it's got the attractions of mathematics and that - that you get - it's er, you get to - to you get results from it.

You say the attractions of mathematics - why do you say the
attractions of mathematics?

V: Well, the attraction I put that is one attraction I can think of, the fact that you get a solution to a problem.

11.3 M3 Negative personal attitudes

TR20

I: we were expected to regurgitate, for example in ancient purposes, complex mathematical do erm and most of the people didn't have the mathematical background to really understand it, so you had to memorise bits of it; and I could see the point of regurgitating a proof where half-way through it you had to memorise what a certain differential - or integration gave you - er - I just didn't ever see the point. And yet, the powers that he seemed to think it was important

TR26

I: Why do you find that difficult - be it -

Z: (interrupting) The mathematical side, I think it was, I - I just couldn't handle numbers - er - this is why I'm an organic chemist, I guess, I go the the qualitative side of chemistry rather than the quantitative side of chemistry. Erm - so there's nothing I dislike - it's just that there're areas that I avoid.
12. CATEGORY N: Nature of chemical reaction  
(Number of instances - 1)

TR4

D: I think probably the problem lies earlier than that, in this idea that erm A and B react to give C and that's an end of it - I think er I, I mean perhaps right - - - I mean i - i - in principle the concept of things being in equilibrium and that A can go to B and B can go to A is not - there's nothing difficult about that. It's only difficult if one's been lead to believe that A and B react to give C - and then later on you're trying to say erm - 'ah! but wait a minute. In fact C can sometimes go back to A and B! And they - then you've got a block 'cos you're con - you're thinking's conditioned to thinking that A and B will react to give C

13. CATEGORY P; Personal philosophy of science  
(Number of instances - 2)

TR5(a)

E: I would say that - mechanisms is something that is in our imagination-

I: ah!

E: and that th - the fact is the thing changing colour on the bench or product A disappears and product B appears. Erm - I think you must never lose sight of that experiment on the bench. Our mechanism may be just a load of nonsense - just a way of thinking about it. What doesn't change is that chemical reaction on the bench. That's going to be the same for every - our theory about mechanisms maybe rather different in twenty years time - fifty
TR5 (b)

E: Yes. But I - - the, the, the, point that has to be got across is that - - - I - I'm convinced of this experiment - that's the important thing 'cos that's the thing that doesn't change. The interpretation will change depending on our own stand, and the thing that you've gotta get across is the role of the working hypothesis if you like, that at the moment this is how we can see this reaction and our present understanding leads us to believe that this happens, and we'll go away and use that as a working hypothesis until it fails.

14. CATEGORY R: Relevance of courses
(Number of instances - 24)

TR3

E: Again, it's mathematical again. I seem to have a feeling that when I was at secondary school it was - very mathematical again. It's a sorry thing even though it was the same teacher who was teaching everything, it's an area again were people tend to switch off with and don't find interesting again, because it's not put in, in any sort of context and make it really interesting. I mean a stream of figures really and er laws to learn - the Gas laws and all this sort of thing. I think you'd take them in much better if you had something to relate them to, rather than just a - just a string of facts.
K: Yes! Well, sort of, the view of the industrialist may not be the same as the view of the student -

I: Certainly true, certainly true!

K: - and the value to the industrialist, and the value to the student - quite different - yes.

I: Which would you think was most important in terms of the training of people for industry?

K: Well - there's a - wh - wh - if you're trying to train for industry it's the value to the student, and er if in fact the value to the industrialist is is not er so profound he - er - he's got to be persuaded in that er he 0 in that er if it is of value he's going to get a better man to work for him - ermm - when that student graduates.

S: I don't know how - how much you know about (organic) chemistry, but, but - because it is - i - it's a theory that's related to the practice. It's telling you what should be able to be done and what shouldn't, and therefore it - it's a very theoretical subject, but it has tremendous practical significance. Er - and I'm afraid, u - unless I can see the practical significance I find it difficult to appreciate why it should be there really! (laughs).

T: You say you found the physical chemistry difficult. Have you any idea, sort of, what the root of the difficulties were?

AA: Yes, I think so, looking back on it. I mean, I didn't know what it was at the time. I think it was because it was not made clear at any stage why you were doing a particular set of equation derivation or whatever it might be, what was - you know - what was the purpose of it. You started off with erm well, I mean, thermodynamics you er which we
did - er - of course in those days from the Carnot cycle, you started off with this, er, strange perception of - er - ideal gases doing peculiar things erm under rather artificial conditions which didn't seem to bear any significant relationship to any chemistry that I could see, and - and you derived a series of equations - and -- at no point that I can remember, was it made apparent that this had any er sort of real value in terms of - of its relevance to what one might actually have been doing on the - on the bench with chemicals in in flasks and test tubes.

15. CATEGORY RC: 'Realism' in chemistry (Number of instances - 10)

I: Yes. Thank you. Um - are there any parts of chemistry you find either difficult, or that you dislike?

U: Gosh! That's, er, that's a difficult one. I suppose I - er, one tends to - - I tend to, to, to leave out, these days, erm - good gracious! I don't know. I suppose I, I - so many things that I haven't thought about for a while (laughter). Erm - I suppose theoretical chemistry - trying to, erm, define and redefine one's pictures of what matter is, unless we say O.K. fine - we just look at matter using pictures, and what people are doing is trying to get better and better pictures. But it seems to me, we're reducing everything to mathematical concepts I like to, sort of, imagine things and, erm, in concrete terms and say yes, we - I got this solid sitting in this bottle, and if I take this solid and react it in solution with another solid, I can get another solid out of it. These are concrete terms, and I - I can follow this, but trying to - to put it through in theoretical terms - and to represent everything by mathematics computations I would find - er - probably it illustrates my own early - I wouldn't say problems with maths, but - er - and yet my, my family are reasonably mathematical.
But that was - you know I mean - it was a very extreme version of that which was my own experience that thermodynamics was equations it wasn't chemistry - erm - and I think that was, you know, that was really why I - I just didn't see the point in it and therefore I couldn't work up any enthusiasm to - to actually learn it (laughs).

16. CATEGORY T: Teaching approaches
(Number of instances - 28)

everything really at University everything seems to be geared to swotting up - I have memories of just learning things written on pieces of paper and - er - trying to cram in as much as possible, and these equations were some of them, and - er - it's just that when you had a particular -- reaction for 50% of you (WHERE OPEN Fuß ) temptation which is apply these things you have learned to them without actually thinking about what - what - is actually meant in ter - in real terms, in terms of the actual reaction itself, and which is I - I suppose a fault of the - maybe the exam system. It's all geared to cramming in as much as possible.

Well I was - I was actually in industry as a physical chemist, and - er - you need to use a combination of kinetics and thermodynamics all the time - I mean, it's, it's - er - you know, if you just rely for example on one area, like kinetics, er - then you find that - er you can get very misleading conclusions, I mean equally if you
rely on thermodynamics you can, you can get the wrong result, I mean if - you can have something which is kinetically determined, a reaction which is kinetically determined and yet the thermodynamics would predict another product, and you have to consider both. In fact we would usually do - kinetic experiments to measure the rate of formation of say two or three products and say well after two days you would have this product predominating even though is not the thermodynamically most stable and you might have to wait six months for that to interconvert, to the most stable species. So, all the time there was an interplay, in practice, between the two.

Would that have implications for undergraduate teaching do you think? I think so, I think it means that you've got to teach them - I don't think the way we do it now is perfect but I think it's better than the traditional way I was exposed to where things were put in boxes, you know, and they say 'this is kinetics', 'that's thermodynamics' - an it - there didn't appear to be any obvious connection. I mean, I think we should change the titles away from kinetics and thermodynamics to something which is more general - I - I, I don't claim that we've got it right, but I think a title like 'Energy and Entropy' is sufficiently general that it doesn't mean that we're just going to talk about kinetics or thermodynamics in - in that course.

there when you're comparing them between you. Erm - how would you say, in general terms, you thought the courses were run - in terms of helping you to understand chemistry, being enthusiastic about chemistry and so on? Let's start with you, Brian, first.
Well - erm - I thought the courses were run very well and co-ordinated very well. As far as interest goes it obviously depended upon the lectures, the stimulus coming from, you know, the personality of the lecturer, as it were, and some were obviously much more interested than others, because - erm - I think unfortunately a lot of them - a lot of them were - erm - biased towards their research and erm - you know, they could have been much more helpful.

I: In what way do you think they might have been more helpful?

Well - erm (coughs) - I mean, they - well I don't know, it might have been the student as well - they said they were available for help but just feel that they - you know, they could've contributed more, sort of, during the lecture time - it was, it was (inaudible) come again.

I: More of what, and what sort of help are you - you hinting at?

Well it was very - the lectures were, you know, extremely didactic - so erm -

I: Please be as open as you like, because this is totally confidential.

I agree with everything Brian's just said, I mean, he's just - everything you said, I would have said - er also, I didn't, perhaps it's - obviously the lecture situation, I hated the way they just came in, garbled on for 40 minutes and wrote all over the board, and went out again, and that was it -

No - no time for feedback, during it (inaudible - coughing) very much a presentation.

I: No interaction?

Nothing nothing at all.

No.

You see at our College, we were expected to go up to the lecturers after lectures and things and if we had any problems to ask them then, -
like go up during lunch-time or go up Wednesday afternoon -

W1: Well our's said they were available for help, yes, I mean.

W2: You try finding them though!

W1: What I found is that your own - your own personal tutor was probably

the - the person to go to in the end anyway.

W1: Yes I must admit my personal tutor was very good.

I: Did that system work, Chris?

W1: All the bright sparks generally did go up and, erm, if they had any

queries ask - but it was really, it was your own tutor who helped you most.

17. CATEGORY U: Choice of undergraduate course

(Number of instances - 4)

TR3

I: what made you go there?

C: well - did the applied chemistry course which was very industry

related, and - er - I heard from other people it was the best

place to do it.

I: uh-hm

C: Loughborough I think was an alternative er and er Cardiff

(?) was the other one. Strathclyde - I didn't fancy going up

to Strathclyde so that limited the choice down a little.
F: and I studied biochemistry with chemistry, they do a funny erm
unit system there, where your degree is made up of all bits and
pieces and y - you sort of choose your, shape your course as you want to.
I: yes
F: it's very wide - if you want it to be, - on very narrow
shape
I: how did you shape your course?
F: I made mine as wide as possible, simply because I had an eye for
going a job at the end of it (laughter). Left to my own devices
I'd have chosen biology, I think, because it did interest me
most. I must admit, that I - I thought there were fewer jobs in
Biology so I - with an eye to the future, I chose chemistry

*   *   *   *
RESEARCH QUESTIONNAIRE

Personal perceptions of chemical kinetics and equilibrium, and their relevance to chemical practice.

Please read Pages 1 and 2 carefully before answering the questions.

All responses given will be treated in total confidence and not attributable in any subsequent reporting.

D W HORSCROFT
MARCH 1986
Introduction

This questionnaire forms part of a research project which is inquiring into chemistry practitioners' perceptions of two conceptual areas in chemistry - kinetics and equilibrium.

The intention is not to analyse these concepts, nor is it to assess your knowledge of them. The purpose is to attempt a description of how these areas relate to your experience as a chemist. The questions will thus deal with a range of aspects, including certain characteristics of the concepts, your experience of them in education and work, and one or two other closely related factors.

You are asked to select and ring a number on a five point scale which best represents the position of your view between two poles. The numbers imply no numerical weighting. e.g.

'B1: Did you find your 1st degree course in total:-

Very enjoyable 1 *2 3 4 5 not at all enjoyable

"pretty good on the whole!"

Other questions are left open to give you an opportunity for a more personal response.

Before working through the questions please read the definitions on the next page. These are provided to state clearly what I mean by certain terms which are used in the questions. You do not have to agree with my 'meanings' nor are they intended to be definitive statements of scientific fact! I would also appreciate some indication of some of your meanings, as indicated.

Thank you in advance for your time, help, and kind consideration of this questionnaire.

Don Horscroft

March 1986
Some personal definitions:

1. **Physical chemistry**: this equates broadly with chemical kinetics, chemical equilibrium and chemical thermodynamics.

2. **Mathematical modelling**: the use of mathematical logic and analysis to describe a chemical phenomenon in terms of mathematical variables and equations.

3. **Molecular modelling**: the use of molecular and/or structural images together with concrete interpretations of electron configurations, to describe chemical phenomena.

If you disagree with 1. above please state briefly your definitions (descriptions) below, of the following:-

**X1** 1. **Chemical kinetics**:

**X2** 2. **Chemical equilibrium**:

**X3** 3. **Chemical thermodynamics**:
SECTION A: Biographical information

A1 Name: M/F (delete as appropriate)

A2 Employment: Job Title: Organisation

A3 Age Range

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Please tick as appropriate

A4 Academic qualifications:

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A5 Other qualifications:
SECTION B: Conceptual areas of chemical kinetics, equilibrium and thermodynamics

(a) Chemists frequently use mathematical and/or molecular modelling in attempting to describe chemical phenomena. Please circle the number which best fits your view of the following:

In Chemical Kinetics
Molecular modelling is:-
B1 Very useful 1 2 3 4 5 not useful
B2 Easy to understand 1 2 3 4 5 difficult to understand
B3 Very accurate 1 2 3 4 5 not very accurate

Mathematical modelling is:-
B4 Very useful 1 2 3 4 5 not useful
B5 Easy to understand 1 2 3 4 5 difficult to understand
B6 Very accurate 1 2 3 4 5 not very accurate

In Chemical equilibrium studies
Molecular modelling is:-
B7 Very useful 1 2 3 4 5 not useful
B8 Easy to understand 1 2 3 4 5 difficult to understand
B9 Very accurate 1 2 3 4 5 not very accurate

Mathematical modelling is:-
B10 Very useful 1 2 3 4 5 not useful
B11 Easy to understand 1 2 3 4 5 difficult to understand
B12 Very accurate 1 2 3 4 5 not very accurate

In Chemical thermodynamics
Molecular modelling is:-
B13 Very useful 1 2 3 4 5 not useful
B14 Easy to understand 1 2 3 4 5 difficult to understand
B15 Very accurate 1 2 3 4 5 not very accurate
Mathematical modelling is:-

B16 Very useful 1 2 3 4 5 not useful
B17 Easy to understand 1 2 3 4 5 difficult to understand
B18 Very accurate 1 2 3 4 5 not very accurate

(b) In what ways do you think chemical equilibrium, kinetics and thermodynamics are interrelated? (Open question)

B19 .................................................................

(c) The concepts of chemical equilibrium, kinetics and thermodynamics can involve both quantitative and qualitative approaches. Which of these two approaches do you consider important for understanding these concepts?

B20 Kinetics: Qualitative 1 2 3 4 5 Quantitative
B21 Equilibria: Qualitative 1 2 3 4 5 Quantitative
B22 Thermodynamics: Qualitative 1 2 3 4 5 Quantitative

(d) Please state the extent of your agreement with the following statements; relating to these concepts:
*Qualitative understanding and quantitative understanding are inseparable:
B23 Strongly agree 1 2 3 4 5 Strongly disagree
*Qualitative understanding is a prerequisite for quantitative understanding:
B24 Strongly agree 1 2 3 4 5 Strongly disagree
*Quantitative understanding is a prerequisite for qualitative understanding:
B25 Strongly agree 1 2 3 4 5 Strongly disagree

*Qualitative understanding is more elementary than quantitative understanding:
B26 Strongly agree 1 2 3 4 5 strongly disagree

*Qualitative understanding gives greater chemical 'realism' than quantitative understanding:
B27 Strongly agree 1 2 3 4 5 strongly disagree

*Quantitative understanding gives greater chemical 'realism' than qualitative understanding:
B28 Strongly agree 1 2 3 4 5 strongly disagree

*A qualitative understanding is less abstract than a quantitative understanding:
B29 Strongly agree 1 2 3 4 5 strongly disagree

SECTION C Chemical education in Higher Education (undergraduates)

(a) Did you find your undergraduate course, in total:
C1 Very enjoyable 1 2 3 4 5 not very enjoyable
C2 Very difficult 1 2 3 4 5 very easy
C3 Very interesting 1 2 3 4 5 very uninteresting
C4 Matching expectations 1 2 3 4 5 not matching expectations
C5 Examination success orientated 1 2 3 4 5 not examination success orientated
C6 Vocationally orientated 1 2 3 4 5 not vocationally orientated
C7 Intentionally promoted chemical understanding 1 2 3 4 5 accidentally promoted chemical understanding

(b) Did you find the chemical kinetics component of your undergraduate course:-
C8 Very enjoyable 1 2 3 4 5 not very enjoyable
C9 Very easy 1 2 3 4 5 very difficult
C10 Very interesting 1 2 3 4 5 very uninteresting
C11 Very mathematical 1 2 3 4 5 not very mathematical
C12 Matched your expectations 1 2 3 4 5 did not match expectations
C13 Examination success orientated 1 2 3 4 5 not examination success orientated
C14 Vocationally orientated 1 2 3 4 5 not vocationally orientated
C15  Intentionally promoted understanding  1  2  3  4  5  accidentally promoted understanding
C16  has proved useful on your work  1  2  3  4  5  has not been useful in your work

(c) Did you find the chemical thermodynamics component of your undergraduate course:
C17  Very enjoyable  1  2  3  4  5  not very enjoyable
C18  Very easy  1  2  3  4  5  very difficult
C19  Very interesting  1  2  3  4  5  very uninteresting
C20  Very mathematical  1  2  3  4  5  not very mathematical
C21  Matched your expectations  1  2  3  4  5  did not match your expectations
C22  Examination success oriented  1  2  3  4  5  not examination success oriented
C23  Vocationally orientated  1  2  3  4  5  not vocationally orientated
C24  Intentionally promoted understanding  1  2  3  4  5  accidentally promoted understanding
C25  Has proved useful in your work  1  2  3  4  5  has not been useful in your work

(d) Did you find the chemical equilibrium component of your undergraduate course:
C26  Very enjoyable  1  2  3  4  5  not very enjoyable
C27  Very easy  1  2  3  4  5  very difficult
C28  Very interesting  1  2  3  4  5  very uninteresting
C29  Very mathematical  1  2  3  4  5  not very mathematical
C30  Matched your expectations  1  2  3  4  5  did not match your expectations
C31  Examination success oriented  1  2  3  4  5  not examination success oriented
C32  Vocationally orientated  1  2  3  4  5  not vocationally orientated
C33  Intentionally promoted understanding  1  2  3  4  5  accidentally promoted understanding
C34  Has proved useful in your work  1  2  3  4  5  has not been useful in your work
(e) In your undergraduate course how did you find the mathematical aspects of:-

**Kinetics**
- C35 Enjoyable: 1 2 3 4 5 not very enjoyable
- C36 Easy: 1 2 3 4 5 difficult
- C37 Interesting: 1 2 3 4 5 not very interesting

**Equilibrium**
- C38 Enjoyable: 1 2 3 4 5 not very enjoyable
- C39 Easy: 1 2 3 4 5 difficult
- C40 Interesting: 1 2 3 4 5 not very interesting

**Thermodynamics**
- C41 Enjoyable: 1 2 3 4 5 not very enjoyable
- C42 Easy: 1 2 3 4 5 difficult
- C43 Interesting: 1 2 3 4 5 not very interesting

(f) Please indicate the extent of your agreement with the following statements; relating to undergraduate physical chemistry courses:-

*Mathematics should only be used as a tool to solve problems:
- C44 Strongly agree: 1 2 3 4 5 strongly disagree

*Physical chemistry should only be taught by specialists who are actively researching in the area:
- C45 Strongly agree: 1 2 3 4 5 strongly disagree

*Physical chemistry should be taught by lecturers who have a wide understanding of physical chemistry:
- C46 Strongly agree: 1 2 3 4 5 strongly disagree

*Physical chemistry should be clearly related to experimental work which is designed to help concept understanding:
- C47 Strongly agree: 1 2 3 4 5 strongly disagree
(g) In your undergraduate physical chemistry courses:

*Mathematics was mainly used as a tool to solve problems:

C48 Strongly agree 1 2 3 4 5 Strongly disagree

*Mathematics was mainly used to model chemical phenomena

C49 Strongly agree 1 2 3 4 5 strongly disagree

*Chemical kinetics were closely related to real chemical problems/situations

C50 Strongly agree 1 2 3 4 5 strongly disagree

*Chemical equilibrium was closely related to real chemical problems/situations

C51 Strongly agree 1 2 3 4 5 strongly disagree

*Thermodynamics was closely related to real chemical problems/situations:

C52 Strongly agree 1 2 3 4 5 strongly disagree

SECTION D Personal perceptions

(a) What expectations did you have of your first degree course?

That it would be:

D1 Useful in terms of employment: High 1 2 3 4 5 Low

D2 Stimulating in terms of understanding chemistry: High 1 2 3 4 5 Low

D3 Valuable in gaining professional status: High 1 2 3 4 5 Low

D4 An efficient means of gaining knowledge: High 1 2 3 4 5 Low

D5 Simply a mechanism for obtaining a degree: High 1 2 3 4 5 Low

D6 Personal development via a subject of interest to you: High 1 2 3 4 5 Low

D7 Others: (please specify)
(b) Has your first degree course been:

- Useful in terms of employment: High 1 2 3 4 5
- Stimulating in terms of understanding chemistry: High 1 2 3 4 5
- Valuable in gaining professional status: High 1 2 3 4 5
- An efficient means of gaining knowledge: High 1 2 3 4 5
- Simply a mechanism for obtaining a degree: High 1 2 3 4 5
- A means of personal development: High 1 2 3 4 5

(c) What do you consider to be the most important and the least important factors to be considered in designing a relevant chemical education course?

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SECTION E  Design of physical chemistry courses

(a) Who should be involved in making decisions concerning content selection for Higher Education Physical Chemistry Courses:

E1 Schoolteacher: Always: 1 2 3 4 5 Never
E2 Higher Education Teachers: Always 1 2 3 4 5 Never
E3 Industrial Chemists: Always: 1 2 3 4 5 Never
E4 Students: Always: 1 2 3 4 5 Never
E5 Others: (please specify) ................................
..........................................................

(b) How strong should be the influences of the following on curriculum content decisions (higher education physical chemistry):

E6 Schoolteacher: Exclusive: 1 2 3 4 5 None
E7 Higher Education Teacher: Exclusive: 1 2 3 4 5 None
E8 Industrial Chemists: Exclusive: 1 2 3 4 5 None
E9 Students: Exclusive 1 2 3 4 5 None
E10 Others: (please specify) ................................
..........................................................

(c) Please indicate your order of priority for the following criteria for selecting content (higher education physical chemistry courses):

Priority

E11 *Important concepts in chemical education: High 1 2 3 4 5 Low
E12 *Importance in industry: High 1 2 3 4 5 Low
E13 *Ease of quantification: High 1 2 3 4 5 Low
E14 *Ease of examination: High 1 2 3 4 5 Low
E15 *Good practical possibilities: High 1 2 3 4 5 Low
E16 *Good available examples of application: High 1 2 3 4 5 Low
E17  *Elegance of theoretical explanation:  High 1 2 3 4 5 Low
E18  *High student interest potential:  High 1 2 3 4 5 Low
E19  *Essential for future research capability:  High 1 2 3 4 5 Low

E20  (d) In other aspects of this enquiry, people have spoken of the importance of "chemical reality" in learning physical chemical concepts. Is this important for you - and if so what does it mean for you?

E21  (e) Please use the remaining space for any other observations you wish to make concerning this area of chemistry, its importance in education and in industry, etc:

Thank you for your perseverance and co-operation.
APPENDIX 7.

Questionnaire Data and PEST profiles.

This Appendix contains:

a) numerical data chart
b) recoded numerical data chart
c) row percentage tables
d) linear percentage charts for all the questionnaire items
e) a compilation of row percentages from the P, E and S groups within the sample
f) examples of PEST comparison profiles derived from (e)

For brevity, full details of the questionnaire items are not included; greater detail can be obtained by reference to Appendix 6.
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For interpretation of item codes, see PEST profile data.

Linear percentage bar charts - 1
For interpretation of item codes, see PEST profile data.

Linear percentage bar charts – 2.
For interpretation of item codes, see PEST profile data.
Linear percentage bar charts - 4.

For interpretation of item codes, see PEST profile data.
KINETICS

Molecular modelling:

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THERMODYNAMICS

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**Key:**
- P: practitioner
- E: educator
- S: student
- T: total
- Y: tendency to agree
- N: tendency to disagree
# PEST Profile Data (Cont'd - II)

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### Notes:
- Qualitative and Quantitative approaches:
- Enjoyable, difficult, interesting, matching exp, exam. orient, voc. orient, promoted work are the different categories for the total undergraduate course.
PEST PROFILE DATA (cont - III)

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PEST PROFILE DATA (cont.-V)

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Course Design

Who should be involved:

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Key: H: High  
L: Low
## PEST PROFILE DATA CON° - VI°

### Importance as criteria for content selection:

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N = 17   N = 18   N = 10   N = 40
PEST profiles for Items B1 - B6.
PEST profiles for Items C26 - C32.
APPENDIX 8.

Excerpt from TR25; university lecturer discussing the changes brought about by industry/education links.

I: Fine. Now y - you've obviously got quite a lot of links with industry -

Y: That's right, yes.

I: Erm - not only you, but the Department has, as far as I can see. Are they having much of an impact on what you teach?

Y: Oh yes. Erm - er - yes because for example we have CASE awards with industry - erm - and, the examples that I use in my lectures are usually drawn from my personal experience, because I know those examples very well, and we even - that man I spoke to * is, in fact a visiting Professor from industry, and he gives 10 lectures in, in the course on Materials Science - er - so we have men who just come in - er - which didn't happen a few years ago, and just teach, and - er - er - so in that sense, I've been replaced by outside speakers from industry. The material I teach is - is also industrially orientated - er - although fundamental as well so I think the material has changed in that the examples have become richer - er - perhaps the emphasis on fundamental science has been reduced, I mean, it - it - it - by definition it's had to. Erm - and then we try and teach things which are in some way topical or relevant, I mean, we don't talk about things which were important say in the early '50's, or - you know, we try and talk about things which are important in the '80's - so, I think the examples change, but the fundamental science in an area like solid-state chemistry, or gas-phase chemistry, stay the same.

* refers to earlier telephone interruption.
I: Do you think there are any positive and negative factors from a change like that you could pick out briefly?

Y: Well, I think the positive factors are that - er - er - we are at least in, in touch with the real world now, I mean, that - you can talk to the man in the street and I was very much aware of the fact that he thought the university was an ivory tower - er - where taxpayers money went and it was a complete waste of time and, and erm - - they are now the people who - are affecting the - or at least vote for the people who - who stand in Parliament and say we should cut down on universities and close half of them, and so on. So I think we are beginning to get through to the public that at least in a very small way - we've still got a lot to do - but, erm, we may be doing a reasonable job. Er - er - so that's one factor which is good. The other factor which is good is that the involvement of these people and the involvement of these - er - industrial examples in the courses, means that - er - er - the students go out into industry, they're far more aware of - er - the relevance of our teaching and hopefully the their job prospects are improved slightly. And also the involvement of people from outside means that our research is financed. Er - the negative aspects of it are that we tend now to I think offer a - a broader and shallower course than we did before - er - the depth element is, is, is going, so that - er - you get a broad and shallow view of things like polymer science or solid state chemistry - but the really detailed depth that we perhaps used to do is beginning to go - er - and I personally regret that from an academic point of view, but I feel that economics
and - the general university climate is forcing it upon us.

I :  Do you see that as a lowering of standards, or just a change?

Y :  Oh, just a change in emphasis. I think we still have - we're still picking good people and the standards are still present, but the emphasis of the - where those standards are and in what areas, and what criteria you use er - certainly the criteria have changed slightly. I don't think the standards are lower. But we're producing now a different product.