

Understanding the Teaching of Biology at A Level

ALISON FRANCIS BLACK

Thesis submitted to the University of Oxford for the degree of D.Phil.

Green College



Trinity Term 2004
{ 2005 }
(11.11.06)

Thesis Title: Understanding the Teaching of Biology at A Level

CONTENTS

	<u>Page</u>
Abstract	i
Acknowledgements	ii
Transcription Instructions	iii
CHAPTER ONE: INTRODUCTION	
Autobiographical context	1
The A level biology context	5
Overview of the study	9
CHAPTER TWO: REVIEW OF THE LITERATURE	
Introduction	12
Research into the teaching of biology/science	13
Research into teacher cognition during interactive teaching	51
Conclusion	63
CHAPTER THREE: OVERALL RESEARCH STRATEGY AND DATA COLLECTION	
Introduction	65
Research approach	67
Methodological principles	69
Case selection	81
Data collection	87
CHAPTER FOUR: DATA ANALYSIS	
Introduction	130
The principles used to guide the analysis of data	131
The analytical procedures	136
Developing the written account	157
Plausibility, credibility and trustworthiness in the final account	158
Summary	161
CHAPTER FIVE: THE THREE TEACHERS AND THEIR CONTEXTS	
Introduction	162
Case Study One	163
Case Study Two	183
Case Study Three	197
Summary	212

continued ...

CONTENTS (CONTINUED)

CHAPTER SIX: CONSTRUCTING THE A LEVEL BIOLOGY CURRICULUM FOR STUDENT SUCCESS IN A LEVEL EXAMINATIONS

Introduction	213
Conceptualising substantive biological knowledge for success at A level	216
Encouraging students to conceptualise substantive biological knowledge in particular patterned ways	242
How do the teachers decide what substantive biological knowledge needs to be known and in what ways it needs to be known for success at A level?	260
Developing students' understanding of the nature of biology/ science: an unnecessary feature of students' preparation for A level biology examination success?	270
Summary of the chapter's main findings and their relationship to previous studies	284

CHAPTER SEVEN: CONCLUSIONS

Introduction	291
Answering the research questions	291
Critical evaluation of the study	303
Implications of the study	307

BIBLIOGRAPHY	313
--------------	-----

APPENDICES

APPENDIX A: A copy of the three teachers' syllabuses outlining the content comprising the different topic areas they taught during their respective units-of-work	342
APPENDIX B: A copy of all letters and information sent to teachers, and key gatekeepers, before the project began	347
APPENDIX C: A copy of the interview guides used to collect contextual information about the three teachers in the exploratory and unit-of-work interviews	353
APPENDIX D: Interview transcripts from each type of interview used in this study: 'short' and 'long post-lesson interviews' and vignette interviews	357
APPENDIX E: Examples of lesson summaries for all three teachers	380
APPENDIX F: Examples of interview summaries for all three teachers	383
APPENDIX G: Examples of teacher comment/teaching episodes for all three teachers	386
APPENDIX H: Curriculum materials and copies of all notes put on the board/OHT during John's unit-of-work	406
APPENDIX I: Curriculum materials and copies of all notes put on the board/OHT during Catherine's unit-of-work	435
APPENDIX J: Curriculum materials and copies of all notes put on the board/OHT during Sally's unit-of-work	456

Understanding the Teaching of Biology at A level

This research focuses on uncovering, from the perspectives of practitioners themselves, the practical knowledge and understanding that shapes three teachers' successful teaching of biology at A level. Adopting a case study approach, it investigates the ways in which these biology teachers characterise their successful teaching of the subject at A level. It also explores the subject matter knowledge and understanding that shapes and accounts for these characterisations without making assumptions about the nature of this knowledge.

Data are collected through the non-participant observation of a connected series of the teachers' A level biology lessons as well as informant-style interviewing following the observed lessons.

The findings suggest that the main aim of the teachers' successful teaching of biology at A level is to ensure their students achieve examination success. In light of this, their teaching can be characterised in terms of three central features. First, they believe that to achieve this aim their students only need to know the substantive dimension of biological knowledge – they do not consider knowing the syntactic dimension to be a prerequisite to examination success. Second, they believe that their students need to conceptualise this substantive biological knowledge in several patterned ways. Third, they believe that the best way to encourage their students to develop and retain these specific conceptualisations is by adopting carefully controlled and highly structured teacher-centred pedagogical strategies. The teachers' characterisations appear to be shaped and accounted for by specific conceptions of biology which provide an overall structure to substantive biological knowledge – a structure that is determined by various guiding principles.

This research provides a first attempt to map out the practical knowledge and understanding that shapes the successful teaching of biology at A level from the perspectives of teachers themselves. The ways in which these teachers characterise their teaching differ significantly from the ways in which such teaching is described in most of the extant literature in science education on teaching and learning. This study suggests that the teachers, far from lacking in knowledge, skills and understanding, are highly skilled practitioners who respond to the local and national contexts in which they work and, taking account of these, shape their subject matter teaching accordingly such that their main aim – student examination success – is achievable. This study highlights the discrepancy between academic writing in science education on practice and practice itself. The thesis ends with a consideration of the implications of the study for the research agenda in science education, the school science curriculum and the curriculum for teacher education in both preparing and supporting the professional development of science teachers.

Acknowledgements

To begin with I would like to thank the three teachers who formed the basis of this research. All highly skilled practitioners, they willingly gave up their professional time to share their considerable expertise with me. Without them this research would simply not have been possible. I am enormously grateful to John, Sally and Catherine for the interest they showed in this project and the wisdom they shared.

I would also like to thank my supervisors Dr. Hazel Hagger and Dr. Geoff Hayward. They have both provided me with huge emotional and intellectual support. Their care, patience and stimulating supervisions have been unrivalled. I cannot thank them enough for all they have done.

I would also like to thank my wonderful husband, Alan, who despite my frequent doubts has always believed I would finally finish this project. His never-ending patience is a constant source of admiration to me and his interest in my work, even at 6am(!), has been unparalleled. There is no way on earth I could have done this without him. I also must mention the unconditional love of our border collie Finn. Over the years our many walks in the countryside have provided me with creativity and the occasional flash of inspiration (?!).

I could not have begun, let alone finished this research without my Mum and Dad. They have given me masses of emotional, intellectual and financial support. I am wholly indebted to their love and patience. Thank you.

My sister Cath has been a constant prop throughout this project. She has watched me despair and delight in the research process and has provided me with a constant stream of advice, flowers and cream cakes.

I am very lucky to have been blessed with wonderful parents-in-law who have helped me tremendously at different points in this research. Thank you Janet for the many hours you spent transcribing lesson tapes and Roger for patiently typesetting my thesis on more than one occasion!

I want also to thank my fellow Lochrians, Nerissa and Matt, for their help and support over the years. Thanks Nerissa for your help with transcription in the early days. Thanks Matt for your stimulating conversations (particularly about chapter six) on the way to and from gigs! And thank you both for your painstaking proof reading at the end.

I have made many friends along the journeys this research has taken me. There are three in particular I wish to mention for their thoughtfulness, care and intellectual insights. Thank you Sherrill, Will and Richard.

Transcription instructions

Quotations from primary data are presented in many of the chapters in this thesis. The primary data is presented as transcriptions of lesson and interview audio tapes. Since transcriptions are not representations of reality but rather artificial constructions and their production involves a series of judgements and decisions, a set of clear instructions for notating them was produced and followed throughout the transcription process. These notations are set out in the following pages to assist the reader in interpreting any primary data found in the chapters of this thesis.

Many of the instructions followed when transcribing the lesson and interview audiotapes were taken from those suggested by Ogborn *et al* (1996, p. vi). These are outlined below:

- Full stops (.) and capitalizing initial letters of new sentences are used to create a 'written' version of the speech, where the speech without them would be tiresome or puzzling to read.
- Dashes (-) indicate places where the speaker abandons one way of expressing something and starts again, or where an aside is inserted. A dash is also used for an uncompleted word (for example, 'Hen –' where a speaker might start to address 'Henry' but then switches to another name).
- Commas (,) indicate places where the listener feels a pause, even if there is no actual pause, because an idea is being extended or repeated. Sometimes there will be an audible pause.
- Question marks (?), used at the end of an utterance or after a word (e.g. 'OK?') indicate a questioning intonation. A question is being asked or implied.
- [] indicates a noticeable pause or hesitation, longer than those of the speaker's habitual rhythms.
- [?] symbolizes a device quite often used by teachers – a hanging questioning space at the end of an utterance, which expects an answer which would complete the utterance (as in 'So this is called a [?]').
- Where turns to speak are taken normally, each speaker's text begins with a capital letter. Where one person interrupts another, the first speaker's transcript is broken off without a final punctuation and the interruption is inserted without an initial capital letter.
- A special pace and intonation is used when dictating or when giving something particular emphasis. This has not been represented textually, but notes in parentheses indicate where it occurs. Words 'spelt out' are printed with spaced characters.
- Occasionally italic type is used to indicate the stress, where there is otherwise ambiguity (for example, '*I* do' versus 'I *do*').
- The teachers and students are identified by pseudonyms, which remain the same throughout the thesis.

In addition to these I also adopted some of my own notations. They are identified below:

- Laughter is indicated by the following symbol (**).
- When the tape is unintelligible the following symbol is given [^].
- Comments written in italics inside square brackets indicate what the teacher and/or students are doing at a particular point in time, in the lesson or interview, in order to give information to the reader to help him/her make sense of the transcript.
- In vignette interviews, text in normal type indicates the teacher or interviewer's comments during the interview and text in bold type indicates the teacher and/or student's comments in the lesson.
- Occasionally, apostrophes are used to help clarify the meaning of the transcript. For example, in post-lesson interview 2 Catherine is talking about an instance of her good biology teaching where she encourages her students to hold a maggot and tells them that maggots respire in the same way as humans. In the interview she repeats various comments she made in the lesson (e.g. 'I said 'this organism is doing exactly the same as you'). These comments are put in apostrophes to help the reader appreciate their sense within the transcription produced.

In memory of Bump Number One and Grandpa Malthus

This thesis is dedicated to my son Owen

Chapter One

Introduction

This chapter comprises three sections. The first section introduces and explains the background to the study. For readers unfamiliar with the English, Welsh and Northern Irish system of post-16 education, the second section presents a brief overview of the A level context at the time of the study, with particular reference to biology. The third section provides an overview of the remainder of the thesis.

Autobiographical context

This study's focus upon the teaching of biology at A level relates strongly to my background in the teaching and learning of the subject. After a first degree in Human Sciences I went on to train as a science teacher with a specialism in biology. During my training year, I became actively involved in the teaching of biology at A level. In these lessons, gone were the classroom management issues I faced with my Year 9, 10 and 11¹. Instead, I found myself able to concentrate solely on the teaching of the subject I love: biology. But it was then that my challenge really began – how was I supposed to successfully teach seventeen Year 12 students biology at A Level? I spent some time observing my mentor interacting with the A level biology class I would teach. She was considered, by staff and students alike, to be an excellent biology teacher and I wanted to know what she did and why she did these things when, in her opinion, she felt she was

¹ The reference to Year groups in this thesis refers to a body of students of a particular age studying a particular curriculum. Typically in England, Year 9 refers to students aged between 13 and 14, Year 10 refers to students aged between 14 and 15 and Year 11, the last year of compulsory schooling, refers to students aged between 15 and 16. Years 12 and 13 refer to students aged between 16 and 18 who are studying non-compulsory courses such as A levels.

teaching biology well. I wanted to know what I needed to know about biology in order to do these things. Did I, for example, need to develop a particular conception of biology in order to teach it well? In short, so that I could grow and develop as a practitioner, I wanted to know what it was that made her so good at getting her students to learn successfully so many complex biological ideas. I frequently quizzed her after lessons about what she had been doing and, in addition, turned to the science education literature to investigate what it had to say about the effective teaching of biology.

Research into the effective teaching of biology appeared to be a popular area of work and I explored an abundance of studies. As I read, however, three things struck me. First, whilst there was a plethora of studies presenting various resources, experiments and approaches to teaching biology there were no accompanying descriptions of how they might be used successfully in the classroom. As a beginning practitioner this was puzzling to me; how might I use chequerboard diagrams for teaching Hardy-Weinberg (Buck 1986)? What sort of knowledge did I have to acquire and what sort of thinking did I need to do in order to develop some of these ideas myself?

Second, many of the resources, experiments and approaches to teaching biology suggested by the studies seemed to be based upon the anecdotal evidence of practitioners and teacher educators (e.g. Ash 2001; Pickering 1999a, 1999b; Eltringham and Lock 1998; Lester and Lock 1998; McTiffin 1996). Indeed, there

appeared to be a scarcity of rigorous evidence supporting the claims made by these studies.

Third, many of the studies I came across seemed to prescribe what researchers believed biology/science² teachers 'ought' to do in the classroom in order to teach biology/science effectively (e.g. Clement *et al* 1989; Bentley and Watts 1987; Screen 1986). Over the years, however, such prescriptions seemed to have had little effect on classroom practice. Perhaps these prescriptions do not work in the complex context of the classroom?

As my PGCE year continued, I came across the writings of Donald Schön (1987, 1983). The basic tenet of his work is that the knowledge and understanding that shapes professional practice is different in nature to academic knowledge. Professional practice is not, therefore, the application of theoretical knowledge to a practical context but rather the exercise of another type of more practically based knowledge. Schön's thesis had a profound effect on me and I hypothesised that if I

² It is important to explain the reason for, at times, the introduction of the term 'science' in conjunction with 'biology' – e.g. biology/science – in the main text. Whilst there is a body of research literature specifically exploring the teaching of biology, a larger body of research literature has explored and continues to explore the teaching of science in general. In this context, the term science embraces the subjects of biology, chemistry and physics. In the main text, therefore, the reference to biology/science signals research that has focused on a combination of the three sciences as opposed to focusing solely on biology. Since biology is a science and therefore shares similarities with chemistry and physics, by implication the results of these studies are considered significant to this research project.

was to uncover what I needed to know in order to teach biology at A level well, it might be this practical component of biology teachers' knowledge that I would need to tap into.

I investigated the literature exploring teachers' practical knowledge. Of particular interest was the work of Brown and McIntyre (1993) who explored the practical knowledge of a number of teachers and discussed in detail the methodology they developed to access this knowledge and the findings that emerged from their project. From an exploration of the literature investigating teachers' practical knowledge, however, I found that whilst many studies had been undertaken they had tended to focus on the practical knowledge and understanding shaping the generic aspects of teaching rather than the teaching of specific subjects. Little research had been done in the science subjects and a thorough search revealed none in biology. Consequently, my analysis of the science education literature, my introduction to the teachers' practical knowledge perspective and my desire to teach biology well provided the stimuli for this research.

The A level biology context

A levels provide a course of study equipping post-16 students with an education in a variety of subjects (e.g. biology, chemistry and maths) either as a basis for further study or as part of a broader education. Idolised as the 'gold standard' of English, Welsh and Northern Irish education (Tomlinson 1993) they persist, despite many attempts at reform (e.g. Department of Education and Science/Welsh Office 1988 – The Higginson Report), as an integral facet of post-16 education in England, Wales and Northern Ireland.

At the time of this study³ eight different examination boards providing A level biology syllabuses existed within England, Wales and Northern Ireland. The A level biology syllabuses used by the teachers in this study were AEB⁴ and NEAB⁵. Each syllabus contained a compulsory subject core mandated by SEAC⁶. Outside of this subject core, the examination boards were free to select the content they deemed appropriate for students to study at A level. Despite these differences, the general aims and assessment objectives of the syllabuses shared much in common. These are outlined overleaf.

³ The research that formed the basis of this thesis was undertaken in 1997 before the changes to post-16 education in England, Wales and Northern Ireland in 2000 came into effect.

⁴ The Associated Examining Board (AEB), Stag Hill House, Guildford, Surrey GU2 5XJ

⁵ The Northern Examinations and Assessment Board, 12 Harter Street, Manchester, M1 6HL

⁶ SEAC stands for Schools Examination and Assessment Council. This has now been amalgamated into QCA, the Qualifications and Curriculum Authority.

Aims

There were six overriding aims common to each syllabus. These were to:

- assist students to acquire knowledge and understanding of biological concepts and principles;
- assist students to acquire the ability to apply concepts to explain unfamiliar phenomena and information;
- assist students in developing a scientific approach to the solving of problems including, for example, forming hypotheses and predicting outcomes;
- assist students to develop the skills necessary to work safely with apparatus, biological material and organisms;
- assist students to recognise and evaluate some of the social, environmental and economic effects, and political, ideological and ethical implications of the applications of biological science;
- provide a scientific training, either as an end in itself or as a foundation for more advanced study.

Assessment objectives

The assessment objectives for the three syllabuses could be loosely grouped into three areas.

Knowledge and understanding

This included assessing the candidates' ability to:

- recall and show a knowledge and understanding of factual knowledge, theories or generalisations, terminology, conventions, definitions, concepts, principles and relationships;
- show a knowledge and understanding of the social, economic, environmental and technological applications of science and of related political and ethical issues.

Application and analysis

This included assessing the candidates' ability to:

- apply knowledge and understanding of models, theories, concepts, Laws and principles to solve problems in familiar and unfamiliar situations;
- analyse and interpret scientific information presented in a variety of forms.

Investigation

This included assessing the candidates' ability to:

- formulate hypotheses and design feasible experiments to test them;
- investigate by means of experiment, make accurate observations and record results;
- analyse, evaluate and draw conclusions from the outcome of experimental investigations;
- select, critically evaluate, organise and present relevant information, ideas, descriptions and arguments clearly and logically, taking into account their use of grammar, punctuation and spelling.

In addition, candidates were also expected to have a basic understanding of various mathematical skills including the ability to display and interpret data and make simple calculations within a biological context involving percentage, ratio and scaling.

Assessment

Assessment for both the AEB and NEAB syllabuses took the form of either modular or end-of-course. Modular assessment involved taking examinations throughout the two-year course whilst end-of-course assessment involved taking examinations having completed the entire two-year course. In addition to written papers, both syllabuses involved centre-based coursework as part of the final assessment.

Overview of the study

This study is concerned with understanding more about how these syllabus aims and objectives are enacted by experienced A level biology teachers. In particular, it seeks to explore how biology teachers think about the organisation and representation of biological knowledge in order to teach it well at A level.

This thesis is organised into seven chapters. This first chapter has outlined the major stimuli for the evolution of this research and has provided some contextual information for those readers unfamiliar with the English, Welsh and Northern Irish system of A level study at the time this research was undertaken.

Chapter two begins by setting out more fully the intellectual context within which this research was undertaken and the previous research and thinking on which it built. To this end, it discusses literature from two fields of research – the science education research literature exploring the teaching of biology/science and literature investigating teacher cognition during interactive teaching.

Chapter three describes and discusses the research design of the study. In doing this it considers: the research approach adopted; the methodological principles underpinning the conduct of the study; the procedures for selecting cases and gaining access; and the procedures for the collection of data.

Chapter four describes and discusses the ways in which the data of this study was analysed. In doing this, it considers the principles that underpinned the analytical procedures and the analytical procedures themselves.

Chapters five and six present the findings of this thesis. Chapter five provides rich, descriptive accounts of the three case study settings by presenting details concerning the three teachers, their respective students, the schools in which they worked, and the units-of-work⁷ they taught during the research period. Whilst setting out the contexts in which the teachers worked draws more on secondary than primary data, it is considered essential to assist the reader in making sense of the interpretations presented in chapter six, and in addition, providing plausibility and credibility to the interpretations offered.

Chapter six presents the three teachers' perceptions of their successful teaching of biology at A level. In particular, it examines the ways in which they believed their students needed to know the A level biology curriculum for examination success and how they worked to bring about the development of such knowledge in their students.

⁷ A unit-of-work refers to a series of lessons comprising a discrete part of the A level biology syllabus. For example, a discrete part of the Northern Examinations and Assessment Board (NEAB) syllabus is referred to as a 'topic'. A discrete part of the Associated Examinations Board (AEB) syllabus comprises a numbered section e.g. 3.9 The blood system of a mammal transports metabolites between exchange surfaces. Refer to Appendix A for an outline of the content comprising each teachers unit-of-work.

Chapter seven discusses and relates the findings presented in chapters five and six to the three research questions posed in chapter three. It critically reflects upon the design and conduct of the research study, and finally, discusses the implications of the findings for policy, practice and research.

Chapter Two

Review of the Literature

Introduction

This chapter sets out to consider more fully the intellectual context within which this research was undertaken and the previous research and thinking on which it built. To this end, there is a specific focus on the science education research literature exploring the teaching of biology/science and the research literature investigating teacher cognition during interactive teaching.

The chapter is split into three main sections. The first main section examines the four major traditions that explore the teaching of biology/science. The second main section reviews the research literature investigating teacher cognition during interactive teaching. It considers the most influential perspectives in recent years within this field of research. Both sections set out to review their respective literature by describing and evaluating the major findings of each tradition/perspective and by showing how the work of this thesis has been informed by and builds upon each of them. The third and concluding section locates the study given the intellectual context presented in sections one and two.

Research into the teaching of biology/science

In the last forty years, a vast array of studies in the science education literature has focused on exploring the nature of biology/science teaching. An overall review of these suggests that there are four different traditions which highlight the particular emphases and interests of the individuals working within them. They can be identified as:

- practising teachers and teacher educators sharing their experience and thinking about the teaching of substantive biological content knowledge;
- empirical studies exploring the teaching of substantive biological content;
- suggested approaches to teaching science based on conceptions of learning in science;
- research investigating the role of subject matter knowledge and understanding in biology/science teaching.

Each tradition is considered in turn.

Teaching substantive biological content knowledge: practising teachers' and teacher educators' experience and thinking

The first tradition comprises practising teachers and teacher educators sharing their experience and thinking about the teaching of substantive biological content knowledge; knowledge that is taken to mean the facts, concepts, processes, principles and theories of biology. This tradition has been prolific in its output but the many studies can be grouped into four categories.

The first category concerns studies describing possible resources for the teaching of specific biological subject matter. These resources can be classified into two groups. The first group embodies models, games and diagrams. Typical of such studies are those advocating the use of: air pumps for modelling the heart (Lee 2001); plaster of Paris for modelling cell ultrastructure (Bushell 2001); dolly mixtures (Evans 2003) and rope ladders (Sindall 2003) for modelling DNA; aprons to study the structure and function of the human urino-genital organs (Eltringham and Lock 1998); various different games to help students make sense of photosynthesis, pollination and biodiversity (Bromley 2002), genes and alleles (Ash 2001) and reproduction, cells and digestion (Franklin *et al* 2003); chequerboard diagrams for solving Hardy-Weinberg problems (Buck 1986) and ready made revision aids for topics such as the Krebs Cycle (Pickering 1999a) and B vitamins (Pickering 1999b). The second group comprises articles describing and reviewing ICT¹ resources which practising teachers might call upon in their teaching of substantive content. These include, for example, articles concerning useful websites (Baggott la Velle and Maddon 2003; Baggott la Velle 2003; Baggott la Velle 2002a; Baggott la Velle 2002b; Baggott la Velle 2002c; Baggott la Velle 2001; Bailey 2001) and articles concerning useful software (Tsui and Treagust 2003; Howarth 2003; Strange 2002; Annan 2000; Castells-Brookes *et al* 1999; Delpech 1999).

¹ The abbreviation ICT refers to Information and Communication Technology.

The second category comprises practising teachers and/or teacher educators describing experiments which demonstrate various biological concepts including behavioural kinesis (Morris 1999), circadian rhythmicity (Cheverton and Ebling 1997), various properties of enzymes (Marques *et al* 2001; Meatyard 1999) and osmosis (Wood-Robinson 2001).

The third category embodies descriptions of particular approaches to teaching specific biological subject matter used by practising teachers or suggested by teacher educators. Examples include analogy when teaching about DNA (Srinivasan 1998), greater biochemical emphasis when teaching the Krebs Cycle (Akeroyd 1983) and using computer simulations when teaching complex concepts which include mathematical and graphical components such as population dynamics (Barker and Beare 1999).

The fourth and final category comprises a number of books dedicated to the discussion of biology teaching. These books reflect the experience of practising biology teachers and teacher educators. Generally they are broad in scope, focusing not just on the subject aspect of biology teaching but also considering wider issues such as general teaching and learning methods (e.g. using an OHP² in the classroom and using radio and television broadcasts). On the subject side of teaching biology they provide a wealth of useful suggestions for practice and

² OHP refers to a piece of equipment called an overhead projector. This is a commonly used classroom teaching aid.

outline detailed plans for the teaching of various biological topic areas (Reiss 1999; Brown 1995; Dowdeswell 1981; Dallas 1980; Kramer 1975; Duvigneaud 1964).

Although these studies provide an exhaustive and valuable resource base for teaching, what is common to them all is that they are limited in what they reveal about biology teachers' understanding of their teaching of biology. Whilst the studies describe the resources, experiments, approaches and plans that can be used when teaching biology, they do not describe and/or analyse in detail the interactive teaching that biology teachers deem necessary to implement them. For example, Pickering's (1999a and 1999b) articles include photocopiable resources, in the form of diagrams, which could be used by other teachers but no accompanying description of how they might be used in the classroom is provided.

Similarly, an article by Wood-Robinson (2001) provides detailed guidance for an osmosis practical but does not describe the interactive teaching required to implement the experiment in the classroom. For example, no suggestion is given of what the students might need to know before the practical, how it might be introduced, or the sort of help that might usefully be given to a student engaged in it.

Furthermore, what is common to all these studies is that they are limited in what they reveal about the subject matter knowledge and understanding that informs the use of these resources, experiments, approaches and plans in the classroom. For

example, Srinivasan's (1998) article suggests the use of analogy as an approach to teaching DNA³. However, no accompanying description of the subject matter knowledge and understanding of the teacher that shapes the use of this strategy in the classroom is given. Rather, Srinivasan states that 'one has to be familiar with both the subject and its metaphor' (p. 43). But what exactly do teachers need to be familiar with? In what ways do they need to know and understand DNA to use this approach successfully in the classroom?

Similarly, whilst the authors in Reiss' (1999) edited book suggest possible teaching routes for ten National Curriculum⁴ biology topics, no description or analysis of the subject matter knowledge and understanding informing these teaching routes is given. What, for example, do teachers consider they need to know and understand about biology to develop such sequences? Might they require particular conceptions of their subject? If so, what might these be?

³ This stands for deoxyribonucleic acid. This is a 'complex NUCLEIC ACID molecule found in the chromosomes of almost all organisms, which acts as the primary genetic material, controlling the structure of proteins and hence influencing all enzyme-driven reactions' (Hale *et al* 1995, p. 213).

⁴ The National Curriculum applies to pupils of compulsory school age (5 to 16) in all maintained schools in England and Wales. Organised on the basis of four key stages it comprises compulsory subjects for which programmes of study set out what pupils should be taught and attainment targets set out the expected standards of pupils' performance.

Overall, a review of this tradition reveals an extensive and valuable resource base for teaching. Nevertheless, it also highlights a paucity of literature that:

- describes and analyses biology teachers' understanding of their classroom action – that is what they do in the classroom and why they do these things when teaching biology;
- explores the subject matter knowledge and understanding that shapes this teaching.

It could be argued that the studies reported in this section do not constitute 'research' in the more conventional sense of the term since they do not have a strong empirical and/or theoretical base. However, a handful of studies have investigated the teaching of substantive biological content through empirical work. Collectively, these studies form the second tradition within the science education literature exploring the teaching of biology/science and are discussed next.

Empirical studies exploring the teaching of substantive biological content

Common to the studies within this tradition is a concern, through empirical work, with investigating the effectiveness of one or more different approaches to teaching substantive biological content. The work of Gayford (1984) is a typical example of this genre. Gayford examined the influence of teachers' use of biological terminology – that is the 'old' style of diffusion pressure deficit or the 'new' style of water potential – on students' understanding of water relations in vacuolated plant cells. Forty-four randomly selected schools formed the site for Gayford's research. In these schools, 543 students were taught the topic of water relations by their

biology teachers – the teachers using whichever terminology they preferred. The students' understanding of the concepts involved was subsequently assessed by a standard test. The test was designed to determine which pupils had been taught the topic using the 'old' terminology and which using the 'new'. Gayford analysed the test data and found that 'Those who had been taught using old terminology consistently obtained slightly poorer marks than those who had been taught using the new' (p. 155) – although no tests of statistical significance were performed. Gayford implies that these results show that the 'new' terminology is more effective for pupil understanding of water relations in a vacuolated plant cell than the 'old'. There may well, however, be alternative explanations for these results. It might, for example, have been the case that those students taught the topic areas using 'old' terminology were lower in ability than those taught using 'new' terminology. Furthermore, in general, the teachers teaching the topic area using 'new' terminology might have been more 'effective' in bringing about students' learning than those teaching the topic using 'old' terminology *irrespective of the terminology they used*. Therefore, before accepting Gayford's findings wholeheartedly, it would seem that there is a need for further empirical work that takes account of these potentially confounding variables.

Killermann's (1996) work provides an additional example of research typical of this tradition. In his study, Killermann investigated the efficacy of four different methods used to teach biology - laboratory activities, fieldwork, use of live animals, and educational television programmes - through four different controlled experiments. One of these – testing the efficacy of laboratory activities in developing Year 5

(10-11 years old) students' and Year 7 (12-13 years old) students' understanding of water balance in plants – is discussed in more detail as an exemplar of his research. In this study, three large groups of students from Year 5 and Year 7 were assigned to a treatment: experimental group one involved students carrying out the experiment themselves; experimental group two involved the teacher demonstrating the experiment; and the control group involved a presentation on the same theme without experiments. The students were given a pre-test to assess their knowledge of the topic in question before the experiment, and were then taught according to their treatment group. They were tested immediately after the treatment period, and again some days later. The results indicate that experimental work – whether students' own or teacher demonstration – leads to a greater increase in knowledge of water balance in plants than no access to experimental work at all. For the fifth graders, knowledge increase in post-tests was significantly greater for groups experiencing experimental work – whether it be through students engaging in the practical work themselves or through teacher demonstration – in comparison to the control group. For seventh graders, knowledge increase in post-tests was significantly greater for the groups experiencing experimental work through teacher demonstration rather than for the other two groups.

The sample size for Killermann's study was large (605 students) and he identifies the need for this as an attempt to 'try to minimise the effect of extraneous factors such as the time of day, or the differing level of engagement of the class' (p. 335). No information, however, is provided about the ability level of the students or the

teacher teaching the groups. Were the groups matched for ability or randomly assigned? Did the same teacher teach all three groups? Without answers to these questions, Killermann's results cannot be accepted wholeheartedly and his claims, therefore, need further empirical testing.

While there are methodological limitations to the work of both Gayford (1984) and Killermann (1996) their research does offer useful suggestions to teachers of biology. For instance, Gayford's study indicates that it might be better to teach water relations in plant cells at A level using the terminology of water potential rather than diffusion pressure deficit; a position that has been widely adopted in schools. Furthermore, Killermann's research suggests that experimental work improves students' knowledge of water balance in plants.

Whilst the studies within this tradition suggest that certain approaches to teaching biology are more effective than others they reveal little about how teachers use these approaches successfully in the classroom. Indeed, what seems to be missing from this research are rich descriptions of the classroom actions and reflections on those actions of teachers using these approaches to teach biology. For example, it would be useful to know what teachers do and why they do what they do when they use the terminology of water potential, rather than diffusion pressure deficit, to teach water relations in plants. Furthermore, it would be useful to know what sorts of experiments teachers consider beneficial to the teaching of water balance in plants and more specifically how they use them in the classroom to develop their students' understanding of this topic area.

In addition, the studies within this tradition do not explore the nature of the subject matter knowledge and understanding that shapes the successful use of these approaches in the classroom. What, for example, do teachers need to know and understand about biology to use particular experiments to teach water balance in plants successfully to their students? Do they, for example, need to conceptualise water balance in a particular sort of way?

To summarise, a review of this tradition further highlights the dearth of research:

- describing and analysing biology teachers' teaching of biology;
- exploring the subject matter knowledge and understanding that informs this teaching.

Suggested approaches to teaching science based on conceptions of learning in science

A third tradition in the science education literature involves a range of studies suggesting different approaches to teaching science, based on certain conceptions of learning in science. Three movements embodying differing conceptions of learning in science have dominated this literature over the past forty years. The first movement, the 'Discovery Approach', emerged in the 1960s and spanned two decades (Gott and Duggan 1995). This approach grew from the English Nuffield Science Projects in all three sciences. Developments in the philosophy of science and psychological theory also seemed to provide a sympathetic intellectual backdrop to the creation of this approach (Solomon 1980).

The 'Discovery Approach' considered learning in science to be a process of students discovering scientific concepts in the classroom through playing and experimenting (Gott and Duggan 1995). Researchers working within this paradigm assumed that scientific knowledge and understanding is 'waiting locked up in nature to be peered at and dug out by schoolchildren' (Harris and Taylor 1983, p. 277).

The second movement – the 'Processes and Skills Movement' – emerged in the late 1960s and, according to Millar and Driver (1987):

can claim direct descent from the ideas embodied in the primary science course *Science – A Process Approach* (SAPA) (AAAS, 1967) which was based on the view of 'science as process' outlined by Gagne (1965).

(p. 35, original emphasis)

It was also embodied in various curriculum projects of the 1980s such as Warwick Process Science (Screen 1986). In contrast to the 'Discovery Approach', the 'Processes and Skills Movement' considered learning in science to be a process of mastering the scientific method. Researchers working within this paradigm assumed that science proceeded in an orderly fashion by following a particular method (Millar and Driver 1987). According to this movement, this method includes: measuring; observing; hypothesising; predicting and inferring (Gott and Duggan 1995; Woolnough 1994).

The 'Processes and Skills Movement' was superseded by the third movement - the 'Constructivist Movement' in the 1980s. This movement has been considered by

many, including Jenkins (2000), Tao and Gunstone (1999) and Banet and Nunez (1997), to be the dominant paradigm of research into the learning of science - with inherent implications for the teaching of science - over the past two decades. The 'Constructivist Movement' considers learning in science to be a process of conceptual change. Researchers working within this paradigm make two assumptions (Millar 1989). The first is that learners have prior ideas or conceptions about many science topics before instruction. The second is that individuals construct their own meanings for events and phenomena. In light of these assumptions, learning science is perceived as the product of the interaction between existing conceptions and new experiences leading to the reconstruction of meaning (conceptual change) rather than simply the accretion of new ideas (Millar 1989).

More recently, in addition to these assumptions, there has been an acknowledgement in the science education literature that learning science takes place in a social context and that this context is extremely influential on learning (Leach and Scott 2000). This social constructivist perspective on learning in science takes account of both the individual and the social context within which the learning takes place, thus recognising the significance of the interactions individuals have with their teacher and other students throughout the learning process.

What is common to these three movements is that they each offer a conception(s) of what science teaching might comprise based on their assumptions of what

learning in science involves. The 'Discovery Approach', for example, considered teaching to comprise providing students with situations in which they could discover scientific concepts (Ogborn *et al* 1996). Furthermore, the 'Processes and Skills Movement' considered teaching to involve developing students' mastery of the scientific method including teaching them various skills and processes such as measuring and observing (Gott and Duggan 1995). Finally, the 'Constructivist Movement' has offered various suggestions as to what the teaching of science for conceptual change might comprise. Based on the work of CLISP (Children's Learning in Science Project), for instance, Driver (1989) proposes a teaching sequence designed to promote conceptual change in science. This involves, as Millar (1989) summarises:

Elicitation of prior ideas, their clarification and exchange within the class group, exposure to conflict situations and construction of new ideas, followed by review of progress in understanding.

(pp. 588-9)

Furthermore, Hewson *et al* (1998) provide various guidelines and strategies for teachers wishing to teach for conceptual change. Similar to Driver, one of Hewson *et al*'s guidelines suggests the importance of eliciting students' ideas using techniques such as pre-instructional quizzes, small group posters and interviews with students about the topic. Additional guidelines include encouraging explicitly metacognitive classroom discourse and the discussion and negotiation of the status of different ideas.

This tradition, however, has not shed much light on our understanding of what science teachers do and why they do what they do when teaching science. It is plausible to suggest that this situation has arisen because the starting point for each movement is a particular set of assumptions about learning in science which leads to a prescription of what it is believed teachers 'ought' to do rather than an in-depth understanding of what it is they actually do.

Additionally, the literature suggests that these prescriptions for classroom practice have been of limited use to practising teachers. For example, in writing about the 'Discovery Approach', Solomon (1980) documents that providing students with situations in which they can discover scientific concepts is not always possible. She describes various difficulties she confronted when engaging her students in an experiment with levers as part of the Nuffield Physics course. These difficulties meant that she had to interrupt her students in the midst of their investigating in order to give instructions so that the "desired result" was "discovered" (p. 46). Discovery learning in these situations, she argues, becomes an 'elaborate hoax', 'manipulated from behind the scenes by a conniving teacher' (*ibid.*, p. 47). It seems that such difficulties arise from an assumption underpinning this tradition – that is, as Harris and Taylor (1983) point out, 'the view that concepts can be learnt by drawing them out of objects or apparatus in which they are embedded' (p. 277).

Furthermore, various academics writing about the 'Constructivist Movement' indicate that despite persuasive evidence that teaching for conceptual change is a fruitful way to develop students' understanding of science, teachers, with the

exception of a few highly committed practitioners linked to various constructivist research projects (e.g. Viennot and Rainson 1999), seem generally reluctant to adopt this model of teaching in the classroom. Solomon (1994), for instance, documents that back in 1983 at the first Misconceptions conference:

some largely unsuccessful attempts to 'use' constructivism to teach science – programmes for 'conceptual change' as they are usually called – had been reported.

(p. 10)

Indeed, the position seems to have changed very little as Jenkins (2000) points out:

Sizmur and Ashby (1997) found that few teachers elicited young children's views about natural phenomena in any systematic way when introducing them to scientific concepts, and Larochelle and Bednarz (1998 p. 3) have commented that "... taking students' knowledge into account seems to have scarcely modified the usual teaching modus vivendi at any level of instruction one chooses to examine."

(p. 604)

In an attempt to explain why this might be the case, Jenkins (2000) suggests that, despite a recommended model of instruction and various so-called constructivist curriculum materials, little guidance from researchers concerning how to teach for conceptual change has been given. In his words:

are eliciting and reorganising students' ideas to be seen as distinct steps or, as some writers suggest (e.g. Harlen 1996) better regarded as part of a continuous process? ... are ideas, once elicited, meant to assist a teacher to plan what he or she must now do in response or is their principal purpose to help students clarify their own thinking?

(p. 602)

Moreover, the assumption that students develop alternative understandings of concepts that they have never encountered (e.g. ATP, Gibbs free energy, and osmosis) is difficult to comprehend. Indeed, it may well be that for many of the concepts that students learn in science, they have no alternative conceptions at all to be elicited (Jenkins 2000).

In addition, the assumption that the various strategies suggested by researchers will be fruitful in achieving conceptual change in students has also been challenged. Claxton (1986), for instance, argues that the assumption that exposing students to conflict situations – as Driver (1989) suggests in her proposed teaching sequence outlined on p. 25 – in order to promote their conceptual change about a particular science concept or idea could well be unsound. Indeed, he argues that, rather than promoting conceptual change, challenging or confronting students with an alternative theory might result in:

a defensive entrenchment, and a denial or erosion of the learning opportunity; ...
Conflict may be neither sufficient, nor necessary, nor even helpful.

(pp. 127-8)

Finally, the possibility that conceptual change teaching does not always make sense within the various contexts and constraints of the classroom provides an additional explanatory reason for the lack of support it has gained from teachers. Insufficient time and class size have both been cited by Millar (1989) as possible constraints reducing the likelihood of its wide adoption in the classroom.

Nevertheless, Viennot and Rainson (1999) present modest evidence to challenge the reasons given above for the lack of support for conceptual change teaching in the classroom. Their study of upper secondary school students learning about electricity in physics suggests that conceptual change teaching sequences, which take no more time than conventional methods, can be designed and can improve students' learning when compared to traditional approaches. However, more research needs to be undertaken to show that teachers, other than the highly committed constructivist teacher in their study, can successfully enact conceptual change teaching in the classroom.

To summarise, whilst these three movements have offered many insights into our appreciation of what is involved in the learning of science, it seems that the prescriptions for classroom practice suggested by them have been of limited use to teachers, not least because they take little account of the various contexts and constraints of classrooms. Furthermore, in focusing primarily on the learner and offering suggestions of what interactive teaching might comprise based on each movement's agreed conceptions of learning, it seems that these approaches have missed out on other avenues of exploration. As Ogborn *et al* (1996) point out:

Whatever their merits – and they have many – these ... traditions have combined to draw attention away from the teacher, except as a provider of productive 'learning situations'.

(p. 145)

The more recent focus within the constructivist movement on the social context of learning, however, seems to be beginning to bring the teacher back into the

equation. Indeed, the assumption that social interactions between teachers and their pupils have a crucial role to play in shaping pupils' learning has opened up potentially fruitful avenues of exploration. The work of Ogborn *et al* (1996) provides an example of research where the interest lies in making sense of the role of language in the process of learning science. Through the study of fifty-two hours of video recorded science lessons, Ogborn *et al* (1996) examined how secondary school science teachers construct and present scientific explanations in their classrooms. Whilst this study offers many insights, in particular, 'a language [presented as a theoretical framework] for describing explanations in the science classroom' (p. 8) its findings are based solely on *researcher interpretations of teachers' actions*. Regrettably, despite having 'informal discussions with teachers about what they thought had gone on in the lesson' these 'conversations were not recorded or used as data' (*ibid.*, p. 146). Drawing upon teachers' perceptions during the interpretive process might have resulted in the incorporation of an additional perspective to the theoretical framework offered. Neglecting the teachers' input in this study suggests that the findings are limited in what they reveal about teachers' own understandings of what they do and why when teaching science in the classroom. Furthermore, it suggests limitations to the usefulness of their theoretical framework in further developing and extending teachers' practice.

Research investigating the role of subject matter knowledge and understanding in biology/science teaching

A fourth tradition in the science education literature involves a range of studies investigating the role that subject matter knowledge and understanding plays in biology/science teaching. In 1985, Lee Shulman gave a presidential address to the annual AERA conference which was to have a far-reaching impact on the educational research community. In his address, he argued that research on teaching had 'ignored one central aspect of classroom life: the subject matter' (Shulman 1986, p. 6). He stated that past research had emphasised generic teaching skills and not 'questions about the content of the lessons taught, the questions asked, and the explanations offered' (*ibid.*, p. 8). He referred to this gap in the literature as the 'missing paradigm' and urged the educational research community to focus its energies on investigating this forgotten dimension of teaching. He encouraged researchers to begin to explore the content knowledge and understanding used in subject teaching.

Furthermore, in this presidential address, Shulman offered a very useful and influential distinction between the different aspects of the subject matter knowledge and understanding assumed to inform teachers' practice. Shulman distinguished teachers' subject matter knowledge and understanding into three categories:

- subject matter content knowledge;
- pedagogical content knowledge;
- curricular knowledge.

These distinctions have shaped the nature of the many studies that have emerged as a result of his call to investigate the content dimension of teaching. Indeed, researchers have explored teachers' subject matter content knowledge, pedagogical content knowledge and curricular knowledge in a wide range of curriculum subjects. However, as the focus of this thesis is with biology teaching, only research exploring these three categories in relation to the teaching of biology/science will be considered.

Moreover, in later work Shulman and his colleagues subsumed the category curricular knowledge into the category pedagogical content knowledge (e.g. Grossman 1990). Consequently, in this review, only the two categories subject matter content knowledge and pedagogical content knowledge will be discussed. The subject matter content knowledge informing the teaching of biology/science will be considered first.

Subject matter content knowledge

There are a number of studies that have explored the role of subject matter content knowledge in the teaching of biology/science. Typical of these is a study by Sanders *et al* (1993). In this study, the researchers compared three experienced science teachers' interactive teaching⁵ when teaching a topic within and outside their specialist area. The assumption underpinning this study is that the teachers,

⁵ They also compared the three teachers' planning and reflecting. However, as the interest of this study is in interactive teaching, only the findings pertaining to this phase of teaching are considered in this review.

when teaching within their specialist areas, would have greater content knowledge than when teaching outside their specialist areas. Indeed, considerable differences between the teachers' interactive teaching were found when comparing their teaching within and outside their specialist areas. For example, when teaching within their specialist areas, all three teachers 'had the lessons fine-tuned and focused on the details of the concepts' (p. 730). Furthermore, they 'all knew several ways to present the content' (*ibid.*, p. 730). In contrast, when teaching outside their specialist area 'the teachers were uncertain of some of the content. ... Sometimes they were confused themselves and occasionally made mistakes or errors' (*ibid.*, p. 730).

Whilst these findings suggest the significance of strong subject matter content knowledge for teaching, it is important to recognise their tentative nature in light of the study's small sample size. Furthermore, whilst it is useful to appreciate the value of strong subject matter content knowledge in teaching it would also be useful to gain insights into the nature of this knowledge. For example, what specific content knowledge and understanding did the teachers in this study require to focus on the 'details of the concepts' in lessons or to present the content in several ways when teaching a topic within their specialist area? Did they need to conceptualise their subject and/or the specific topic areas in particular sorts of ways in order to present the content so their students could make sense of it?

Whilst these sorts of questions are not investigated in the work of Sanders *et al* – and other similar studies (e.g. Carlsen 1993) – several researchers have begun to

explore the nature of biology/science teachers' subject matter content knowledge. This growing body of literature can be grouped in light of a distinction first proposed by Schwab (1964a, 1964b). This distinction classifies subject matter content knowledge into the two dimensions of substantive knowledge and syntactic knowledge. To academics exploring the role of teachers' subject matter content knowledge in teaching this has been a particularly influential distinction as their research has tended to investigate biology/science teachers' subject matter content knowledge by examining either its substantive and/or syntactic dimension(s).

Substantive knowledge

In the literature, this dimension is described as embodying two aspects:

- the 'stuff of the subject', a subject's 'specific information, ideas and topics' (Ball and McDiarmid 1990, p. 440);
- the subject's 'conceptual schemes' (Hashweh 1987), overriding principles or knowledge structures (Schwab 1978).

Various studies have explored these aspects of biology/science teachers' substantive knowledge and their role in classroom teaching. An extensive review of the literature identifies only one study that has explored the former aspect of teachers' substantive knowledge in biology/science and its role in classroom practice. This is a study by Hashweh (1987). In this research, Hashweh mapped out three biology and three physics teachers' knowledge of two topics – one in biology and one in physics – using techniques including concept-map line

labelling and sorting. He found that teachers within their field of expertise, whether biology or physics:

had more detailed knowledge of their topic, more knowledge of other discipline entities (whether they be other discipline topics or concepts or high-order concepts, principles ...), and more knowledge of ways of relating the topic to other discipline entities.

(p. 119)

Furthermore, he traced the effects of this knowledge on simulated teaching tasks. These involved describing orally to each teacher a set of critical incidents⁶ that might occur during the teaching of the topic and then asking them what their reaction and response to these incidents would be. Hashweh found that the teachers most knowledgeable about the different topic areas, whether biology or physics:

were more likely to detect student preconceptions, to exploit opportunities for fruitful "digressions", to deal effectively with general class difficulties, and to interpret correctly students' insightful comments.

(*ibid.*, p. 118)

Whilst this study offers insights into the nature of this aspect of science teachers' substantive knowledge of biology and physics by suggesting categories for describing this knowledge (e.g. knowledge of topics, knowledge of approaches), the methods employed have inherent limitations which suggest that the findings

⁶ The critical incidents were of four types. 'One type portrayed situations that revealed the probable existence of student's preconceptions' (Hashweh 1987, p. 117). 'Another type of incident presented the teacher with opportunities to discuss some physics or biology concepts that he may not have planned to discuss' (*ibid.*, p. 117). 'A third type of incident required the teacher to appreciate an insightful student comment' (*ibid.*, p. 117). The fourth type of incident portrayed general class difficulties.

should be considered with caution. As Gess-Newsome and Lederman (1995) point out:

card sort methodologies provide teachers with a set of items that are to be included in their content maps, or SMSs⁷. Such restrictions in topics may influence the outcome of an investigation (Gess-Newsome and Lederman, 1993; Lederman, Gess-Newsome, and Latz, 1994). In addition, providing terms may create knowledge by acting as a stimulus for the formation of relationships among topics that have not been previously considered.

(p. 302)

Furthermore, Hashweh's study is limited in what it reveals about the role that this aspect of substantive knowledge plays in shaping the classroom practice of biology/science teachers since the knowledge outlined in the study is not drawn from observations of and discussions with teachers about their teaching. Rather, it is drawn from research settings outside the classroom context. Consequently, it cannot be assumed that the subject matter knowledge and understanding of Hashweh's teachers – outlined in a laboratory context – is of a similar nature to the subject matter knowledge and understanding that shapes these same teachers' classroom practice.

A handful of studies have investigated biology/science teachers' conceptual schemes⁸. An example of such a study is the work of Hauslein *et al* (1992). In this

⁷ SMS refers to a Subject Matter Structure which is defined as any conceptual framework or schema that teachers have for their knowledge of the content they teach. Research that has focused more specifically on this sort of substantive subject matter knowledge and understanding will be considered next.

⁸ Conceptual schemes have been variously described in the literature as 'biology content cognitive structure' (Hauslein *et al* 1992) and Subject Matter Structure (SMS) (Gess-Newsome and Lederman 1995) and broadly refer to the same aspect of substantive knowledge – that is the conceptual frameworks or schema that teachers have for the knowledge of the content they teach.

research, the F-Sort of Biology Concepts⁹ - and think aloud traces during this sorting task - was used to assess the biology content cognitive structure of five groups of individuals: preservice secondary science teachers; in-service biology teachers with one to three years experience; in-service biology teachers with five or more years experience; scientists in any biological science field; and college seniors majoring in biology.

Two dimensions of biology content cognitive structure were identified in their analysis. These were deep-versus-surface and fluid-versus-fixed. A deep cognitive structure was defined as well organised and hierarchically arranged with broad principles used as a base for organisation. A surface cognitive structure was defined as unstructured and loosely organised. A fluid cognitive structure was defined in terms of lots of cross-linking between parts of the cognitive structure whereas a fixed cognitive structure had little cross-linking between parts. The researchers found that the scientists and experienced teachers had a deep cognitive structure whilst all the other groups had a surface cognitive structure. On the other dimension, only the scientists were found to have a fluid cognitive structure. The experienced teachers and all the other groups were found to have a fixed cognitive structure. The researchers suggested that the reason for this is because scientific research dictates the need for a fluid cognitive structure. The

⁹ In Hauslein *et al*'s (1992) study, the F-Sort of Biology Concepts consisted of the research subjects sorting 37 biology terms representing concepts on separate self adhesive address labels (e.g. diffusion, osmosis, evolution) into categories based upon their understanding of the relationships among the concepts. When the subjects were satisfied with their classification they were asked to remove the backing on the labels and stick them to paper in columns, one column for each group. In addition, the subjects were asked to label each column with a word or two that reflected the relationship of the concepts within that group.

work of scientists involves continually incorporating new ideas into already established ones and challenging perspectives, and a dynamic cognitive structure might be necessary to achieve this. Hauslein *et al* (1992) conjecture that because practicing teachers tend not to 'attend scientific seminars, read scientific literature, or take science courses' (p. 961) they have no need for a fluid cognitive structure.

Like Hauslein *et al*'s (1992) study, the work of Hashweh (1987) also provides insights into science teachers' conceptual schemes. As mentioned earlier, Hashweh (1987) mapped out three biology and three physics teachers' knowledge of two topics – one in biology and one in physics – using techniques including concept-map line labelling and sorting. He found that teachers within their field of expertise, whether biology or physics, had richer conceptual schemes. He identified some of the physics teachers' conceptual schemes as force/motion and work/energy and some of the biology teachers' conceptual schemes as an ecological approach, a macro plant-structure approach and a molecular/energy approach. Furthermore, he found that the teachers with rich conceptual schemes were more effective in simulated teaching tasks.

However, whilst both studies offer insights into the nature of biology/science teachers' conceptual schemes they also suffer from the limitations of card sort methodologies identified earlier. Furthermore, these studies are limited in what they reveal about the conceptual schemes that inform biology/science teachers' actual classroom practice as the knowledge outlined in them is drawn from research settings outside the classroom context and not from observations of and

discussions with teachers about their actual classroom teaching. Consequently, it cannot be assumed that the conceptual schemes outlined by teachers outside the classroom are of the same nature as the conceptual schemes that inform their classroom practice. Indeed, Gess-Newsome and Lederman (1995) highlight this in their study investigating the SMSs of five experienced biology teachers as exhibited in interviews and as exhibited in the classroom. They found that the degree of relationship between the SMS exhibited in the classroom and the SMS exhibited in the interview varied. In only one of the five teachers studied was the SMS identified in the interview also exhibited in the classroom. For the other four, only limited aspects of the SMSs identified in the interview were exhibited in classroom practice. Gess-Newsome and Lederman argue that the degree to which the biology teachers' SMSs as exhibited in the interviews were translated into their classrooms was influenced by a variety of contextual variables including the teachers' intentions, content knowledge, pedagogical knowledge, and knowledge of students.

Gess-Newsome and Lederman's study is significant because it demonstrates that the investigation of teachers' conceptual schemes of their scientific subject outside of the classroom context can generate different findings to their investigation inside the classroom context, not least because of the additional variables of real classrooms.

Syntactic knowledge

In the literature, this type of knowledge is described as comprising the methods and modes of inquiry a discipline develops as well as the canons of evidence and warrantability it draws upon in order to verify its knowledge claims (Schwab 1978, 1963). In science education, syntactic knowledge has been variously described as comprising the 'nature of science' or 'philosophy of science' and is seen typically to refer to:

Knowing how scientists work within the norms, practices and discourses of science – the ways in which scientists, both individually and as communities, come to agree that there is good evidence to support a current theory, or to argue that the evidence is contradictory or insufficient, or to claim that a model is flawed.

(Smith and Anderson 1999, p. 756)

Early studies (e.g. Kimball 1968; Miller 1963; Behnke 1961 – as cited in Lederman 1992) exploring science teachers' conceptions of the nature of science reveal little about the syntactic knowledge informing their classroom practice. In these studies, the researchers assumed a direct relationship between teachers' conceptions of the nature of science as expressed in a laboratory context and the knowledge and understanding of the nature of science presumed to inform classroom practice. At no point was this assumption tested. As Lederman (1992) points out, studies were undertaken without 'any direct focus on actual classroom practice and/or teacher behaviours' (p. 346).

Later studies recognised the importance of focusing upon the realities of daily classroom instruction in order to comment upon the syntactic knowledge that

informs teachers' classroom practice. These studies have shown that whilst teachers' conceptions of the nature of science exhibited outside the classroom can be consistent with those exhibited inside the classroom this is not necessarily the case. For example, in a qualitative study, Brickhouse (1990) explored the nature of three teachers' syntactical knowledge outside the classroom and its expression in the classroom. Two of these teachers exhibited classroom practices consistent with their beliefs about the nature of science whilst the other teacher demonstrated classroom practices that were not congruent with his beliefs.

A similar position is found in Lederman's (1999) study. In this research, the relationship between five high school biology teachers' (two novice and three experienced) views of the nature of science as exhibited outside the classroom and their views of the nature of science as exhibited inside the classroom was examined. Lederman found that the two novice teachers in the study did not directly translate their understanding of the nature of science into the classroom as they were concerned primarily with management issues and therefore were not, as he suggests, 'ready to take on the challenge' (p. 924). In addition, one of the experienced teachers also did not teach in a manner that was consistent with her views of the nature of science. It seems that she considered syntactic knowledge simply too complex and abstract for her students to grasp and this seemed to ensure that she did not teach in a manner consistent with her conceptions of the nature of science.

In addition to the variables identified here, further studies suggest many others that can 'mediate and constrain the translation of teachers' NOS [nature of science] conceptions into practice' (Abd-El-Khalick and Lederman 2000, p. 670). These include:

pressure to cover content (Abd-El-Khalick *et al* 1988, Duschl and Wright 1989, Hodson 1993) ... institutional constraints (Brickhouse and Bodner, 1992) ... and the lack of resources and experiences for assessing understandings of NOS (Abd-El-Khalick *et al* 1988).

(Abd-El-Khalick and Lederman 2000, p. 670)

This research further draws attention to the significance of taking account of the classroom context in any attempt to make sense of the subject matter knowledge and understanding that shapes teachers' teaching of biology/science.

To summarise, the research reviewed in this section offers many insights into the role of subject matter content knowledge in biology/science teaching. However, the review has also highlighted some methodological limitations which suggest that certain findings should be considered with caution. Furthermore, this review suggests that a number of the studies discussed are limited in what they reveal about the subject matter knowledge and understanding that shapes teachers' classroom practice, as the knowledge outlined in them is not drawn from observations of teachers' teaching and discussions with teachers about their teaching. Rather, it is drawn from research settings outside the classroom context. Indeed, several of the studies reviewed have drawn attention to the differences between teachers' conceptions of their subject matter knowledge and understanding in a decontextualised setting and its expression in the classroom.

This signals the importance of taking account of the classroom context when exploring the subject matter knowledge and understanding that informs teachers' classroom practice. Finally, whilst Schwab's distinction between the substantive and syntactic dimensions of subject matter content knowledge has been of considerable theoretical use to researchers, it is possible that it might not be of practical use in understanding the role that teachers' subject matter knowledge and understanding plays in teaching. Indeed, teachers might not think about the subject matter knowledge and understanding that informs their practice in terms of substantive and syntactic structures. It could be argued that, by drawing upon this distinction to shape research into this area, academics might have missed out on more exploratory avenues of research. In light of this, it seems there is a need for research that assumes a more exploratory position; research that aims to make sense of the subject matter knowledge and understanding that shapes teachers' classroom practice from observations of and discussions with them about their teaching, *without* theorising *a priori* about the nature of this subject matter knowledge and understanding.

Pedagogical content knowledge

Further to the subject matter content knowledge described and discussed in the previous section, Shulman also suggested, in his presidential address to the 1985 AERA conference, that teachers possess an additional form of content knowledge - pedagogical content knowledge. This, he argues, is a:

kind of content knowledge ... which goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge *for teaching*.

(Shulman 1986, p. 9 original emphasis)

Through a series of research studies at Stanford University¹⁰, Shulman and his colleagues, working first with novice teachers and later with experts in a variety of different subject areas, provided a description of pedagogical content knowledge. This description comprises four general components. These are summarised by Grossman (1990) as:

- knowledge and beliefs about the purposes for teaching a subject at different grade levels – referred to as ‘orientations’ in the literature;
- knowledge of students’ understanding, conceptions, and misconceptions of particular topics in a subject matter;
- knowledge of curriculum materials available for teaching particular subject matter, as well as knowledge about both the horizontal and vertical curricula for a subject;
- knowledge of instructional strategies and representations for teaching particular topics.

This description has been very influential to research in this field with the four components guiding the exploration of teachers’ pedagogical content knowledge within different curriculum areas. Even so, criticisms have been levelled at the concept of pedagogical content knowledge and the description offered by Shulman and his colleagues. For instance, Pendry (1994) argues that there seems to be

¹⁰ For examples of this work see Grossman *et al* (1985), Gudmundsdottir and Shulman (1987) and Gudmundsdottir (1988).

some confusion over whether the concept of pedagogical content knowledge and the description offered is based on empirically derived data or hypothetical theorising. She argues that it is not clear whether pedagogical content knowledge represents teachers' actual thinking about their teaching or prescriptions about how teachers 'ought' to think about this issue. One of Shulman's colleagues, in a recent unpublished conference paper, suggests that such a criticism might have arisen from 'Shulman's use of the metaphor of a "knowledge base"' (Grossman 2002, p. 3) leading critics to have:

interpreted this work to mean [that] pedagogical content knowledge represents a static conception of teacher knowledge, generated by university researchers *for* teachers

(*ibid.*, p. 3)

Whilst Grossman argues that 'this is a fundamental misreading of the work on pedagogical content knowledge' (*ibid.*, p. 3) she does not offer any suggestions to clarify this confusion.

Furthermore, Pendry (1994) argues that the concentration on novice, as opposed to expert, practitioners in the first stages of Shulman and his colleagues' research, might have implications for the description of pedagogical content knowledge offered. She suggests that novice teachers, the original focus, are likely to have possessed rather less sophisticated knowledge than their more experienced counterparts, involved later on, thus possibly leading to a limited description of pedagogical content knowledge. Moreover, Pendry (1994) suggests that the

generalisability of research findings to all teachers is questionable from a sample of novices.

Despite these criticisms, research exploring the subject matter knowledge and understanding informing science teachers' classroom practice has been greatly influenced by Shulman's concept of pedagogical content knowledge. Indeed, there is a growing body of literature exploring the pedagogical content knowledge of science teachers using Shulman and his colleagues' conception and description of pedagogical content knowledge as a basis for inquiry. This is exemplified in a comprehensive review by Magnusson *et al* (1999). In this review, studies exploring each of the four components outlined in Shulman and his colleagues' initial description of pedagogical content knowledge are considered. This description of pedagogical content knowledge is further extended by the addition of another component, namely knowledge about assessment. Whilst a summary of each component is not appropriate here, a critical analysis of the findings presented will be briefly considered.

What is not always made clear in the Magnusson *et al* (1999) review is the status of the findings presented. Are they empirically based? Are they grounded in observations of and discussions with teachers about actual classroom practice? Or are they hypothetical, developed from researcher theorising about what the different components of pedagogical content knowledge suggested by Shulman and his colleagues 'ought' to comprise for science teachers? A review of the various studies that define different orientations to science teaching, for example,

indicates that the origins of the findings presented are mixed. While some are apparently generated from empirical data such as the 'academic rigor' orientation defined by Lantz and Kass (1987), it appears that others result from researcher theorising. An example of the latter is found in Tamir's (1983) article where he describes an 'inquiry' orientation to science teaching. In this article he declares that 'science teachers have the responsibility of presenting science as inquiry' (p. 658) and that the primary purpose of his article is to 'clarify the notion of inquiry ... and to suggest how the teachers' lack of knowledge of and reluctance toward science as inquiry can be remedied' (p.658). As Tamir deems teachers to be reluctant to adopt an 'inquiry' orientation to science teaching, it seems unlikely that their views will have shaped the conceptualisation of this orientation. Indeed, Magnusson *et al* hint that, in relation to this component of science teachers' pedagogical content knowledge, the findings they present may well be the result of researcher theorising rather than empirical research when they say that literature in this area illustrates:

the hypothesised central role of this component of PCK [referring to orientations] in decision-making relative to planning, enacting and reflecting upon teaching. ... Few studies have been conducted ... that directly assess teachers' orientations to teaching science in order to put that claim to an empirical test.

(p. 102, my emphasis)

Moreover, in Magnusson *et al*'s (1999) review, the various categories of pedagogical content knowledge are, on occasion, not discussed with reference to empirical work at all. Rather, comments such as the following – in relation to knowledge of students' conceptions and misconceptions of particular topics in a subject matter – are made:

teachers *should be knowledgeable* [about students' misconceptions] with respect to the topics they teach because *it will help them* to interpret students' actions and ideas.

(p. 106, my emphasis)

Such comments suggest that the origins of these claims are not drawn from empirical studies of teachers' conceptions but rather generated from researcher assumptions concerning what a particular component of pedagogical content knowledge 'ought' to comprise for science teachers.

Shulman's conception of a special kind of subject matter knowledge for teaching – pedagogical content knowledge – has offered a useful heuristic to researchers which has guided research into the content dimension of teaching. However, the confusion over whether the concept and its description is empirically based or hypothetically derived suggests that caution must be exercised when considering its usefulness in describing the subject matter knowledge and understanding that shapes science teachers' interactive teaching. Despite the caution outlined, many researchers exploring Shulman's four components in relation to science teaching have extended the difficulty by presenting findings based more on researcher theorising than empirical study. This analysis suggests the need for more research exploring the subject matter knowledge and understanding that informs biology/science teachers' classroom practice grounded in empirical work not preconditioned by researcher theorising.

To summarise, whilst there have been many valuable insights into the teaching of biology/science over the last forty years, this review suggests two gaps in the research. First, there appears to be a scarcity of rich descriptions and analyses of biology/science teachers' perceptions of their classroom actions. Previous research has either not provided such descriptions or has prescribed what biology/science teachers ought to do and why when they teach biology/science, with limited impact on their classroom practice. This poverty of literature suggests a need for research that sets out to provide insider accounts of what biology/science teachers do and why they do the things they do when teaching biology/science. Developing an understanding of teachers' perspectives of how they work in the particular contexts in which they work might encourage the development of initiatives that are embraced rather than rejected by teachers because they take account of what teachers know, believe and do, and they take account of the constraints and affordances of their classrooms.

Second, there appears to be a shortage of research exploring the subject matter knowledge and understanding that shapes biology/science teachers' classroom practice from the viewpoint of teachers themselves. Previous research has tended to investigate this knowledge from the basis of clear prior assumptions about its nature (e.g. the influence of Schwab's theoretical distinction between substantive and syntactic knowledge and Shulman's concept of pedagogical content knowledge). These assumptions might not be useful for making sense of this knowledge. Furthermore, research has tended to explore this aspect of science teachers' knowledge in decontextualised settings which may suggest that the

findings presented have limited applicability to the classroom context. Moreover, in some cases it is not clear whether findings that result from investigations into the subject matter knowledge and understanding shaping science teachers' classroom practice are grounded in observations of and discussions with teachers about actual classroom practice or are hypothetical, developed from researcher theorising. This gap in the literature suggests a need for research that explores the subject matter knowledge and understanding that shapes biology teachers' teaching of biology from observations of and discussions about classroom practice with the teachers concerned *without* making *a priori* assumptions about the nature of this knowledge.

Research into teacher cognition during interactive teaching

The second body of research literature that has informed the development of this thesis comprises studies investigating the knowledge and thinking that informs teachers' classroom teaching. For over a hundred years, teaching has been the subject of research. An historical review of this research suggests that three traditions have been particularly influential. The first tradition, which dominated early research, involved studies in teacher characteristics. These sought to isolate any teacher attributes such as sex, age, and personality traits which might have a bearing on teachers' effectiveness (e.g. Cattell 1931). Labelled 'black box' research by McNamara (1980), as the researchers working within this tradition did not study what was going on in classrooms, teacher characteristics research gave way to the second tradition – process-product research – in the middle of the last century.

In contrast to teacher characteristics research, the process-product tradition was:

dominated by attempts to investigate what teachers and their pupils observably did in classrooms

(Brown and McIntyre 1993, p. 3)

The purpose of this work was to describe teaching in terms of observable behaviours and then investigate the relationship between these behaviours and student achievement (e.g. Flanders 1970). However, in time, academics argued that viewing teaching as a fragmented set of behaviours 'left much of the skilfulness of teaching out of the account' (Calderhead 1996, p. 710).

Consequently, interest began to turn to the way in which teachers think, and a new tradition was born.

The early 1970s saw the development of this third tradition of research on teaching; the study of teachers' thinking. A number of researchers including Clark and Peterson (1986), Brown and McIntyre (1993) and Hagger (1995) all point to the same report (US NIE report 1975) as playing a significant role in the emergence of this tradition. This report issued a request for proposals for an Institute for Research on Teaching (established in 1976 at Michigan State University) that would focus on research into teachers' thought processes and initiate the first large programme of research in this genre.

Research on teacher thinking is a diverse field of investigation that has tended to concern itself with making sense of teachers' cognitive processes – that is their thinking and knowledge (Hagger 1995). Despite the diversity, distinct trends are apparent within the tradition where researchers have focused on similar aspects of teachers' cognitions. Indeed, of particular use to this thesis is a review of teacher thinking research by Clark and Peterson (1986) which classifies the many studies comprising this area of literature into three categories. These include investigations of:

- teacher planning (preactive and postactive thoughts);
- teachers' interactive thoughts and decisions;
- teachers' theories and beliefs.

Since the focus of this thesis is exploring the knowledge and understanding that shapes A level biology teachers' classroom practice, research comprising the second category has been of particular influence. The discussion now turns to a closer examination of this literature.

Several particularly influential perspectives can be seen in a review of the recent research literature concerning teacher cognition during interactive classroom teaching. One of these, Shulman's concept of pedagogical content knowledge, has already been discussed at length in the previous section.

Perhaps the most influential perspective in research investigating teacher cognition during interactive teaching has come from the work of Donald Schön (1987, 1983). Schön's work considers the sort of knowledge that informs professional expertise. He rejects the orthodox view of professionalism as technical rationality¹¹ and proposes instead a view of professional expertise as depending upon a 'kind of knowledge' that is 'inherent in intelligent action' (Schön 1983, p. 50). He argues that, 'starting with protocols of actual performance, it is possible to construct and test models of knowing' (*ibid.*, p. viii). Through empirical research examining five professions – engineering, architecture, management, psychotherapy and town planning – Schön suggests a model of professional knowing as 'reflection-in-action'. He argues that 'reflection-in-action' occurs when,

¹¹ This refers to a conception of professional expertise as the application of theoretical knowledge to professional situations.

during spontaneous and intuitive performance, a problematic situation is encountered. In this situation, the practitioner becomes a researcher in the professional practice context. S/he engages her/himself in a 'reflective conversation' through which the problematic situation is reframed, analogous problematic situations previously encountered are reconsidered and possible solutions to the problematic situation are tested.

Schön's perspective has been of considerable importance to research investigating the knowledge and thinking that shapes teachers' classroom practice because it has promoted the idea that professional practice does not necessarily depend on the application of theoretical knowledge to the practice context. Furthermore, Schön emphasises the significance of experience in professional knowledge as he proposes that the recall of previously encountered situations plays a role in the process of reframing and making sense of new ones.

However, it is important to note that his model of knowing – 'reflection-in-action' - is based on empirical studies in five professions other than teaching – professions unlikely to experience the 'complex' and 'ill-structured' context of the classroom (Carter 1990). Whilst his proposals for 'reflection-in-action' are attractive, the use of this model in the context of teacher cognition during interactive teaching must be treated with caution. Further empirical work needs to be done in the interactive teaching context before its usefulness in describing teacher cognition during interactive teaching can be assessed.

Whilst Shulman's work on pedagogical content knowledge and Schön's on 'reflection-in-action' have much to offer the educational research community, the criticisms outlined suggest that their usefulness in making sense of teacher cognition during interactive teaching is limited. However, an alternative perspective – which is referred to here as teachers' practical knowledge – appears more promising. This perspective brings together the work of a number of researchers from different countries. Similar to Schön, the researchers working within this perspective reject the notion of technical rationality in favour of practical rationality. They assume that, during interactive classroom teaching, teachers draw upon a particular type of knowledge and understanding that is similar to Schön's conception of knowing-in-action¹². Different researchers use different terms to describe this knowledge (e.g. 'personal practical knowledge' - Clandinin and Connelly 1997, 1985; Clandinin 1989; Connelly and Clandinin 1984; 'professional craft knowledge' - Brown and McIntyre 1993, 1986, 1985; 'practical knowledge' - Elbaz 1983, 1981). These different terms arise from the researchers varying backgrounds and interests which lead them to emphasise certain aspects of this practical knowledge. However, it is not their differences that are of interest here; but their commonalities. A review of a number of these studies reveals commonalities in the researchers' conceptions of this practical knowledge and in their beliefs about the most fruitful ways of investigating it. These commonalities indicate their shared conception of this knowledge as:

¹² It is worth pointing out, however, that some researchers working within this perspective argue that this type of practical knowledge shapes not only practice in the interactive teaching context but also practice in other teaching contexts such as planning and evaluation (Clandinin 1985).

- embedded in action ('embedded in, and tacitly guiding, teachers' everyday actions in the classroom' - Brown and McIntyre 1986, p.36 ; 'a special kind of knowledge' which is 'expressed in a person's actions'. - Clandinin 1985, p. 362; 'work of teaching ... [is] the exercise of a particular kind of knowledge' - Elbaz 1981, p. 47);
- tacit ('seldom made explicit' - Brown and McIntyre 1986, p.36 ; 'largely unarticulated' - Elbaz 1981, p. 47);
- derived from experience ('derived from practical experience rather than formal training' - Brown and McIntyre 1986, p.36 ; 'knowledge which has arisen from experience' - Clandinin 1985, p. 362).

Further commonalities suggest that they assume that this knowledge can be described through:

- the study of teachers' teaching involving the detailed observation of classroom practice ('The complete unit-of-work is directly observed by a researcher and the teacher's talk during it is tape-recorded.' – Brown and McIntyre 1985, p. 16; 'It is knowledge which can be discovered in ... the actions of the person' - Connelly and Clandinin 1984, p. 137; 'Data for the study was collected through ... two periods of observation in Sarah's classes.' – Elbaz 1981, p. 53);
- discussions with teachers about what they do when they are teaching and why they do the things they do ('we interview each teacher after ... each ... lesson.' – Brown and McIntyre 1985, p.16; 'It is knowledge which can be discovered ... by

discourse or conversation' – Connelly and Clandinin 1984, p. 137; 'Data for the study was collected through a series of five interviews' – Elbaz 1981, p.53).

Over the past twenty years, research into teachers' practical knowledge has been popular and the many studies comprising this perspective have offered various insights, both methodological and substantive, into teacher cognition during interactive teaching. However, the majority of these studies have tended to focus on exploring the generic nature of teachers' practical knowledge. Indeed, out of the many studies undertaken, few have explicitly considered the nature of the subjects taught by the teachers in question and how this might shape their practical knowledge. For example, Brown and McIntyre (1993) explored the practical knowledge – which they refer to as professional craft knowledge – of sixteen¹³ 'good'¹⁴ teachers. Four of these teachers taught in the upper end of primary school and the remaining twelve spanned ten different subject departments in secondary school. The researchers found a number of generalisable elements to all sixteen teachers' practical knowledge. For example, one of these was a concern to establish and maintain what they refer to as a Normal Desirable State (NDS) – that is a pattern of classroom activity deemed by the teacher to be desirable. These NDSs varied from teacher to teacher and also varied with stages of a lesson. However, any differences observed could not be attributed to the different subjects the teachers taught because of the nature of the research design.

¹³ The sixteen research participants included four primary teachers and twelve secondary school teachers teaching in a range of different curriculum areas.

¹⁴ Teachers were identified as 'good' largely as a result of consensus from their pupils about their strengths. Further criteria, however, including ensuring a wide range of subject specialisms were represented and availability and willingness to participate were also seen as important.

More recently, researchers have begun to explore the subject aspect of teachers' practical knowledge. Indeed, research by Batten *et al* (1993) and Cooper and McIntyre (1996) suggests that the nature of the subject taught does have an impact upon the practical knowledge that teachers develop. For example, in a study using a similar methodology to Brown and McIntyre (1993), Margaret Batten in Batten *et al* (1993) mapped out the practical knowledge of twelve Australian teachers from three different subject areas – humanities, science/mathematics and practical subjects. She found that teachers from particular subject areas gave more emphasis to certain elements of their practical knowledge than teachers from other subject areas. For example, the teachers from humanities subjects tended to place more emphasis on the significance of classroom environment factors in their teaching, such as developing a relaxed, friendly, comfortable atmosphere and a positive teacher-student relationship, than the teachers from the other two subject areas.

Research by Cooper and McIntyre (1996) further suggests the influence of the nature of the subject taught on teachers' practical knowledge. In a direct follow up to Brown and McIntyre's (1993) work, Cooper and McIntyre studied eight English and five history teachers and their Year 7 classes within the National Curriculum context. They found a set of generalisable constructs concerning these teachers' practical knowledge. However, in addition they found that depending on whether the subject was English or history the constructs were conceptualised and enacted by the teachers in different ways. For example, one of the constructs comprising these thirteen teachers' practical knowledge was a concern with aims or long-term

goals. These aims tended to be more affective in nature (e.g. encouraging students to adopt a positive attitude to the subject area) or more cognitive in nature (e.g. related to pupils' acquisition of particular knowledge). Furthermore, it seemed that the teachers often felt a tension between these two qualitatively different types of aims. They sometimes believed that it was not possible to achieve both types of aims simultaneously and that they had to either choose one type of aim to achieve or prioritise one type of aim over the other. Interestingly, in comparison to the English teachers, the history teachers in this study tended to prioritise cognitive aims over affective aims. Cooper and McIntyre suggest that the perceived highly prescriptive – in terms of content and learning outcomes – nature of the National Curriculum in history in comparison with English might help to explain the greater emphasis of the history teachers' practical knowledge on cognitive aims. Indeed, it might be that the affective dimension is a much more crucial element to learning English than learning history as a result of the differing nature of these school subjects.

Research is beginning to suggest, therefore, that whilst teachers' practical knowledge might take the form of a number of constructs that are generalisable across subject matter domains (e.g. NDSs, affective and cognitive aims) the ways in which these constructs are conceptualised and enacted by teachers is shaped by the nature of the subject taught. Furthermore, research by Olsen *et al* (1996) suggests that, in addition to these generalisable constructs there might be certain elements of teachers' practical knowledge that are subject specific. Olsen *et al* suggest that one aspect of science teachers' practical knowledge might comprise

a conception of preordained science¹⁵, a conception of student autonomy¹⁶ in relation to practical work in science and the ability to manage the potential dilemma that exists between these two constructs. Their study involved the extensive observation and interview of three science teachers teaching Newton's second law and the conservation of energy. They found that for two of the teachers, Mr Dodgson and Mr Jewell, the ways in which they conceptualised the role of preordained science and student autonomy in their science teaching meant that no dilemma between these constructs existed. However, for the third teacher, Ms Sorenson, the way in which she conceptualised preordained science and student autonomy meant that a dilemma did exist. Interestingly, her strategy for managing the dilemma involved her in compromising her conception of student autonomy.

To summarise, a review of the literature investigating the knowledge and thinking that informs teachers' classroom teaching suggests that whilst two of the most influential perspectives in recent years – Shulman's concept of pedagogical content knowledge and Schön's concept of 'reflection-in-action' – have much to offer the educational research community, their usefulness in making sense of teacher cognition during interactive teaching is limited. Indeed, the confusion over

¹⁵ This was defined as 'the body of knowledge about the natural world, normally expressed in the form of generalised laws and principles, that has progressively been developed over decades and centuries by means of scientific methods. It is knowledge that many accept as the truth about the world' (Olsen *et al* 1996, p. 776).

¹⁶ Student autonomy was defined as students having responsibility for the decisions made during practical work and the analysis and interpretation of experimental results offered.

whether Shulman's concept of pedagogical content knowledge and its description is empirically based or hypothetically derived suggests that caution must be exercised when considering its usefulness in describing the subject matter knowledge and understanding that shapes teachers' interactive teaching. Furthermore, the development of Schön's concept of 'reflection-in-action' from empirical work with five professions other than teaching suggests that research in the interactive teaching context needs to be done before its usefulness in describing teacher cognition during teaching can be assessed. In contrast, the alternative perspective of teachers' practical knowledge appears more promising and will provide a useful broad conceptual framework for this thesis. Indeed, whilst some assumptions are made about the nature of this knowledge – i.e. it is embedded in action, tacit and derived from experience – descriptions of this knowledge do not appear to be the result of researcher theorising but rather the interpretation of detailed observation of teachers' classroom practice coupled with discussions with teachers about their practice. Over the last twenty years researchers have begun to map out the nature of teachers' practical knowledge. Various studies have suggested that teachers' practical knowledge might take the form of a number of constructs that are generalisable across subject matter domains. However, since differences have been observed between the conceptualisation and enactment of these constructs in a number of teachers teaching different subjects it is likely that the nature of the subject taught has a role to play in shaping their conceptualisation and enactment. These findings suggest the need for more research investigating teachers' practical knowledge in different subject areas. Additional research (e.g. Olsen *et al* 1996) suggests that teachers

might also develop practical knowledge specific to their subject matter domain further indicating the need for research to explore the practical knowledge of teachers in different subject areas.

Conclusion

This chapter has suggested that despite the wealth of studies in the science education literature that have focused on exploring the nature of biology/science teaching, little is known about the interactive classroom practices of biology/science teachers from the perspectives of the teachers themselves. Indeed, there is a lack of insider accounts of biology/science teachers' classroom practices and a paucity of exploratory research investigating the subject matter knowledge and understanding that shapes biology/science teachers' teaching of biology/science without making assumptions about its nature.

Furthermore, this chapter has suggested that a particular perspective – the teachers' practical knowledge perspective – from the teacher thinking literature offers useful ways of conceptualising and exploring the knowledge and understanding that teachers themselves consider to shape their classroom practice. Moreover, recent research within this perspective has suggested that the knowledge and understanding that guides teachers' classroom practice is shaped to some degree by the nature of the subject taught and therefore there is a need to explore the practical knowledge of teachers in a variety of different subject areas. There has been little research of this sort in science and a thorough search of the literature revealed none in biology.

This thesis, therefore, is located at the intersection of these two fields of literature, biology/science teaching and teachers' practical knowledge. It aims, therefore, to generate rich, thick descriptions (Goetz and LeCompte 1984) of three A level biology teachers' classroom practice and explore the subject matter knowledge and understanding that shapes these teachers' teaching of biology.

Chapter Three

Overall Research Strategy and Data Collection

Introduction

Informed by the literature described and discussed in chapter two, this study investigated the following research questions:

1. What are the teachers' characterisations of their successful teaching of biology at A level?
2. In what ways and to what extent do these characterisations vary between the teachers?
3. What subject matter knowledge and understanding shapes and accounts for these characterisations?

In light of the above questions, there was a need for a methodology that would enable the generation of teacher accounts of what they consider themselves to be doing and why when, according to them, they are teaching biology at A level successfully. A methodology was required that would enable the exploration of the knowledge and thinking that underlies what the teachers believe to be their successful classroom teaching of biology. The purpose of this chapter is to describe and discuss the research design of this study: a design formulated to investigate the research questions outlined above. In doing this it will consider:

- the research approach adopted;
- the methodological principles underpinning the conduct of the study;
- the processes by which access was gained and the selection of cases made;
- the procedures for the collection of data.

Research approach

A case study was considered to be the most appropriate research strategy for this project. Drawing on the work of Hammersley *et al* (1998), case study research was taken to refer to:

research that involves collecting detailed data relating to a relatively small number of cases, data that are predominantly unstructured in character, and that are subjected to qualitative analysis

(p. 2)

In particular Hammersley *et al* conceptualise case study research in terms of 'parallel distinctions between focus and case' (*ibid.*, p. 15). According to them the research focus concerns 'the most general set of phenomena (one or more) about which a study draws conclusions' (*ibid.*, p. 2) and the case(s) studied concerns 'the particular objects, specifically located in place and time, about which data were collected' (*ibid.*, p. 3). Applying this distinction to the research reported here, the research focus becomes teachers' characterisations of their successful A level biology teaching and the cases studied become the series of lessons (unit-of-work) of three A level biology teachers with one of their A level biology classes. In brief, the current study's methodological approach comprised a case study of the teaching of A level biology within a small number of A level biology lessons undertaken at three sites. Work at these three sites involved spending several months in each school attending all A level biology lessons of three selected teachers during the teaching of a unit-of-work chosen by them.

The concept of case study as a research strategy is problematic (Schwandt 1997). Indeed, Hammersley *et al*'s definition of case study research is not universally accepted in the research literature as sufficiently all encompassing. Their definition, for example, suggests that case study research relies upon qualitative evidence whilst Yin (1994) argues that case study research 'can be based on any mix of qualitative and quantitative evidence' (p. 14). However, I chose to align myself with Hammersley *et al* in this investigation, as their definition proved most appropriate. In particular, Hammersley *et al*'s distinction between research focus and case was found to be very useful.

Methodological principles

The following section discusses the ideas and assumptions that underpinned the design and execution of this study. Its purpose therefore is not to provide information about the specific data collection procedures that were followed but to provide a justification for the ways in which this study was carried out. This conceptualisation of the purpose of this section resonates with Smith's (1989) perspective of 'method as logic of justification' rather than 'method as technique'. The aim of this section, therefore, is to explicate the 'logic of justification' of this study as conceptualised in terms of its four methodological principles. In doing this it draws heavily on the work of Brown and McIntyre (1993) and Cooper and McIntyre (1996). The four methodological principles are to:

- adopt an open approach;
- adopt a positive stance;
- focus on classroom practice;
- recognise the importance of researcher-participant relationships.

Each of these four principles will be explained in turn and a discussion of how they manifested themselves at the data collection level will be presented.

An open approach

The first methodological principle concerned the adoption of an open approach. This developed from the intention to gain a deep understanding of the three teachers' perspectives of their own successful teaching of biology at A level.

Therefore, the research was not concerned with analysing the teachers' thinking and practice in relation to any particular *a priori* models of teaching such as teacher as decision maker (e.g. Butefish 1990) or facilitator of conceptual change (e.g. Clement *et al* 1989; Bentley and Watts 1987). Instead, the open approach encompassed a disciplined avoidance to import my own judgements concerning, for example, what successful teaching of biology at A level might comprise, in order to encourage the perspectives of the teachers to come through. Openness was seen to be essential if the teachers were to be encouraged to share their perceptions of their successful teaching of biology at A level.

The adoption of an open approach was seen as particularly important in light of the paucity of research of this kind in biology/science education. As shown in chapters one and two, research into the teaching of biology/science has tended to be dominated by studies prescribing how teachers 'ought' to teach biology/science rather than exploring what they actually do and why. This has contributed to a situation where there are few detailed descriptions of teachers' accounts of their everyday teaching of biology/science and there are almost no theories or concepts concerning how teachers teach biology/science derived from empirical evidence. Consequently, in order to address this imbalance, an open approach, aimed at making sense of teachers' experiences, was seen to be important.

Various strategies were adopted in order to achieve an open approach. First, I attempted at all times to refrain from asking closed questions in data collection

interviews¹ and asked instead deliberately open questions (e.g. What did you think went well in that lesson in terms of your teaching of biology?) so that I could encourage the teachers to share with me their perceptions of their successful teaching of biology in the lessons observed.

Second, when probes were used in interviews I attempted to formulate them from what the teachers had said or from the lessons themselves rather than importing my own ideas. These probes – referred to in the literature as echo probes (Bernard 1994) - are discussed in more detail on p. 112.

Finally, I sought to emphasise throughout the project that I was interested in the teachers' own understanding of what, for them, constituted successful teaching of biology at A level. I hoped that in making explicit the purpose of the project, I might reduce the possibility of the teachers producing contrived accounts concerning their own subject matter teaching. Indeed, a quotation from a data collection interview of one of the teachers, Catherine (identified as C in quotations) suggested that she recognised the project's concern with her own understanding of her practice. In this quotation, Catherine identified a successful aspect of her practice as revisiting subject matter content her students had already come into contact with. Having established this, she sought confirmation from myself as to the appropriateness of this comment but quickly remembered that it was her

¹ Interviews formed one of the major research instruments in this study and are discussed in greater detail on pp. 103-121.

thoughts and experiences that were of primary interest. Consequently, she retracted her question and continued to explore her own perceptions. In her words:

C: Right, so recall is important I think, I mean don't you think it is? No you're not supposed to answer that! I, yes, I think recall is important because that was difficult the first time.

(VI2 C 576-579²).

A positive stance

The second methodological principle was the adoption of a positive stance. This concerned my intention at all times to adopt a positive perspective on teaching. A positive stance was considered to be necessary for three reasons. First, an emphasis on the positive provided the teachers with a way of prioritising what to talk about after they had taught their lesson. It provided them with a focal point for their accounts of their subject matter teaching. They were able to filter out the parts of the lesson they felt could have been improved and concentrate on what they felt had gone well.

Second, as the data collection interviews required considerable introspection by the teachers themselves it was felt that focusing on the positive aspects of the teachers' teaching would mean the teachers would be less inclined to be put on the defensive when talking about their practice. Indeed, it was felt that an

² Information stated in brackets after quotations taken from the contextual information or data collected in this study indicates where it is taken from by stating the source first, plint refers to a post-lesson interview of either short or long type, VI refers to a vignette interview, Expl Int refers to the exploratory interview, L refers to a lesson transcript (e.g. L3 refers to the transcript from lesson 3 of a teacher's unit of work), the research participant next, C refers to Catherine, J to John and S to Sally, and the line numbers in the transcript last. The different types of interviews are discussed in more detail later on in this chapter (see p. 103).

emphasis on the positive might engender confidence in them and encourage them to explore their practice. This is supported by several researchers (e.g. Brown and McIntyre 1993; Cooper 1993) who have suggested that inviting teachers to talk about their own successes in the classroom appears to have a motivating effect giving them the confidence 'to talk about and explain their actions in the classroom' (Brown and McIntyre 1993, p. 35).

Third, it was felt that exploring the thinking behind what teachers consider they do well in the classroom would be of more use to the recipients of the research. It was deemed, for example, that student teachers and teacher educators would benefit more from findings that focused upon teachers' perceptions of their successful teaching rather than of their perceptions of teaching requiring development.

The methodological principle of adopting a positive stance manifested itself in this study in two ways. First, through the approach to teachers before the project began³ and throughout its duration, and second, through the positive emphasis given to questions asked in interviews during data collection (see p. 111). It was felt that this would encourage the teachers to focus on what they deemed to be the successful aspects of their teaching of biology rather than their areas for development.

³ A copy of the resume of the project, with its positive emphasis, given to each teacher when she/he agreed to be part of the project is found in Appendix B.

Focus on classroom practice

The third methodological principle concerned the project's commitment to start with classroom practice. By this it is meant that the study deliberately took the teaching events of actual lessons as the starting point for the investigation and has sought to work from these events to generate understandings of teachers' knowledge and thinking. This principle is seen as important for three reasons. First, a number of empirical studies have shown that there can be a significant difference between teachers' plans for their lessons and the ways that they actually teach (e.g. Weade 1987). The findings of such studies imply that what teachers do in the classroom can differ from what they intend to do. These implications strongly suggest that any desire to understand the actual classroom practice of A level biology teachers' teaching of their subject needs to focus not on the teachers' intentions for a lesson but concern itself with making sense of actual lessons events and teachers' perceptions of those events.

A theoretical distinction made by Argyris and Schön (1974) also supports the suggestion that making sense of teachers' classroom practice requires the direct study of that practice. These academics distinguish between two types of theories of action, a person's: 'theory-in-use' defined as the theory that actually governs the actions of a person; and a person's 'espoused theory' defined as the theory that a person believes guides his/her actions. As Argyris and Schön make quite clear, an individual's 'theory-in-action' 'may or may not be compatible with his espoused theory' and in light of this put forward the case for the direct observation of an

individual in order to learn about his/her 'theory-in-action' as is illustrated in the following quotation:

We cannot learn what someone's theory-in-use is simply by asking him. We must construct his theory-in-use from observations of his behaviour.

(pp. 6-7)

The second reason for the practice-orientation of this study relates to the largely unarticulated knowledge and understanding of teachers that was sought. A number of academics, notably Brown and McIntyre (1993) and Cooper and McIntyre (1996), have argued that grounding teachers' accounts (and in the case of Cooper and McIntyre also pupils' accounts) of practice in researcher observed classroom events encourages access to tacit knowledge and understanding because:

1. It reinforces the point that the focus of research is on what actually happens in classrooms.
2. It constrains the teachers to concentrate on real and shared events rather than imagined reconstructions.
3. It provides the means for a limited check from the researchers' observations and the audio recording, on the teachers' accounts of what has happened.

(Adapted from Brown and McIntyre 1993, p. 36)

The third reason for this study's commitment to begin with classroom practice is motivated by arguments that research that is grounded in the events of real classrooms is more likely to generate findings of relevance to practitioners in the school context. This recognises a gap that is often seen to exist between research in education and actual practice and suggests that one way in which this gap can begin to be bridged is through research that focuses on exploring the practice that occurs in real classrooms.

The principle of starting with classroom practice has influenced the conduct of this study in several ways. To begin with, it was evident in the data collection procedures that were used, for example, the observation and audio-taping of the teachers teaching a series of lessons. Furthermore, it shaped the ways in which the teacher interviews were carried out in that the focus of my questions and probes in these interviews were explicitly concerned with the teachers' actions and perceptions of their actions in the observed lessons.

Recognition of the importance of researcher-participant relationships

The fourth methodological principle, recognition of the importance of researcher-participant relationships, emerged from my awareness that decisions had to be made concerning the most appropriate relationship to develop and sustain with the teachers over the duration of the research project in order to gain access to the information sought. I felt that if I gained their trust and developed a good relationship with them I would be more effective in encouraging them to share with me their thinking about what they were doing, and why, in the specific lessons observed, when, according to them, they were teaching biology successfully. This belief is supported by evidence from the research literature that suggests that rich data is more likely to be collected when trust and rapport have been established between researcher and participants. Johnson (1975), for example, states that field researchers identify the 'critical importance of personal relationships involving trust for gathering data in social research' (p. 111). Furthermore, Cooper (1993) illustrates the importance of good field relations in order to gain access to subjective experience when he describes the need to combine 'ease of manner,

trustworthiness and approachability' in order to access 'less superficial levels of experience' (p. 326).

The need to recognise the importance of researcher-participant relationships permeated all phases of the project. To begin with, it led to the development of an ethical statement (see overleaf) which guided my practice in all three case studies. Furthermore, the preparatory phase, outlined in detail on pp. 90-97, set out, as the main purpose, to build good relationships through informal conversations, regular periods of observation in the participants' classrooms, meetings and interviews. Similar opportunities to sustain good relationships during the data collection phase were planned involving informal social conversations both before and after lesson observations and interviews. In addition, various steps were taken to ensure that the atmosphere of the interviews was as unthreatening as possible (see p. 95 for a description and discussion of these steps). Finally, after data collection reasonably regular contact was maintained with the three research participants. It was felt that such social contact was important to sustain rapport with the teachers and to repay their contribution to the research undertaken.

The Study's Ethical Statement

Responsibilities of the researcher

1. **Confidentiality** - to ensure that all teachers have confidentiality of their words, whether spoken or written, and anonymity within any written product of the research; but, in addition, that they are aware of the limits of such confidentiality and anonymity given the small-scale of the study.
2. **Informed consent** - to ensure that all teachers are fully and honestly informed about the purpose of the research, what it entails, the role of the researcher and the likely outcomes of the study before any research begins. Participants should give full consent - with the knowledge that they have the right to withdraw from the study at any time - before the research goes ahead.
3. **Maintain appropriate relationships** - to ensure that the relationships developed between researcher and participants are characterised by honesty and openness and that the researcher is supportive, rather than critical, of the actions of the teachers and the contexts in which they work.

Researcher's rights

1. **Interpretation** - to interpret the results using empirical evidence to support the views developed.
2. **Protection of information** - to withhold access from teachers to data concerning other participants in the study.
3. **Right to publish** - to publish the final report or parts of it without the permission of the teachers.
4. **Methodological developments** - to negotiate any methodological developments felt necessary as a result of interactions with research participants.

The study's ethical statement (above) draws upon the guidelines suggested by BERA (1992) and various other researchers (e.g. Kvale 1996; Hammersley and Atkinson 1995). It was produced at the start of the first case study and guided my practice in all three case studies. Table 3.1 overleaf provides examples of its operationalisation within the three case studies.

Table 3.1 The operationalisation of the Ethical statement

The ethical measures deemed necessary to ensure:	The actions undertaken with respect to the teachers:
<u>Responsibilities of the researcher</u> 1. Confidentiality a) access to raw data will be restricted to the researcher and her academic supervisors. b) pseudonyms will be used for all teachers, pupils and schools in the study as well as any other information deemed necessary to protect the anonymity of the teachers, their pupils and their colleagues etc. c) teachers will be informed of the possible limits of the above measures. 2. Informed consent a) teachers will be fully and honestly informed about the purpose of the research, what it entails, the role of the researcher and the likely outcomes of the study before any research begins. b) teachers will be informed of their right to withdraw from the study at any time. 3. Maintain appropriate relationships a) the nature of the relationship between the researcher and the respective teachers will be discussed at the outset of the research. b) the researcher will seek to be supportive, rather than critical, of the actions of the teachers and the contexts in which they work.	a) and b) carried out. c) discussed with teachers in first meeting with them (see gaining access pp. 85-86). a) discussed with teachers in first meeting with them (see gaining access pp. 85-86); provided with written summary of project and what it would entail plus a further confirmation letter upon their agreement to participate in the research project (see Appendix B); further discussed with teachers in preparatory phase of project (see pp. 90-97). b) discussed with teachers in first meeting with them (see gaining access pp. 85-86). a) discussed with teachers in first meeting with them (see gaining access pp. 85-86); further discussed in preparatory phase (see pp. 90-97). b) achieved through positive, non-judgemental interviewing role; further achieved through trying to be helpful before and after classes e.g. tidying up, shutting windows etc.

The ethical measures deemed necessary to ensure:	The actions undertaken with respect to the teachers:
<u>Rights of the researcher</u> 1. Interpretation a) the researcher reserves the right to interpret the data collected using empirical evidence to support the views developed. 2. Protection of information a) the researcher reserves the right to withhold access from teachers to data concerning other participants in the study. 3. Right to publish a) the researcher reserves the right to publish the final report or parts of it without the permission of the teachers. 4. Methodological developments a) the researcher reserves the right to negotiate any methodological developments deemed necessary in response to data collection.	a) discussed with teachers. a) discussed with teachers. a) discussed with teachers. a) discussed with the first case study during data collection.

Case selection

As stated at the beginning of this chapter, the current study's methodological approach comprised a case study of teachers' characterisations of their successful teaching of biology at A level within a small number of A level biology lessons at three sites. Consequently the project involved selecting three teachers of A level biology from which the three cases – a unit-of-work each teacher was teaching to an A level biology class – could be drawn. This section will consider the thinking behind these selections and the way in which they were carried out.

Selecting the teachers

The selected teachers represented a purposive sample (Miles and Huberman 1994) of three biology teachers. Four criteria governed their selection. The selected teachers were:

1. teaching A level biology to an A level class;
2. teachers judged to be successful practitioners;
3. willing to work with myself and volunteer their professional time and expertise;
4. working in schools which were easily accessible from the University Department at which I was based.

The first criterion related to my expectation that investigating A level biology teaching would provide me with the purest possible sample of the subject matter aspect of biology teaching. The reason for this was based on the assumption that since A level students voluntarily choose their subjects and are usually well

motivated and interested in them, the classroom management issues experienced in teaching lower years would be minimal, if not non-existent. Consequently, the majority of lesson time would be spent teaching biology rather than disciplining students. The second criterion related to my desire to explore the knowledge and understanding that shapes the practice of teachers who are deemed successful at getting the subject matter of biology across to their students in a comprehensible way. Identifying successful practitioners, however, is a thorny issue (Brown and McIntyre 1993). There are innumerable ways of judging the success of a teacher's teaching including examination results, pupil comments and observations from colleagues, parents and governors. I was aware, however, that as a novice researcher, accessing information from various sources such as pupils, colleagues and parents would be problematic and might in the end make it difficult to develop relationships with the research participants. Consequently it was decided that the judgements of two individuals who had considerable contact with and general knowledge of practitioners in the area – the Local Education Authority Science Advisor and the University Department of Education's tutor of biology – would be sought in order to select the teaching sample. The third criterion related to my belief that because the research required a considerable time commitment from teachers, only teachers who were still willing to volunteer when made aware of this considerable commitment would make suitable research participants. The fourth criterion related to the practicalities of carrying out a study that necessitated frequent school visits at varying times over a prolonged period. Consequently, only schools that were in close proximity to the University at which I was a research student were identified as potential sites for the selection of cases.

The process of selection occurred in two stages. First, the Local Education Authority Science Advisor and the University Department of Education's tutor of biology were independently interviewed. The purposes and aims of the research were made clear, in particular the reasons why their help was being sought. They were asked to identify any practising A level biology teachers in the area that they judged to be good subject matter teachers – that is, in their opinion, successful in getting their students to develop knowledge and understanding of biology at A level. Second, the names of the teachers suggested by both interviewees were compared and a list compiled. This list was based first on whether the individuals had both described the same teachers and then according to the distance of the schools in which the teachers worked from the University Department. In the first instance three teachers were asked if they would like to participate in the project. It was made clear to them that participation in the project would require them to volunteer a considerable amount of their professional time. It was anticipated that they may be unable to participate or would refuse, however all three accepted so no further selection was required.

There were several reasons for deciding upon a sample size of three teachers from which the three cases would be drawn. To begin with, it was felt important for the number of cases to extend beyond one in order for the study to benefit from the advantage of being able to compare and contrast between cases. Miles and Huberman (1994) argue that multiple-case sampling 'adds confidence to findings' by allowing the researcher not only to develop hypotheses but also to modify and

test them as well. Having made the decision for the project to incorporate more than one case, the reason for the choice of three was governed by practical limitations. Time constraints were the major contributory factor in selecting this number. As the research involved intensive observations of a series of lessons of three A level biology teachers with one of their A level biology classes and subsequent interviews with each participant, it was felt that extending the study beyond three cases would not have been possible in the time frame available. In addition, the nature of the research required close, intensive, maturely developed relationships with the participants from which the cases were drawn. These relationships would have been diminished and diluted by a larger number of cases that would have required relationships to have been established with additional teachers. Furthermore, it was thought that three cases would provide a rich enough data set without generating an unmanageable amount of data.

Selecting the classes and units-of-work

As outlined earlier, I decided that the case for this research project would be a series of connected lessons, termed a unit-of-work, rather than a number of unconnected one-off lessons. A number of reasons governed this decision. Early discussions with all three teachers suggested that they tended to teach biology at A level in relatively discrete topic areas as identified in their syllabuses. These topic areas would span a series of lessons as the large amounts of very difficult content to be understood meant that the topics could not be covered in single lessons. In addition, experiments set up in one lesson often required a follow up in a subsequent lesson. It made sense then to observe a series of connected lessons rather than a number of one-offs. Furthermore, I felt that establishing and

maintaining rapport, identified as so crucial for the generation of rich accounts, would be more readily achieved over reasonably intense periods of research with frequent contacts rather than extended over a long period of time with relatively infrequent contacts. Having decided for the purposes of this project to observe the teachers teaching a series of connected lessons, the selection of the classes the teachers would be teaching and the series of lessons (unit-of-work) to be observed were decided upon by the teachers themselves in early discussions with myself. John decided to teach a unit-of-work entitled Blood and Circulation, Catherine a unit-of-work on Respiration and Sally a unit-of-work termed Digestion. Comprehensive details of the subject matter content comprising each unit-of-work can be found in Appendix A. A detailed description of the lessons comprising each unit-of-work can be found in chapter five.

Gaining access

Access was achieved in the first instance by a letter sent directly to each teacher⁴ setting out the aims of the project and the reason for approaching them. The teachers' response to the letter resulted in a brief meeting between each teacher and myself. This meeting enabled me to elaborate upon the proposed research project, to provide the teacher with a written summary of what the research would entail⁵ and to discuss the ethical issues arising from their involvement. Fortunately all three teachers were interested and at this first meeting made apparent their willingness to become involved. The meeting continued with the negotiation of the

⁴ A copy of this introductory letter can be found in Appendix B.

⁵ A copy of this written summary can be found in Appendix B.

most appropriate time for the research to be undertaken; the A level group to be studied⁶ and whether formal support from school 'gatekeepers' was felt by the teachers, to be required⁷. A letter⁸ followed the initial meeting confirming the teachers' involvement in the research project and included details of the procedure to be subsequently followed.

⁶ As all three teachers taught an A level group from both Year 12 and Year 13 they had to choose which group they would prefer me to observe them teaching.

⁷ For two of the teachers, letters (see Appendix B for copies) were sent to key 'gatekeepers' (i.e. Headteacher, Head of Science) in the school asking for their support for the project. For one of these teachers an additional brief meeting with a key 'gatekeeper' was also arranged. The third teacher obtained 'gatekeeper' support informally.

⁸ A copy of the confirmation letter can be found in Appendix B.

Data Collection

This thesis was concerned with making sense of the knowledge and understanding that shaped three teachers' successful teaching of biology at A level. The focus of the project was to investigate what the teachers perceived they were doing and why when, according to them, they were teaching biology at A level successfully. In light of this purpose, there was a need to generate detailed accounts of what the teachers perceived they were doing and their reasons for why they were doing these things when they were engaged in, what they deemed to be, their successful teaching of biology at A level. As Yinger (1986) points out, however, research of this nature – that is research on interactive teaching – has to confront what he identifies as 'an especially sticky methodological issue' (p. 267). He summarises this in the following quotation:

Basically it [research on interactive teaching] involves gaining access to teachers' thoughts under conditions where it is impossible to have concurrent reporting. Having teachers report what they are thinking whilst in the midst of interacting would lead to incredibly distorted classroom processes even if this complex combination of self-monitoring, reporting and acting would be psychologically possible.

(ibid., p. 267)

In light of Yinger's comments, it was decided that the most appropriate way of accessing the information sought would be through interviews conducted as soon as possible after particular lessons taught by the teachers and observed by myself. Indeed, research by Brown and McIntyre (1993) and Cooper and McIntyre (1996) suggests that interviews undertaken as soon as possible after researcher observed lessons – 'preferably immediately and certainly the same day' (Brown and McIntyre 1993, p. 36) – can help teachers gain access to the practical

knowledge and understanding that shapes classroom practice. Consequently, interview and observation formed the major research instruments in this study. It is important to note, however, that prior to data collection, there was a preparatory phase, the main purpose of which was to develop rapport with the research participants and undertake any necessary preparations for the collection of data. Consequently, in the following section I shall describe and discuss first this preparatory phase and then move on to the data collection phase. In order to provide the reader with an overview of these two phases, table 3.2 (see overleaf) produces a summary of the main purposes and activities of each phase. The general pattern of each phase was the same for each teacher. However, within some of the phases the details did differ. These will be outlined in the following discussion.

Table 3.2 The main purposes and activities of the preparatory phase and data collection phase of this research project

Case Study Phase (Duration)	Main purposes	Activities
<u>Preparatory Phase</u> Case study 1 (4 weeks) Case study 2 (2 weeks) Case study 3 (2 weeks)	1. Develop rapport with research participants 2. Prepare for data collection phase 3. Collect contextual information about research participants to enrich data collected in data collection phase	a. Periods of observation in classrooms b. Two interviews – the Exploratory interview and the Unit-of-work interview c. Informal social interaction with teachers
<u>Data collection phase</u> Case study 1 (5 weeks) Case study 2 (3 weeks) Case study 3 (3 weeks)	4. Collect suitable data to answer research questions	d. Non-participant observation and audio recording of lessons e. Three different types of interviews with each research participant after observed lessons

Preparatory phase

Each case study began with a period of time prior to the specific data collection where I was present in the classroom and school but was not seeking to collect data. This period of time involved a number of visits to each case study site over a period of two to four weeks. The visits combined spending time with each teacher outside the classroom and spending time observing the class that the teacher would be teaching during the research period. These visits served a number of purposes including:

- providing an opportunity to build a relationship with each of the teachers and develop rapport;
- providing an opportunity to collect contextual information about each research participant to enrich the data collected;
- providing an opportunity to: clarify basic issues, such as the role I would adopt throughout the data collection phase of the project; fulfil some administrative objectives such as organise times and dates for data collection interviews; and make practical arrangements such as where I should sit in the class to be least intrusive;
- providing occasions to minimise a potential threat to the validity of the data generated – the reactivity of myself as the researcher.

Each of these purposes, and the details of how they were achieved, are discussed in turn below.

Building relationships with research participants: developing rapport

The key nature of good researcher-participant relations in this study has already been acknowledged in the section on methodological principles on pp. 76-77. As mentioned above, one of the major purposes of the preparatory phase was building a relationship with each research participant. The main goal here was the establishment of rapport. As Bogdan and Taylor (1984) report, rapport is 'not an easily defined concept' as it encompasses many facets including:

- Communicating a feeling of empathy for informants and having them accept it as sincere.
- Penetrating people's "defenses against the outsider" (Argyris, 1952).
- Having people "open up" about their feelings about the setting and others.
- Being seen as an "OK" person.
- Breaking through the "fronts" (Goffman, 1959) people impose in everyday life.
- Sharing in informants' symbolic world, their language, and perspectives (Denzin, 1978).

(p. 36)

A number of strategies assisted the development of rapport and encouraged good ongoing relations with each research participant.

Sociability

The methodological literature (e.g. Hammersley and Atkinson 1995; Bogdan and Taylor 1984; Beynon 1983) advises researchers in the initial stages of developing rapport with their research participants to 'establish what you have in common with

them' (Bogdan and Taylor 1984, p. 37). As Hammersley and Atkinson (1995) point out 'The value of pure sociability should not be underestimated as a means of building trust' (p. 89). My presence in the school throughout the preparatory phase afforded occasions for informal social conversations between each research participant and myself. During these conversations I attempted to find some 'neutral ground' (Hammersley and Atkinson 1995), topics of mutual interest that could provide a resource 'to keep the conversational door ajar' (Beynon 1983, p. 90). With one participant, for example, a mutual teacher colleague provided an early link for conversation. With all three participants, the internship programme at the university to which I was attached as a researcher, provided a common topic of interest as each case study site had been, or was at the time of the research, linked to the programme.

This emphasis on sociability was not only of importance in the initial stages of the project but remained a key strategy throughout the study. Throughout the fieldwork, where appropriate, time was made for each teacher and myself to engage in relaxed, informal social conversation.

Presentation of 'self'

Presentation of 'self' was also key in the development of rapport between the three teachers and myself. As Bogdan and Taylor (1984) suggest, developing rapport relies in part upon the researcher coming across as 'the type of person to whom they [research participants] can express themselves without fear of disclosure or negative evaluation' (p. 38). Indeed, Johnson (1975) suggests to researchers to try to 'appear as a humble person' (p. 95) as Bogdan and Taylor (1984) warn that

research participants may 'be reluctant to express their feelings if the observer acts too knowledgeable' (p. 38).

As it turned out, it would not have been possible for me to have appeared 'too knowledgeable' in this study. As a novice teacher and novice researcher at the time the study began, I had little experience of the classroom and very modest knowledge of research. Consequently, I simply presented 'my' 'self' in the field - an individual with little knowledge and experience about the successful teaching of biology at A level but with a real eagerness to learn from practitioners themselves.

Being flexible

Once it had been agreed that the research participants were happy to be part of the research project, the period of research at each case study site, including lesson observations and interviews, was arranged at the convenience of each research participant. Given the enormous time commitment they would contribute to the project it was deemed essential for this to be the case. It was felt that displaying such flexibility might assist the development and preservation of rapport - certainly, being too prescriptive would not have favoured the fostering and maintenance of good relations.

Collecting contextual information

The preparatory phase also provided the opportunity to collect contextual information about the teachers and their units-of-work. Although not counted as data, and therefore not analysed directly, this information did enrich the data and

inform the analysis and hence is reported here⁹. This contextual information was collected in two interviews – the exploratory interview and the unit-of-work interview. Both of these interviews can be described as ‘semi-structured’ (Bernard 1994) as despite having much of the ‘freewheeling quality of unstructured interviewing’ (p. 209) their execution depended upon the use of an interview guide¹⁰. The exploratory interview was concerned with finding out about the teachers’:

- educational background and life history;
- reasons for becoming a teacher;
- professional history as an A level biology teacher;
- perceptions of teaching A level biology.

The unit-of-work interview focused on obtaining information concerning the teachers’:

- overall unit-of-work including the proposed number of lessons and plans;
- individual lessons including the teaching and learning strategies employed;
- plans for assessment and reason for choosing the unit-of-work.

Guides for each interview can be found in Appendix C. Collectively, these interviews provided information about the teachers, the contexts in which they

⁹ The role of contextual information in enriching data and informing analysis is described and discussed in chapter four.

¹⁰ This refers to a written list of questions or topics that are required to be covered during the interview.

worked and, more specifically, the units-of-work that would provide the focus of the three case studies.

It is worth pointing out that I took various steps to try to ensure that these interviews, and all subsequent interviews, did not come across to the research participants as overly threatening situations. Prior to interviewing, for example, I encouraged the teachers to decide when it would be most convenient for them to be interviewed. It was felt that this would help to encourage them to feel at ease and in control. Choice of location for the interview was also left up to the teacher so that s/he could pick a place where s/he felt comfortable. However, it was suggested that a quiet location would be preferable. In addition, informal chatting with the teacher both before and after the interview was always encouraged and a thorough explanation of the purpose of the interview was always given. Furthermore, during the interviews I attempted to develop a relaxed and friendly atmosphere (Oppenheim 1992), utilising such strategies as the silent probe¹¹ (Bernard 1994), pacing¹² and displaying supportive and interested body language (Gorden 1975).

¹¹ This consists of 'just remaining quiet and waiting for an informant to continue' (Bernard 1994, p. 215). As Bernard points out, such a technique provides interviewees with time to reflect and gather their thoughts at appropriate points in the interview. Gorden (1975) suggests that giving interviewees this space and time sets a relaxed and informal atmosphere.

¹² This concerns the interviewer controlling her rate of speech. If the speed at which she asks questions is reasonably slow, Gorden (1975) suggests this will lower any anxiety on the part of the interviewee and help to develop a relaxed, thoughtful atmosphere.

Clarifying research issues and making arrangements

The preparation phase prior to data collection also provided me with the opportunity to clarify various issues such as the role I would adopt as a non-participant observer throughout the classroom based aspect of the research, fulfil some administrative objectives including organising times and dates for data collection interviews and make various practical arrangements such as where I should sit in the classroom in order to be least intrusive.

Minimising researcher reactivity

The data collection itself – as indicated in table 3.2 – involved, in part, myself as a non-participant observer observing a series of each teacher's lessons. The exact nature of this role and the decision-making involved in choosing to adopt such a role is discussed further on pp. 97-102. The choice to observe as a non-participant in the classroom presented me with a potential threat to the validity of the data generated – namely the reactivity of myself as the researcher. As a non-participant it was inevitable that I would upset the working environment of the classroom. The phase of preparation prior to data collection ensured that I could take measures to minimise this reactivity. During this time, I sat in on lessons with all my audio equipment to provide each teacher and their respective students with the opportunity to adjust to the presence of myself and the research equipment I would be using during data collection. Such a practice, Franfort-Nachmias and Nachmias (1996) argue can reduce the artificiality of an observational research situation as the individuals observed 'become accustomed to the observer and do not regard him or her as an intruder' (p. 206). Similar sentiments as to the value of

this practice are also articulated by Schatzman and Strauss (1973) who suggest that if, prior to data collection, the researcher persists in being present in the potential research situation:

he can reasonably expect that in time his presence – eventually seen as no threat – will become integrated and normalised ... Then, the life and work of the people there will go on much as it did before he came. After all, their work and other pursuits are more important to them than merely impressing the researcher.
(p. 58).

Data collection phase

The purpose of data collection was to generate data concerning the teachers' knowledge and understanding of their successful teaching of biology at A level grounded in real classroom events. To this end it involved:

- non-participant observation and audio recording of every lesson of each teacher's unit-of-work, the taking of lesson observation notes and the collection of any materials, such as handouts, used during the lesson;
- three different types of interview – 'long' and 'short post-lesson' interviews and vignette interviews - following the observations.

The details for each are outlined below.

Non-participant observation

The research design involved observing each teacher teaching a series of connected lessons – a unit-of-work – concerning a particular biology topic that they

had chosen prior to the start of the research¹³. By being present in the lessons I felt that I would be able to experience with each teacher their teaching. Furthermore, I felt that this would help reinforce to each participant that the focus of the research was with their perceptions of their successful teaching of biology within those specific lessons and not reflections on their teaching in general. Furthermore, my presence in the classroom meant that it was possible to make a permanent audio recording of the lessons observed¹⁴. This ensured that the lesson tapes could be used in the vignette interviews¹⁵ and also throughout analysis. Moreover, my presence in the classroom made it possible to take lesson observation notes. These notes provided a general schedule of classroom events¹⁶ and enabled a record of all non-oral components of the lesson such as instructions and diagrams written on the board – see figure 3.1 for an example – to be produced. Furthermore, my presence in the classroom enabled the collection of any additional curriculum materials, such as handouts used during the lesson – see figure 3.2 for an example. These different sources supplemented the permanent audio-recordings to bring together, for the purposes of analysis, a rounded picture of the lessons observed.

¹³ The reasoning behind the decision to observe a unit-of-work was discussed on pp. 84-85.

¹⁴ The teacher was equipped with a radio microphone in order to achieve this.

¹⁵ These interviews are discussed on pp. 117-121.

¹⁶ In order to keep track of time progression in the lesson, at five minute intervals the time was recorded in the notes taken. These lesson observation notes also provided a full record of lesson events if the audio equipment failed – as it did momentarily on several occasions.

Figure 3.1 An extract from Catherine's lesson 6 lesson observation notes.

2.50pm .
C rubs the board clear and
draws up a diagram for the students
to copy. Gives them the reference in
Rowland. (p.132). BOARD.

Energy from non-carbohydrate sources

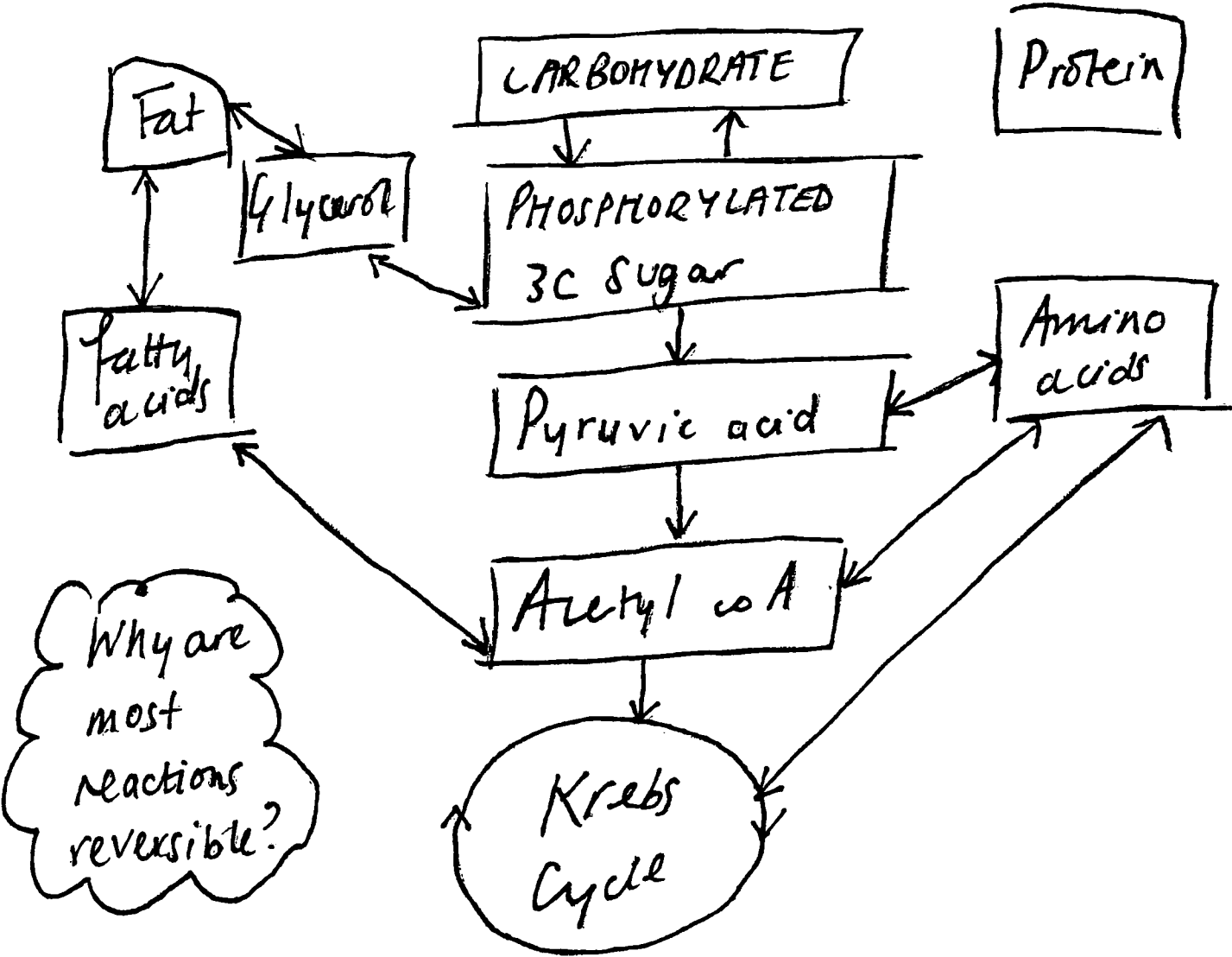


Figure 3.2 A copy of an additional curriculum material – class work and homework questions – given out in lesson 4 of Sally's unit-of-work.

DIGESTION IN MAMMALS

1. What stimulates the salivary glands to secrete saliva?
2. What is the role of mucus in saliva?
3. Describe the action of the enzyme AMYLASE. What pH is its optimum?
4. How would you test for a reducing sugar? For starch?
5. How is mechanical digestion brought about in the mouth?
6. Name the 4 basic GUT LAYERS.
7. Write a definition for DIGESTION.
8. What is PERISTALSIS?
9. What happens in the OESOPHAGUS?
10. There are 3 sphincters (CARDIAC AND PYLORIC) where are they found and what is there purpose?
11. Rennin is in gastric juice. What does it do?
12. Which cells produce PEPSINOGEN? Why is pepsinogen produced? What converts it to PEPSIN? What does pepsin do? Is it an endopeptidase or exopeptidase?
13. Which cells produce hydrochloric acid? What is its job?
14. How does the stomach stop from digesting itself?
15. How would you test for a protein?
16. How is mechanical digestion achieved in the stomach?
17. Is the production of gastric juice as a result of nerves or hormones? Explain.
18. How do hormones reach their target organ?
19. What are the names of the regions of the small intestine?
20. The duodenum produces many enzymes. Name these, the substrate they act on and the end products of digestion. Distinguish between aminopeptidases and carboxypeptidases.
21. What is bile? Where is it made? Where is it stored? What is its purpose?
22. What are the following: secretin, pancreozymin and cholecystokinin and what do they do?
23. What are the enzymes in pancreatic juice?
24. How can we test for lipids (fats and oils)?
25. In the ileum are villi. Draw a diagram (and label) of a villus. What are the advantages of the villi and microvilli?
26. How can the rate of glucose absorption be increased? (in the epithelial cells). Draw a diagram of an epithelial cell.
27. Why is (and what is) active transport necessary?
28. How is absorption of fat droplets (chylomicron) achieved?
29. What is the hepatic portal vein? Where is it? What does it carry?
30. What are the regions of the large intestine?
31. What happens in the caecum and appendix of some herbivores e.g. rabbit? (Hint: Bacteria)
32. The colon is where faeces are formed. Explain how the structure of the colon enables this to happen. Why is fibre useful?
33. What type of muscle is the rectum?
34. Distinguish between ingestion, absorption and egestion.
35. Ask for a sweetie!!

The 'complete observer' (Junker 1960) 'identified with eavesdropping and reconnaissance in which the researcher is removed from sustained interaction with the informant' (Burgess 1984, p. 82) best describes the role I adopted throughout the observational part of the research project. I took up as unobtrusive a position as possible at the back of the classroom and listened to the classroom interactions through the earpiece of my audio-equipment. I chose to adopt this role as I sought, as much as possible, to preserve the 'normal classroom situation' (Singleton *et al* 1993) in order that each of the teachers could continue teaching in the sorts of ways they normally would¹⁷. I was aware, however, that it is not possible to 'eliminate the effect of the observer in science' (Goode and Hatt 1952) and that non-participant observation as an observational strategy poses its own problems. Schatzman and Strauss (1973) succinctly summarise the major problem associated with non-participant observation in the following quotation:

the spectre of a relatively impassive observer whether or not taking notes, barely showing appropriate affect or active curiosity, and offering few if any cues as to what he is 'really up to', can be very disturbing to hosts.

(pp. 59-60)

To mitigate this, I took the advice given by Goode and Hatt (1952) who argue that:

the patterns of the society are not likely to be changed in important ways by the presence of an outsider, if the role for the latter is properly defined.

(p. 122)

¹⁷ Participant observation, as a potential observational strategy, was felt inappropriate, as it would involve me interacting with both teacher and students in the classroom thereby significantly altering 'normal' classroom dynamics.

I ensured that before beginning this phase of the research project I clarified my chosen role as a non-participant observer with each teacher and ensured they were accepting of this. This clarification was achieved in the preparatory phase¹⁸. Here, I described to the teacher the non-participatory, 'fly on the wall' stance I had chosen to adopt including setting out my reasons for deciding to take on this role. Together with each teacher I discussed what in practice this role meant in the classroom including where I would position myself during lessons, how I would be introduced to the students and how they should treat me. Furthermore, as identified on pp. 96-97, I also sat in on several of each teacher's lessons with my research equipment prior to data collection to provide each teacher and their respective students with the opportunity to adjust to the presence of a non-participant observer and audio equipment in their lessons.

A further potential issue concerning the adoption of a non-participant observational stance concerned the sheer physical presence of another adult in the classroom prospectively disrupting proceedings by, for example, sitting unknowingly in front of a drawer full of practical equipment for a particular lesson¹⁹. In order to minimise any disruption of this kind I spoke with each teacher prior to observing every lesson in order to ensure that my observational position within the class would not interfere with normal classroom proceedings.

¹⁸ This occurred during the informal discussions that took place in the preparatory phase.

¹⁹ This problem was encountered when I observed a lesson during the preparatory phase of the project.

The Interviews

This section will discuss the methodological developments that were deemed necessary as a result of experiences with interviewing during the first case study. The three sections following will discuss each type of data collection interview in more detail.

Initially it was planned that each observed lesson would be followed by a 'long post-lesson interview'. The purpose of this type of interview was to generate teachers' accounts of their own successful teaching of biology at A level grounded in real classroom events. 'Long post-lesson interviews' would encourage the teachers to explicate what they felt was their successful teaching of biology at A level and why in the *particular lessons observed*.

There were two requirements associated with these 'long post-lesson interviews': the need for immediacy and the need for quality time. First, it was felt important that the teachers should be interviewed as soon as possible after the observed lesson in order to access the type of information sought. Ideally, the 'long post-lesson interview' should take place either immediately or certainly on the same day. This was considered crucial as it was felt that the longer the space of time between the observed lesson and the interview the greater the chance that the teacher's rich and detailed discussion concerning the specifics of the particular lesson might suffer from memory loss and possible distortion. The nature of a teacher's job is such that within just a day s/he can interact with a number of different classes and teach a number of different subject matter areas. As a result of this, if interviews

were unable to occur immediately after an observed lesson or on the same day as an observed lesson, in the interim period, the teacher would have had many other teaching experiences. Moreover, it is possible that these experiences might mean that recalling specific events from a particular lesson would be more problematic as memories of other lessons might interfere with these recollections. Second, it was deemed important that the teachers be able to give sufficient quality time to these interviews in order that they could explore, at length, their knowledge and understanding of their successful teaching of biology within these lessons. Quality time refers to a situation where there are no interruptions or distractions and where teacher and researcher can focus solely on the task at hand for the length of time deemed necessary.

Experiences with John, the first case, suggested that some methodological developments were needed. The constraints of the naturalistic setting within which he worked meant that sometimes it was not possible to meet the requirements of the 'long post-lesson interview' identified above. For instance, the interviews, planned to take place after every lesson, were sometimes cut short because of other scheduled school commitments. Furthermore, on one occasion an interview had to be cancelled altogether and rescheduled for another day. As the case study progressed, it was felt that the quality of the data that was being generated was diminishing. For example, avenues for exploration raised by John's comments in 'long post-lesson interviews' were unable to be investigated as there was pressure to make interviews shorter so that it was possible for John to fulfil other professional commitments. As John found it problematic, on occasions, to fulfil the

quality time and immediacy requirements of the 'long post-lesson interview', it was felt likely that the same would apply to the other two teachers involved in the project. Consequently, it was considered necessary to develop the methodology in such a way that it still provided a means of accessing the information sought, yet took account of the difficulties that the teachers might have fulfilling the immediacy and quality time requirements. To alleviate these difficulties, it was felt that an alternative strategy that could work in conjunction with the 'long post-lesson interview' identified above needed to be developed. The alternative strategy would come into play when it was not possible for the teachers to fulfil the requirements of the 'long post-lesson interview'.

The alternative strategy that was developed comprised two different interviews: the 'short post-lesson interview' and the vignette interview. The 'short post-lesson interview' was brief and was carried out on the same day as the observed lesson – and, where possible, straight after. It provided an opportunity for the teachers to identify what they deemed to be the successful episodes of biology teaching in the observed lesson without a lengthy exploration as to why they deemed these episodes to be successful as would have been the case in the 'long post-lesson interview'. The data generated from this interview provided the focus for the vignette interview. The successful episodes of teaching picked by the teachers from the observed lessons and termed vignettes²⁰ were copied onto audiotape.

²⁰ The term 'vignette' was used here since in everyday language the term refers, amongst other things, to a 'short description' or 'character sketch' (Elliott *et al* 1997, p. 863). The specific lesson chunks identified by teachers in 'short post-lesson interviews' in essence could be considered as 'short descriptions' or 'sketches' from the particular lessons observed. These vignettes were the basis of the vignette interviews.

These audiotapes were played back to the teachers in the vignette interview. In this interview the teachers were asked to comment on these teaching episodes including describing what they were doing in them and exploring why they considered them to be successful teaching of biology at A level. This encouraged the generation of exploratory accounts of the teachers' own successful teaching of biology at A level grounded in real classroom events.

The vignette interview was planned not to occur immediately after or on the same day as the lesson observed but at another, more convenient time for the teacher involved. The interview, for example, could take place in the teacher's home or at the University Department away from the pressures of the naturalistic setting. Unlike the 'short post-lesson interview' it was a much lengthier interview.

Together the 'short post-lesson interview' and the vignette interview were able to fulfil the requirements of the 'long post-lesson interview' – that is quality time and immediacy. Since the 'short post-lesson interview' was so brief it was able to occur on the same day as the observed lesson, and usually straight after, thereby fulfilling the immediacy requirement. Moreover, as the vignette interview occurred at a later more convenient time and place for the teacher it fulfilled the quality time requirement. Furthermore, the playing back of lesson excerpts in the vignette interview meant that any difficulties concerning the recall and discussion of specific lesson events because of the time delay between the observed lesson and interview might be overcome. Indeed, the teaching episodes provided a stimulus to help the teachers to relive their observed lessons and encouraged them to

explore their perceptions of their successful teaching of biology at A level within these particular lessons.

To summarise, the methodological improvements involved developing two new interviews, the 'short post-lesson interview' and the vignette interview. Both these interviews worked in conjunction with the 'long post-lesson interview'. The revised plan was that each lesson would be followed by a post-lesson interview, either 'long' or 'short'. The teachers tentatively made decisions about which type of interview would follow a particular lesson before the research period began in order that they would fit in most appropriately with their school commitments. However, the arrangements were flexible and if unavoidable circumstances intervened, they could easily be changed. A scheduled 'long post-lesson interview', for example, could become a 'short post-lesson interview' to accommodate unforeseen difficulties.

Discussions with the teachers during the planning of the research period suggested that on at least two occasions during the unit-of-work they would be unable to be interviewed at length on the same day as the lesson observed. Consequently, it was planned to have at least two 'short post-lesson interviews', providing vignettes for two separate vignette interviews, during the course of the unit-of-work. Additional 'short post-lesson interviews' could be scheduled if there was a need to accommodate urgent commitments. The rest of the post-lesson interviews would be of the 'long post-lesson interview' type.

These complementary strategies ensured the generation of accounts of teachers' knowledge and understanding of their successful teaching of biology at A level at the same time as minimising the difficulties that arose as a result of studying this phenomenon in its natural context. It is worth pointing out, however, that the methodological improvements developed during data collection with the first case raise some important methodological issues. For example, would the information accessed from the different interviews be of the same nature? Would the data generated across the different interviews be of a similar richness? These will be discussed in a later section on pp. 121-129 exploring issues related to the use of interviewing as a data collection strategy.

Since these methodological improvements developed as a result of my experiences with the first case the details of the data collection interviews for all three teachers are slightly different as outlined in the following section. Table 3.3 shows that the methodological developments came into play for John towards the end of the case study as two 'short post-lesson interviews' provided material for one vignette interview. For Catherine and Sally the details of data collection are very similar – see tables 3.4 and 3.5. After each observed lesson, Catherine and Sally were interviewed either in a 'long' or 'short post-lesson interview'. Decisions concerning whether a 'long' or 'short post-lesson interview' would be most appropriate after a given lesson were left to them. Across their respective units-of-work both Sally and Catherine engaged in three 'short post-lesson interviews' providing material for two separate vignette interviews each. Whilst the balance of the three different types of interviews is slightly different for John in comparison to

Sally and Catherine, since the data collected from the three different interviews was considered to be of the same nature, as is argued in a later section on pp. 123-129, this was not considered to be an issue.

Table 3.3 An outline of John’s data collection interviews.

Unit-of-work (number of lessons ²¹)	Type of post-lesson interview	Vignette interview 1 draws on excerpts from this lesson
1	long	
2	long	
3	long	
4	long	
5	long	
7	long	
8	short	✓
9	short	✓

Table 3.4 An outline of Catherine’s data collection interviews.

Unit-of-work (number of lessons ²²)	Type of post- lesson interview	Vignette interview 1 draws on excerpts from this lesson	Vignette interview 2 draws on excerpts from this lesson
1	long		
2	short	✓	
3	long		
4	long		
5	short		✓
6	short		✓

²¹ The duration of each lesson was 90 minutes.
²² The duration of lessons 1,3,4, and 6 were 60 minutes. The duration of lessons 2 and 5 were 120 minutes.

Table 3.5 An outline of Sally’s data collection interviews.

Unit-of-work (number of lessons ²³)	Type of post-lesson interview	Vignette interview 1 draws on excerpts from this lesson	Vignette interview 2 draws on excerpts from this lesson
1	long		
2	short	✓	
3	long		
4	long		
5	long		
7	short		✓
8	short		✓

The ‘long post-lesson interview’

The purpose of this interview was to get the teachers to identify, in as much detail as possible, what they deemed to be their successful teaching of biology in the lessons observed. The interview encouraged them to explore what sorts of things they perceived themselves to be doing and their reasons for doing these things when, according to them, they were teaching biology successfully. Each ‘long post-lesson interview’ took place as soon as conceivably possible after the lesson observed²⁴.

²³ The duration of lessons 1,3,4,5, and 8 were 55 minutes. The duration of lessons 2 and 7 were 110 minutes.

²⁴ On some occasions this meant straight after the lesson ended, on others this meant at a free moment later on that day. This depended on the way the teacher’s timetables were set out. For John, on one occasion due to unforeseen circumstances the ‘long post-lesson interview’ took place the day after the observed lesson.

The 'long post-lesson interview' is best described as 'informant' in style as 'the shape and direction of the interview [was] largely dictated by the unfolding pattern of the interviewee's perspective' (Cooper 1993, p. 329). After I posed the initial open positively phrased question, the teacher was free to respond in whatever manner s/he felt comfortable with. An example of such an exchange is given below:

A: What went well for you in terms of the teaching of your biology?

C: Getting through what I'd planned. Well that's important, and so I'd planned to, and I was determined to get right through to anaerobic respiration. I so wanted to do that because I don't want to drag it too much more and I didn't, but I wanted to go slowly enough that I didn't risk loss of understanding and that's why I suppose I sort of apologised really for I kept saying I'm repeating it, I'm repeating it, but I felt I had to keep, and I you know I kept asking everybody and that was I thought good
(plint 5 C 53-61)

To encourage this freedom, in addition to the strategies identified earlier on p. 95 (i.e. the silent probe, pacing and displaying supportive and interested body language), I also adopted a further strategy, avoidance of interrupting the teacher (Kvale 1996; Bernard 1994; Gorden 1975). This ensured that any comments or questions I made did not break the interviewee's flow of ideas. The large lengths of uninterrupted teacher prose found in the interview transcripts illustrate the use of this technique²⁵.

²⁵ Appendix D gives examples of transcripts of all the different types of interviews.

In addition to the techniques described, I also made use of the echo probe (Bernard 1994) in order to guide the subject to a more detailed account of her/his thinking and reasoning. Whilst the teacher was talking I would be listening attentively and jotting down odd words and/or phrases used. I would then paraphrase what the teacher had been saying and feed the information back to her/him to elicit further explanation and clarification. For instance, in the following example, John had just finished a lesson about blood vessels and tissue fluid. In the post-lesson interview he told me that one of the good points about the lesson was that the students had 'got to grips with vessels'. I picked up on this phrase and used it as a probe to get John to expand a bit more on what he meant:

A: Right, you said they 'got to grips with vessels'. Can you tell me a bit more about that?

Having used this probe, John proceeded to expand upon what he meant by this phrase. It seemed that 'getting to grips with vessels' involved being able to distinguish between the three different types – arteries, veins and capillaries – and being able to do this involved making sense of various significant concepts and principles in relation to these biological structures. In his words:

J: Um, at first, as usual they were sort of all over the place with their ideas, especially Harvey who is actually very able ... so he started on about, you know, the usual situation where he starts piling words in that he's picked up over the centuries. They all come out in a funny old order. And that's how I used to be in biology, in science A levels and I used to-, my chemistry teacher's catch phrase was that I couldn't see the wood for the trees and that summed me up perfectly cause I used to get all these terms and remember fine details but I never understood the prin-, it took me a long time to understand the principles and the concepts behind things. That's one thing that I've always been trying-, I've tried to do. What I've tried to do with these kids is get them to understand what is behind the things that we're teaching and I think if they do that they can go on *ad infinitum* learning and building on that ... I think in the end I would be confident enough to say that if you stopped anyone walking out the door they would know the difference between an artery and a vein and a capillary and they'd be able to give you some points about them

(plint 3 J 97-116)

Occasionally I attempted to check my understanding of a point that the teacher was making and encourage further exploration. I did this by feeding back to the teacher what I thought the teacher had been saying. This strategy is apparent in a quotation taken from the vignette interview incorporating lesson excerpts from lesson 2 of Sally's unit-of-work. In lesson 2, Sally's students had been engaged in a practical investigating the digestion of starch. Sally spent a large part of this lesson discussing the biological ideas she believed were relevant to starch digestion with various groups of students. At the end of the lesson she engaged her students in a plenary session where she encouraged them to discuss their results and consider the biological content relevant to the experiment. Having heard an extract from this part of the lesson she commented upon what she felt was successful about it:

S: A lot of repetition going on, a lot of reinforcing, referring back to things which you have to do really at A level because you have to keep going back. You can't forget the basics and you have to keep going over certain concepts, ideas so that they eventually become sort of second nature and doing that helps in understanding some of the other things

(VI1 S 580-585)

As I listened to Sally's response I began to get the feeling that she considered revisiting subject matter an important aspect of her successful teaching because she felt it helped her students to learn biological content. I checked my developing understanding by asking the following question:

A: So, would it be right to say that you feel that if students meet the same subject matter again and again that this helps them to learn it?

Sally's response to this question indicated that I had made sense of her comments and further to this her continued exploration enabled her to expand upon her thinking about specific aspects of biology (e.g. active site) that she considered critically important for her students to know and remember.

S: Yes, the repetition is, yeah, to reinforce, it helps it to become, you know, second nature to them and I think the idea of trying to bring things together and I try and sort of bring in, not stick to one idea in a lesson but to bring in other things we've discussed and to do that as much as possible just so that you can keep on, well hopefully so that they get it all sorted out in their head and that, and as I keep saying you can't forget the, the sort of the core content, the basis of it all, like the active site bit, you cannot stop thinking about that one.

(VI1 S 604-612)

The 'short post-lesson interview'

The main purpose of the 'short post-lesson interview' was to assist in my preparations for the vignette interview. The aim was to encourage the teacher to isolate several episodes from the specific lesson observed that s/he believed to be examples of 'successful' teaching of biology at A level. The intention was then to isolate these excerpts from the audio recording of the lesson, transcribe them and also record them onto another tape for use as a stimulus in the vignette interview.

My role throughout the interview was explicitly concerned with checking and clarifying that there was enough information from the teacher and lesson observations to isolate extracts from the audio record of lessons for later use. At times, however, the teacher also wanted to explore his/her thinking at certain points of the lesson in a similar way to the 'long post-lesson interviews'. Whilst I did not encourage these sorts of explorations in the 'short post-lesson interviews', since the development of this interview was a response to time pressures on teachers, they were not actively discouraged.

In some instances it was easy for the teachers to isolate episodes of the lessons they had taught that they felt were 'successful', 'good' or 'went well'. In one 'short post-lesson interview', for example, in response to my question ('Just really quickly, if you could isolate for me some episodes of good biology teaching in that lesson, just a couple so I can pick them up off the tape?') Catherine began by identifying three episodes of the lesson observed, underlined in the quotation below, that she felt had gone well. These were:

1. The marathon/sprinter discussion.
2. The recap at the beginning of the lesson.
3. The copying exercise at the end of the lesson.

In her words:

C: If I can remember-, ... I can see them really focus the interest when I talked about the sprinter and the-, so yeah, you know, and Linford Christie and focus on that and I've heard him in interview talking about why, you know, holding his breath and what he's focusing on and relating that to the aerobic and anaerobic and so the marathon and the thingamajig. And then the, um, the-, oh I had a plenty of recap at the beginning. Now that was I felt important because, you know, I was coming to the end and I wanted to summarise so I felt that was important. And then the last bit where they were copying

(plint 6 C 21-39)

However, on other occasions the teachers found this problematic and therefore my role became more directive. In the following example, I had asked Sally if she could identify specific episodes of lesson 2 that she felt were examples of successful teaching of biology. She began by talking in quite general terms about the lesson:

S: I suppose with it being a practical and with it the sort of practical where I was redundant as far as telling them what to do because they had the sheet, it meant I was able to go and ask some of them questions, try and get them to think about what was going on. ... I think there were good bits of practical sort of involvement in it, but that wasn't me, that was the nature of the practical, the only way sort of I was involved I just emphasised that you know, read it through first before you do it and then just kept sort of reinforcing the read it through, but they certainly all seemed to know what they were doing, I mean there were a number of tubes to muck about, they didn't, they apart from the ones who tested the odds with the different chemical, that didn't matter. Isolating incidents.

I tried to get her to be more specific by pushing her again to identify specific episodes:

A: Can you remember any specific parts of the lesson that you would say 'that was successful, that went well?'

S: I think the whole practical went well but that's not an isolated little incident. I'm not very good on this you know.

Sally was clearly finding this difficult. Consequently, I picked up on a point that she made in her first discussion – namely that she was able to go and ask some of her students questions during the lesson – and found this fruitful in guiding her to isolate some episodes of successful teaching of biology in the lesson observed:

A: You said you went round to ask some of them questions

S: those two. Kate remembered what I'd, Kate remembered some of it at the end so from asking Kate about the maltose and the polysaccharide so Kate had obviously listened, so that was a plus bit.

A: Ok so would you say that your discussions with the individual groups that you went

S: yeah, that helped yes.

A: [^]

S: What I was trying to do was to get them to tell me some information about what they were doing without actually telling them all the answers and then at the end just seeing if they had remembered it.

A: So would you say then, if you had to look at that lesson and say 'these were successful bits' that the individual group bits on the tape were successful?

S: Yes

(plint 2 S 10-95)

The Vignette Interview

The purpose of this interview was to explore the teacher's reasoning behind what they were doing and why when they deemed themselves to be teaching biology successfully in the particular lesson(s) observed. The idea was to use extracts from lesson tapes as a stimulus to get teachers to talk more about their successful teaching of biology at A level.

The vignette interview worked in partnership with the 'short post-lesson interview'. The episodes of successful A level biology teaching that were identified by the teachers in the 'short post-lesson interview(s)' were located and transcribed from the relevant lesson tapes as well as copied onto a further tape. It was this tape of teacher-selected vignettes that provided the focus for the vignette interview. The vignette interview comprised playing back to the teachers the vignettes they had chosen from previous lessons as examples of their successful teaching²⁶. The teachers were put in charge of the tape recorder and in a preparation discussion prior to the interview itself were encouraged to stop the tape as it was playing when they felt they were engaging in successful A level biology teaching. Having stopped the tape they were encouraged to explore why they felt what they had just heard was an example of their successful teaching of biology at A level. In particular, they were asked to focus on what they were doing and why when engaged in what they deemed to be their successful teaching of biology at A level. My role in this interview was to prompt them, if necessary, to explore why they had stopped the tape (e.g. asking them 'Can you tell me why you stopped the tape?' , 'Can you tell me what it is about what you've just heard that makes it an example of successful teaching of biology at A level?') and also , if necessary, use probes – such as those used in the 'long post-lesson interview' (e.g. echo probes) – to enable further clarification of points raised.

²⁶ Prior to playing, I introduced each vignette hoping to refresh the teacher's memory, reminding her/him of the particular lesson it was taken from and briefly outlining what it concerned.

In the following example, John had been listening to a vignette where he had been talking about monoclonal antibodies²⁷. He stopped the lesson tape at a point in the vignette where he felt that he was engaged in successful A level biology teaching:

J: Now this is the process they actually specify that, you know, about in the syllabus, it came up didn't it Sarah?

Sarah (pupil): Um?

J: Didn't it come up in module three one of them?

Sarah: What was that? Sorry!

J: () What we're talking about, monoclonal antibodies!**

Sarah: I think it did.

J: I thought it did, monoclonal antibodies. Ok, so I would keep hold of that carefully, there is a similar description in Roberts on 4

[J stops the tape again]

Without a prompt from me, he began to reflect straight away upon what he had been doing and his rationale for those actions. In his words:

J: It came up in the syllabus, sorry, it's in the syllabus, and they do specify it. Quite a nice, it's a tidy little bit. Monoclonal antibodies is something that, well, we covered just there and then, and if you understand what is going on, you can answer a question on it basically ... at the end of the day they've got to get through an exam, ... they've got to get through it and just from time to time, you know, I do link back to the syllabus, because to have a syllabus like we've got is such an asset, because, um, I'm sure in the past, you know, teachers have taught biology and they enjoy doing lah de da, and all, you know, everything that's under the sun you could talk about, but you never know what, which part of that's gonna come up in the exam. At least with this syllabus content you can say what, specify, this could be on so you jolly well need to know it, it's not something to be stuffed in the back of your file.

²⁷ To help the reader to distinguish between the lesson data and the teacher's reflection on the lesson, the lesson vignette is presented in bold typeface and the teacher's commentary that follows is presented in normal typeface.

When he had finished his exploration I asked him to talk further about why he felt what he had just heard was an example of successful A level biology teaching.

A: So what is it about what you've just heard that makes it a 'good' piece of 'A' level biology teaching?

He continued to explore his reasons for identifying this episode as an example of successful teaching of biology at A level.

J: Well, I'm helping them. I'm giving them a tip. A jungle tip. ... And the jungle tip of the day then was, 'this bit of paper I'm giving you and what we've just talked about has every chance of coming up, so understand it', and, in a way, a sort of negative way, 'don't come to me in June and say 'Monoclonal antibodies, there was a question on it', you know, which for their benefit they need to know, they need to be reminded, they don't see the value of a syllabus like we do, so every possible point, you know, of help and advice I can give them hopefully is the best way to do it.

(VI 1 J 308-356)

In addition to asking the teachers to explore why they felt what they had just heard, upon stopping the tape, was an example of successful teaching, at times it was also possible to pick up on various points the teachers made and encourage them to elaborate further in a similar way to the probes used in the 'long post-lesson interview'. In the following example, Catherine had been listening to a vignette from lesson 2 of her unit-of-work. At the end of the vignette she talked about why she felt it was an example of her successful teaching of biology at A level. One of the points she made related to the fact that the episode found her revisiting subject matter the students had already covered, something she considered an important aspect of her successful biology teaching as she indicates below:

C: And this is stressing that, and reminding, and saying what we did every time, and it pays off because today when I said 'what do you know about that equation?' and sure they were able to say because it is a multi-step. Plenty of saying the same thing a thousand times. ...

I was keen to get her to explore further why she felt 'saying the same thing a thousand times' was successful teaching and so I used an echo probe to encourage her to further clarify her reasoning.

A: You said that saying the same thing a thousand times is good biology teaching. Can you tell me more about that?

C: That helps the learning process. Saying the same-, recap and recall is reinforcement, that's the word I was looking for. Reinforcing, so that's helping just the learning.

(VI1 C 527-541)

Issues related to the use of interviews as a data collection strategy

Earlier on I identified various potential difficulties connected with the use of non-participant observation as a research strategy and outlined the steps I took to minimise the effect of these on the data collected. Since interviews formed the second major research instrument in this study it is also important to consider the potential problems that might arise from their use in data collection and discuss how I endeavoured to minimise them. To this end, the following section will consider first, the general problems of using interviews as a research instrument and second, the potential problems that might arise from using this study's combination of three different types of interview. In both cases, the various strategies adopted to overcome these potential difficulties are discussed.

When using the interview as a data collection strategy, tension can arise between the desire to maintain good relations with research participants and the desire to gain access to the information sought. In order to mitigate this I utilised the strategies outlined earlier – the silent probe, pacing, displaying supportive and interested body language and avoidance of interrupting the teacher – and furthermore, expressed my understanding of the demanding nature of what I expected the teachers to do - namely attempt to articulate what and why they do the things they do in the classroom when engaged in successful A level biology teaching. I sought to be sensitive to the difficulties of this process at all times and would draw the interview to a close when I felt that the teachers had 'had enough'.

An additional problem associated with using the interview as a data collection strategy concerns the interviewee giving the interviewer answers s/he thinks are being sought. I attempted to combat this, as discussed earlier on pp. 71-72, by stressing my desire to understand what the teachers considered themselves to be doing in the classroom when teaching biology successfully and why they were doing these things in the observed lessons.

As a novice interviewer I was aware that I lacked experience in using the interview as a research instrument. Powney and Watts (1985) warn that inexperienced interviewers can:

Change the subject, offer advice, or share their own experiences, or emotions, with the person being interviewed, thus changing the roles of the participants in the interview

(p. 134)

In light of their advice, I was mindful of these inappropriate behaviours during all interviews so I could prevent them from occurring. Furthermore, after each interview I reflected upon my performance in my research log so that in each subsequent interview I could go on to improve my interviewing technique and consequently the quality of the data collected.

Logan (1984) argues that as interviewers, we need:

constant self monitoring to reveal to what extent we are still guilty of importing into and imposing our categories on to interviewees

(p. 24)

Given that the purpose of this research was to explore teachers' own characterisations of their successful teaching of biology at A level I attempted at all times not to import my own understandings into any interviews. The use of echo probes and a constant awareness of the need for an open approach helped me to combat this potential difficulty.

In addition to the general problems outlined above the use of three different types of data collection interviews raised two further important issues. First, would the information accessed from these different interviews be of the same nature? Second, would the data generated across the three different interviews be of a similar richness? I shall discuss each issue in turn.

As the 'long' and 'short post-lesson interviews' were both conducted as soon as possible after lessons and both involved the teachers identifying what they deemed to be their successful teaching of biology in the particular lessons observed it seems possible to conclude that they were both accessing information of the same nature. It seems that the only difference in the information collected in these two interviews is the depth to which the teachers described these instances of successful teaching and explored their reasons for selecting these particular examples. In the main, the 'long post-lesson interview' provided the teachers with more time to explore their knowledge and thinking in depth and also provided myself with more time to probe into this knowledge and thinking although such reflection, whilst not actively encouraged, was not discouraged from the 'short post-lesson interview'.

A comparison between these interviews, and the vignette interviews, however, highlights two significant differences. First, the vignette interview was not conducted immediately after or at least on the same day as the lesson observed, but instead several days after the specific lesson(s). Consequently, the time delay between the teachers' teaching and their reflection on this teaching was significantly longer for the vignette interviews than for the 'long' or 'short post-lesson interviews'. Might this increased time delay yield different data in the vignette interview in comparison with the 'long' and 'short post-lesson interview'? Before it is possible to answer this question it is important to consider the nature of data that is accessed by discussing and reflecting on actions *after* they have taken

place. As mentioned earlier, it is impossible to access teacher cognitions²⁸ during teaching without severely distorting the teaching process itself (Yinger 1986). Consequently, studies attempting to make sense of teachers' knowledge and thinking-in-action tend to adopt methods which involve teachers discussing and reflecting on their classroom action after it has taken place (e.g. Cooper and McIntyre 1996; Brown and McIntyre 1993). Cooper (1993) argues that discussions and reflections on teaching after it has taken place are unlikely to access individual teachers' actual cognitions during their teaching; rather they are more likely to encourage teachers to present post-hoc rationalisations of their classroom actions. However, he argues that this is not necessarily a bad thing. Indeed, he states that any rationalisations offered in an interview that is grounded in actual classroom events (such as the interviews adopted in this study) develop from the interviewee's perceptions of how, as a rule, they actually think and behave when they are teaching. Consequently, they provide access to the ways in which teachers make sense of their teaching and for that reason can provide an invaluable tool for gaining insight into their practice.

It is likely then, that in this study, all three interviews accessed teachers' post-hoc rationalisations of their classroom actions. The methodological issue of concern, therefore, becomes whether the significantly longer time delay between the teachers' teaching and their discussions of this teaching in the vignette interview

²⁸ The term 'cognition' is used here to refer loosely to the knowledge-in-action, thinking and understanding that shapes teachers' interactive teaching. Indeed, as Calderhead (1987) points out, in the literature the terms 'teacher thinking' and 'teacher cognitions' are used fairly loosely to refer to such activities as those identified previously.

(as opposed to the 'short' and 'long post-lesson interview') affected the validity of the post-hoc rationalisations of action they presented. It could be argued that the longer the delay between the teachers' classroom actions and their reports of those actions the greater the chance that the post-hoc rationalisations presented to explain their actions might have been reinterpreted and therefore suggest different interpretations to any post-hoc rationalisations given immediately after or on the same day as the lesson(s) observed. This argument, however, is based upon the assumption that the teachers in this study would be motivated to and have the time to reflect extensively upon their lessons after they had been taught which is perhaps unlikely as a result of the busy lives they lead.

Furthermore, perhaps the best evidence to check the validity of any post-hoc rationalisations presented in vignette interviews is to see whether they are congruent with any reflections and discussions given in the corresponding 'short post-lesson interviews' and other interviews. Indeed, if there are marked contradictions between data in the vignette interview and data in the corresponding 'short post-lesson interview(s)' it is possible that the concern with the reinterpretation of post-hoc rationalisations is real. However, no such contradictions were found in the data sets for all three teachers in this research project suggesting that despite the differences in the time delay it did not have a significant impact on the data collected.

The second difference between the vignette interview and the 'long' and 'short post-lesson interviews' concerns the fact that, in the former interview, the teachers

not only had their own memory of the lesson to draw upon, they also had the additional stimulus of the tape-recorded vignettes. The 'long' and 'short post-lesson interviews' rely only on the teacher's memory of the lesson to present post-hoc rationalisations of classroom action. In contrast, the vignette interview relies not only upon this source but also segments from the audio record of the lesson. A potential difficulty might arise if the teacher's memory of the lesson is not congruent with the audio record of the lesson and consequently forces him/her to reinterpret the lesson encouraging the presentation of different post-hoc rationalisations than those that might be given without the extra stimulus. However, any incongruence between the teacher's memory of the lesson and their interpretation of the audio record of the lesson is likely to be identified when the accounts they produce in the 'short post-lesson interview' are compared with those produced in the vignette interview. If the teachers' brief initial explorations of their cognitions in 'short post-lesson interviews' are in agreement with the expanded versions in the subsequent vignette interviews it is likely that incongruence is not a major problem. As it happened, in this study the teachers seemed to display consistency across these interviews and so it is possible to infer that the additional stimulus of the recorded vignettes in the vignette interview did not present a major problem. It is unlikely, then, that the 'short' and 'long post-lesson interviews' yielded data of a different nature from the vignette interviews.

Although I have argued that the three interviews are likely to access data of a similar nature, it is possible that their differences might affect the richness of the data collected. Clearly, the 'long post-lesson interview' would generate data with

greater depth than the 'short post-lesson interview' as it was invariably longer and more probing. However, what of the vignette interview? Might there be issues to consider in order to enable this interview to generate data of similar richness to the 'long post-lesson interview'? It was important to consider several issues to ensure the level of richness was not compromised in the vignette interview. The first issue concerned the effect that listening to oneself teaching might have on the respective teachers. Fuller and Manning (1973) suggest that listening to an audiotape of oneself teaching might be an anxiety provoking experience. Consequently, the vignette interview might put teachers under a greater amount of stress than the 'long' or 'short post-lesson interviews' which, as Calderhead (1981) argues, might reduce the extent to which the research subject concerned is able to report the cognitions that shape his/her classroom action. The second issue relates to the fact that individuals unused to listening to tapes of themselves teach might be distracted by their own personal characteristics and consequently focus to a lesser extent on the cognitions that shape their classroom action. Collectively, these difficulties might contribute to reducing the richness of the data from the vignette interview. In light of this I took several steps to minimise these difficulties. First, during the preparatory phase I provided the teachers with the lesson tapes I recorded during my observation sessions in order for them to familiarise themselves with their voices and general class demeanour. This I felt might limit reference to themselves whilst listening to the vignettes and ensure that focus was maintained on exploring their interactive cognitions. Second, if any comment unrelated to successful teaching was made by a teacher during the vignette interview I decided not to respond hoping this would steer the teacher back to the

task at hand. As it happened, only two of the teachers made passing reference to their personal characteristics during their vignette interviews. The overwhelming majority of the discussion in interviews focused solely on the teachers' knowledge and understanding of their successful teaching of biology.

In this chapter I have outlined the research approach adopted and discussed the methodological principles underpinning the conduct of the study. Furthermore, I have identified the processes by which access was gained and the selection of cases made as well as described and discussed the procedures that enabled the collection of data.

The following chapter will give an account of how the data of this study was analysed as well as discuss the ways in which the project aimed at encouraging the development of a plausible, credible and trustworthy final account.

Chapter Four

Data Analysis

Introduction

Since the purpose of this study was to provide an understanding of what three teachers considered successful teaching of biology at A level to involve, the overall aim of the analysis was to produce cross case claims that:

- indicated the teachers' characterisations of what, for them, successful teaching of biological subject matter at A level comprised;
- accounted for any similarities and/or differences identified between the research participants.

In light of this, the purpose of this chapter is to set out the ways in which the data of this study was analysed. To this end, details will be provided on:

- the principles which underpinned the analytical procedures;
- the analytical procedures.

Furthermore, the ways in which the study aimed at encouraging the development of a plausible, credible and trustworthy final account will also be considered.

The principles used to guide the analysis of data

Four principles guided the analysis of data. They were to:

- develop original analytical procedures rather than import pre-determined methods;
- distinguish between different kinds of data and allocate different levels of status to different data sets;
- begin with small units of data and use these as a basis from which to develop cross-case claims;
- remain critically aware of the role of literature in the analytical process.

Each principle will be discussed in turn.

To develop original analytical procedures rather than import pre-determined methods

When considering the analysis of interview data, Kvale (1996) argues that:

There are no standard methods, no *via regia*, to arrive at essential meanings and deeper implications of what is said in an interview. ... The search for techniques of analysis may be a quest for a “technological fix” to the researcher’s task of analysing and constructing meaning.

(p. 180)

In sympathy with Kvale’s position, the first principle derived from a belief in the need to develop original analytical procedures appropriate to the nature and purpose of the investigation rather than import pre-determined methods such as those suggested in methodological texts (e.g. Miles and Huberman 1994; Dey 1993; Tesch 1990). The desire to develop rather than import analytical procedures influenced this thesis’ analytical process. The advice of Coffey and Atkinson

(1996) to 'experiment and play with analysis' (p. 5-6) was taken until a useful way of proceeding was found. In this sense, the analytical procedures evolved over time to meet the needs of the investigation.

To distinguish between different kinds of data and allocate different levels of status to different data sets

This principle derived from a recognition that during fieldwork a variety of different sorts of data had been collected. It was felt necessary to distinguish between these different sorts of data in order to assist the development of analytical procedures. To this end, data was allocated to one of two different categories:

- rich pictures of practice comprising lesson tapes and transcripts, lesson observation notes and curriculum materials such as handouts and worksheets;
- reflections on practice comprising post-lesson and vignette interview tapes and transcripts.

In particular, this distinction was useful when attempting to find a focus for, and a beginning to, analysis. In light of the focus of the thesis – providing an understanding of what three teachers consider their successful teaching of biology at A level to comprise – the data set comprising the teachers' reflections on their practice was assigned the highest status in the initial stages of analysis and used as a starting point for analysis. This data set was used to assist in making sense of the rich pictures of practice comprising lesson tapes and transcripts, lesson observations notes and curriculum materials. By distinguishing between different sorts of data and using one data set as a starting point for analysis it was possible

to integrate the two data sets to produce a coherent account of the three teachers' characterisations of their successful teaching of biology at A level.

Further to these two data sets, contextual information about the teachers and their units-of-work collected during the preparatory phase helped to enrich the data generated and inform the analysis. This is discussed more specifically on pp. 155-156.

To begin with small units of data and use these as a basis from which to develop cross-case claims

Writing about analysis, Wolcott (1994) offers the following guidance:

if it seems too overwhelming: keep breaking down the elements until there are small enough units to invite rudimentary analysis, then begin to build the analysis up from there.

(p. 30)

The third principle embraced this advice by beginning analysis with a focus on small units of data. These comprised the teachers' post-lesson reflections on specific classroom events in the lessons observed where they deemed themselves to be teaching biology at A level successfully, the corresponding transcripts of those events from the lesson tapes and relevant lesson observation notes and curriculum materials. These data units comprised manageable chunks which could be analysed in detail without the analytical task becoming too overwhelming. This principle influenced not only the beginning to analysis but also methods used throughout the analytical process. For example, when writing propositions designed to reflect all the data units within a specific group, small

samples of data units were used in the first instance as the starting point for their construction.

To remain critically aware of the role of literature in the analytical process

Writing about the role of the researcher in the analytical process, Coffey and Atkinson (1996) warn that:

Data are not inert. They are not a fixed corpus of materials on which procedures of analysis are performed.

Instead they suggest that the researcher:

should be using data to think with and think about. That means bringing to bear an active, creative approach. Although one should be careful not to build elaborate theoretical edifices on the data, one should be prepared to speculate about them. Ideas do not emerge from the data or from the imposition of analytic procedures, however helpful it may be to code the data or to map some of its formal features. No amount of routine analytic work will produce new theoretical insights without the application of disciplinary knowledge and creative imagination.

(pp. 191- 192)

Heeding their advice, a large proportion of the time spent analysing the data was also spent further exploring the research literature. Upon reading this wider literature it was often tempting to import theoretical ideas unquestioningly in order to make sense of the data. The fourth principle, however, embraced an attempt to avoid this by encouraging a critical awareness of how literature was being used in the analytical process. Indeed, when literature was drawn upon during analysis

there was an attempt to be self critical about its use. For example, throughout the analytical process I continually asked myself the following questions:

- Am I using the literature to help foster the development of my own theoretical ideas in light of my own understanding of the data?
- Or am I importing theory without question?

Asking these questions on a continual basis encouraged me to think about the data and the literature in a more detached fashion leading me to be more open minded about the role of the literature in the analytical process.

The analytical procedures

The process of analysis took place in two consecutive phases. These were:

- initial data processing;
- cross case analysis.

Initial data processing

The initial processing of data took place as soon as data began to be collected with each of the teachers. In essence, this phase of analysis concerned transforming data from one format to another (e.g. oral interviews to written transcripts), establishing ways of managing the developing corpus of data and data familiarisation. To this end, initial data processing comprised producing:

- transcripts of lessons and interviews;
- lesson and interview summaries.

Producing transcripts of lessons and interviews

To navigate with ease around the data it was felt necessary to transcribe the lessons and interviews from an oral to a written mode. As Kvale (1996) points out:

Structuring the material into texts facilitates an interview and is in itself a beginning analysis

(p. 168-9)

However, since transcriptions are not representations of reality but rather artificial constructions and their production involves a series of judgements and decisions, a set of clear instructions for notating them was produced and followed throughout

the process of transcription. These instructions are reproduced at the beginning of this thesis (see p. iii-iv).

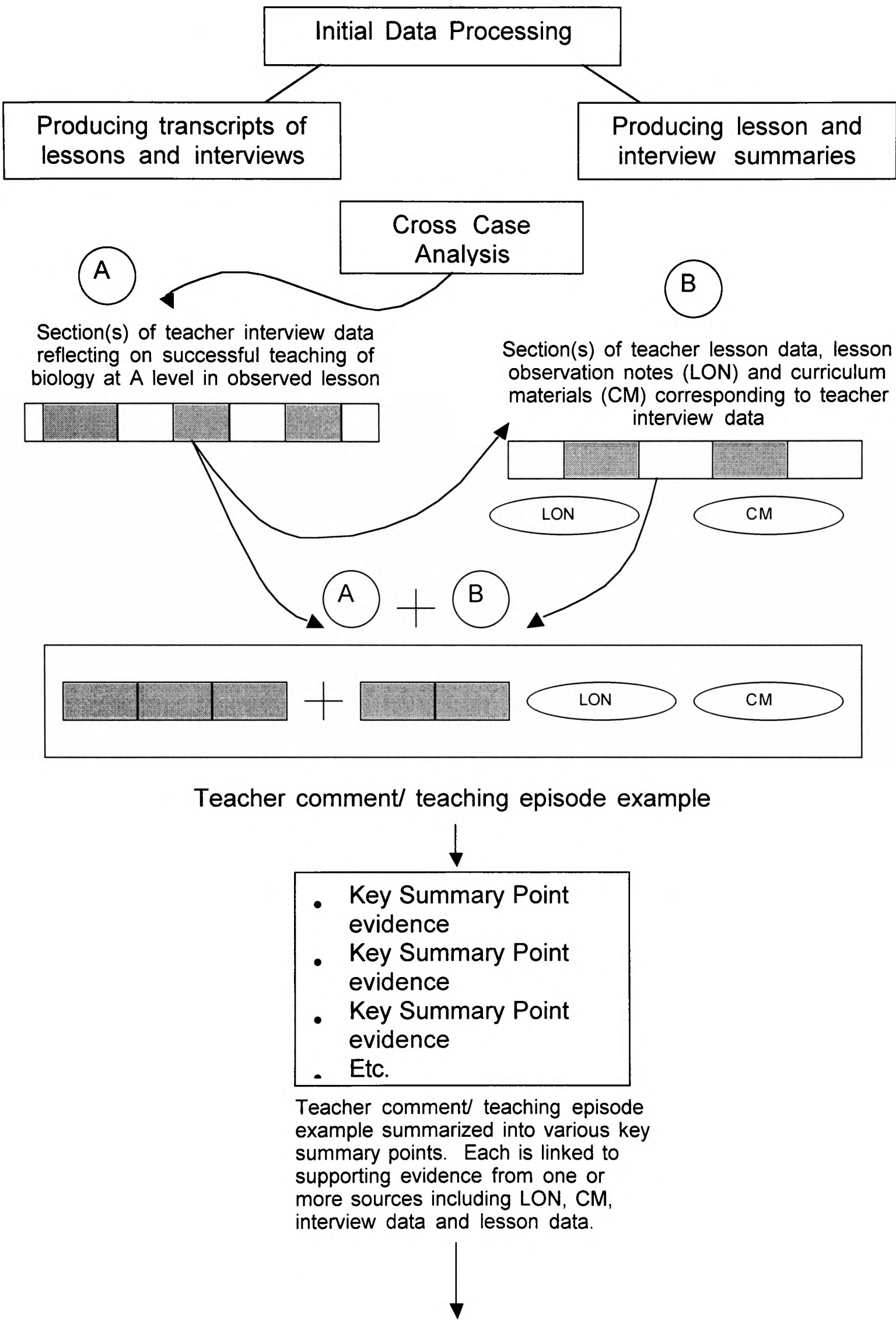
Producing lesson and interview summaries

Initial data processing also involved producing lesson and interview summaries. The basic purpose of this was data familiarisation. The lesson summaries (see Appendix E for examples) comprised the identification of major lesson events as well as the subject matter covered in relation to those events. In addition, all curriculum materials used in particular lessons were collated with these lesson summaries. The interview summaries (see Appendix F for examples) comprised an outline of each interview's major sections.

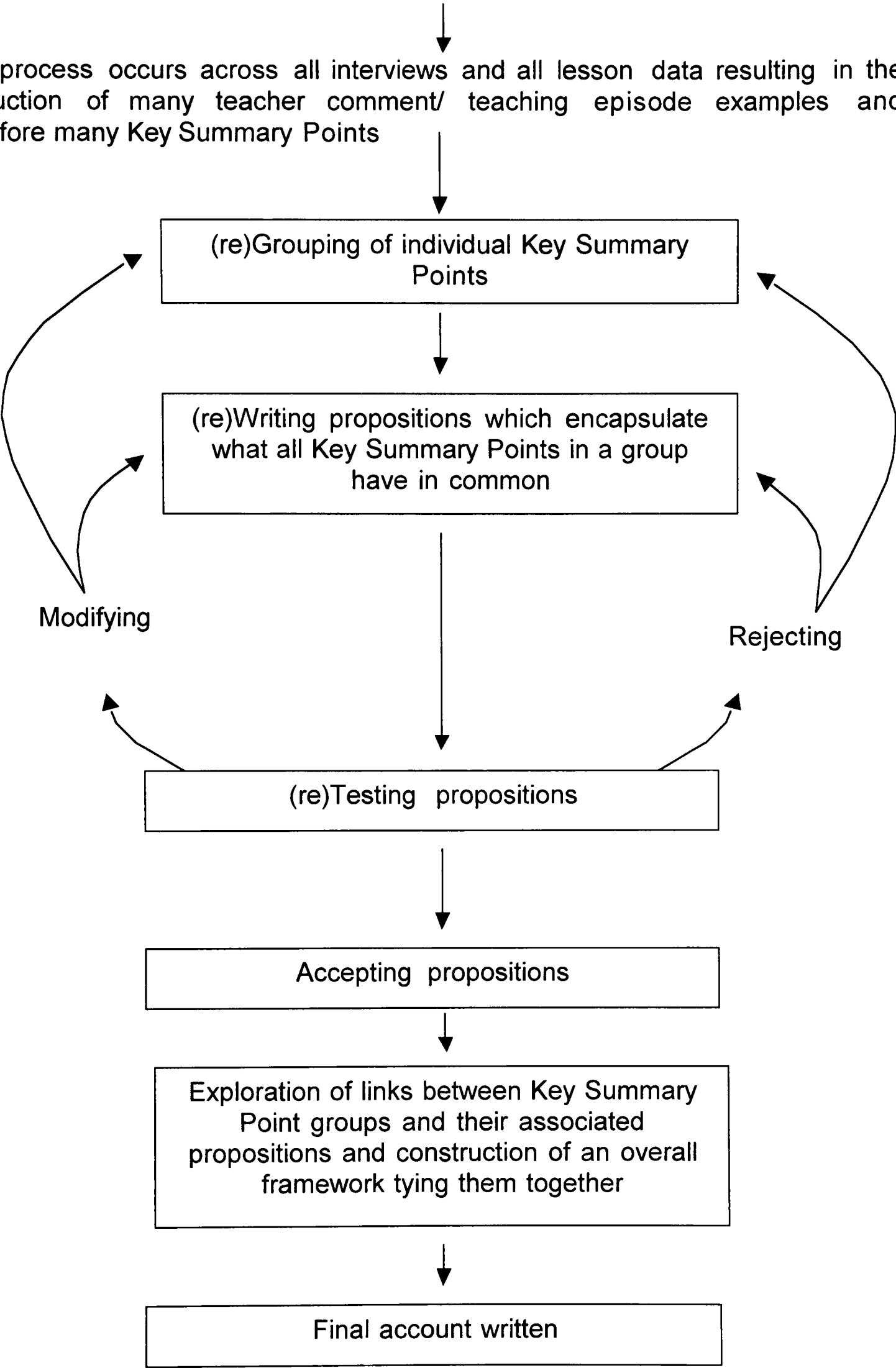
Cross-case analysis

Cross-case analysis took place in five major steps. The whole process, including initial data processing, is summarised in figure 4.1.

Figure 4.1 A summary of the analytical procedures.



This process occurs across all interviews and all lesson data resulting in the production of many teacher comment/ teaching episode examples and therefore many Key Summary Points



Analytical step 1: Finding a way in

By the end of the data collection period a large amount of data had been accumulated. As outlined earlier, the data was of two distinct types:

- rich pictures of practice comprising lesson tapes and transcripts, lesson observation notes and curriculum materials such as handouts and worksheets;
- reflections on practice comprising post-lesson and vignette interview tapes and transcripts¹.

As a researcher, my task was to make sense of this data in order to provide an understanding of what the three teachers believed their successful teaching of biology at A level comprised. In order to do this, I realised that I needed to find a way into the data that would provide me with a fruitful point of departure. In essence this meant deciding which data set would provide the starting point for analysis. Given the main purpose of this thesis – to make sense of teachers' own understanding of their successful teaching of biology at A level – the decision was made to begin analysis using the data comprising teachers' reflections on their practice. The teachers' reflections on their practice would then be used to navigate through the rich pictures of their practice obtained from the audio recording of lessons, lesson observations and the collection of curriculum materials used in lessons.

¹ Given that during data collection it appeared that despite differences between the details of the 'long', 'short' and vignette interviews the data collected remained consistent across all three types of interview, data from all interviews was treated in the same way during analysis.

In this way the teachers' practice would not be interpreted without recourse to their thinking about their practice – their lessons would, as much as possible, be analysed having referred first to their comments about them. It was felt that, by approaching analysis in this way there would be a greater chance of using the teachers' perspective of their successful teaching to shape the interpretation produced.

Analytical step 2: Identifying successful teaching episodes from the lesson transcripts using teacher interview data and matching these episodes to relevant teacher comments

Employing the teachers' reflections on their practice – that is the teacher interviews – as a starting point for analysis involved re-reading through each interview several times and using the teachers' comments in the interviews to identify the parts of their lessons that they considered examples of their successful teaching of biology at A level. In light of the project's focus on making sense of the teaching of biological subject matter, in order to be considered relevant, the comments had to refer to a particular subject matter event² that happened in an observed lesson. Furthermore, the comments about the subject matter event had to be specific so that the appropriate part of the lesson could be identified and located in the transcript (see Box A overleaf for examples of comments considered to be relevant to this analysis and irrelevant to this analysis).

² A subject matter event was taken to mean any classroom happening, however big or small, that was concerned with the teaching and learning of biological subject matter. It could, for example, refer to a single question asked by a teacher or student in a lesson and any discussion that followed, or an activity initiated by the teacher, such as note taking or research and presentation, that dominated a large part of the lesson.

Box A*Relevant teacher comment*

In post-lesson interview 5, Catherine commented on a particular subject matter event in lesson 5 as successful – ‘... the first thing is the bit about the recap ...’ (plint 5 C 64-65). This subject matter event comprised a question and answer session revisiting biological content knowledge that Catherine had introduced to her students earlier on in the lesson. This comment was considered relevant to the analysis as it specified a subject matter event concerning the teaching and learning of the Link Reaction and the Krebs Cycle that could be identified in the transcription of lesson 5.

Irrelevant teacher comment

In post-lesson interview 3, John commented that sending a student to the school office to get some acetates was a successful aspect of lesson 3. In his words:

Ethan, the chap I sent away to get the acetate, that was a success ... He's an interesting personality and character who would have got a lot out of that, believe it or not, in terms of recognition and achievement which he doesn't get in many other aspects of his life.

(plint 3 J 86-92)

Although John's comments in the above quotation describe an event that can be identified from the transcript of lesson 3 they do not refer to a subject matter event – the comments are not directly related to the teaching and learning of biology and therefore were not considered relevant to this analysis.

The end point of this process resulted in the crude production of a series of lesson episodes, called teaching episodes, with their corresponding teacher commentaries (see Appendix G for examples). Accompanying lesson observation notes and curriculum materials used during the teaching episodes were collected together with each teacher comment/teaching episode example. In this way, the analysis was able to combine and integrate the two data sets.

Analytical step 3: Identifying key summary points of the teacher comment/teaching episode examples

Having identified various subject matter rich teaching episodes and their associated teacher comments, the next step was to analyse these in detail. For each teacher comment/teaching episode example the teacher's actions in the teaching episode were reviewed and, in conjunction with their interview comments, lesson observation notes and curriculum materials, key summary points that attempted to encapsulate the essence of the example were established (see Box B overleaf for examples). Evidence to support the key summary points (for example, from one or more sources including interview data, lesson observation notes, curriculum materials and lesson data) was always given below the key summary point itself. In this way it could be seen that the developing analysis remained grounded in the data.

Box B

Arteries, veins and capillaries teacher comment/teaching episode example (lesson 3, John) – see Appendix G

Key summary point 1

For John, 'getting to grips with vessels' - acquiring knowledge of them- means knowing 'points' about them.

Evidence

In the post-lesson interview following this lesson John feels happy with what his students 'learnt' during the lesson and is confident enough to say that he feels his students 'would know the difference between an artery and a vein and a capillary and they'd be able to give you some *points* about them' (plint 3 J 94-122). Furthermore, in the lesson learning about blood vessels involved making '*points*' about them. The '*points*' were made in conversation and discussion between John and his students and then were written as bullet points on an OHT³ which the students copied into their notebooks (see Appendix H, p. 412-413)

Key summary point 2

For John, these 'points' might comprise knowing a vessel's structure or function, or being able to compare vessels.

Evidence

This is evident in the lesson as the structure and function of the vessels comprise some of the '*points*' that are made about them. For example, for arteries, 'Transports blood away from the heart' (te/tc J 9-10⁴) comprises the function of an artery identified by John and written on the OHT for students to copy down. Other points in addition to structural and functional ones seem to include various properties of the vessels (e.g. arteries carry blood that 'flows fast' and 'is under high pressure') and their location (e.g. capillaries 'link arteries to veins'). For a full list of the 'points' made during this lesson episode, see the notes taken from the OHT during lesson 3 – Appendix H, p. 412-413.

³ OHT is an abbreviation for overhead transparency which is used in conjunction with an overhead projector. It is a common classroom teaching aid.

⁴ This abbreviation refers to the numbered lines from the teaching episode/teacher comment example – see Appendix G – from where this, and other quotations in this section, were taken.

Box B continuedKey summary point 3

For John, learning about vessels involves remembering information. It also involves some sort of reasoning ability which entails tying ideas together.

Evidence*Remembering information:*

This is evident when John indicates in the interview immediately after the lesson that remembering is important because he states that you need to do more than 'just remembering' (plint 3 J 124-145). If you need to do more than 'just remembering' clearly 'remembering' is also important.

Reasoning:

This is evident in the interview following the lesson when John argues that there is a need to not 'just remembering parrot fashion' (plint 3 J 124-145) but in addition, 'reasoning behind things' (plint 3 J 124-145) which seems to involve linking ideas together. In the example given in this lesson 'reasoning behind things' seems to involve explaining why it is that veins have structures called valves. Other examples of 'reasoning behind things' in the te/tc example include:

Arteries – blood is under high pressure – Why? How?

Veins – blood is under low pressure – Why?

Box B continued

The Krebs Cycle teacher comment/ teaching episode example (lesson 3, Catherine) – see Appendix G

Key summary point 1

Catherine identifies, for her students, various pieces of information about the Krebs Cycle that she deems they need to know (e.g. what it is – ‘Now it is a cycle so things are going to go round and round and round.’ te/tc C 19-21).

Evidence

This is evident in the lesson as she establishes various information about the Krebs Cycle such as where it takes place (‘takes place in the mitochondrial matrix’ te/tc C 2-3) and what it involves (‘I want to show you that the carbon, where the carbon is being lost and therefore the number of carbon atoms is reducing’ te/tc C 55-58) and also asks the students to summarise this information for their homework (‘now what I’d like you to do tonight is to summarise the Krebs Cycle’ te/tc C 164-165).

Key summary point 2

Catherine describes the information as ‘the main points’, ‘the important bits’ her students need to know about the Krebs Cycle.

Evidence

In post-lesson interview 3, Catherine speaks of this teaching episode as successful because during it she was able to identify ‘the main points’ (te/tc C 3-4), ‘the important bits’ (te/tc C 4), ‘the important parts of the Krebs Cycle’ (te/tc C 24) she feels her students need to know (‘That’s what they need to know for this, you know, for A level’ te/tc C 5-6).

Box B continued

Key summary point 3

Catherine appears to want her students to be able to recognise and use an alternative term for the Krebs Cycle.

Evidence

This was evident in her comment in the lesson 'you ought to know it's also called the Tricarboxylic Acid Cycle' (te/tc C 16-18) and her reflections in the post-lesson interview following 'good biology teaching ... using the terminology Tricarboxylic Acid Cycle' (plint 3 C 44-49).

Key summary point 4

Catherine appears to want her students to be able to recognise a diagram of the Krebs Cycle and be able to reproduce a diagram of the Krebs Cycle themselves.

Evidence

This was evident as Catherine provided her students with two opportunities to view a representation of the Krebs Cycle – a handout which comprised a photocopy of the Krebs Cycle from another textbook (see Appendix I, p. 444) and a simplified version of the Krebs Cycle on an OHT (see Appendix I, p. 443) created by Catherine. The students also copied the diagram of the Krebs Cycle on the OHT into their notes.

Key summary point 5

Catherine staged the introduction of the Krebs Cycle to her students so they would not be overwhelmed and/or confused by the information given.

Evidence

This was evident in the post-lesson interview when she explained how she labelled the compounds after establishing the 'Important features of Krebs Cycle I thought in terms of biology' (plint 3 C 200-249).

Box B continued

Digestion teacher comment/teaching episode example (lesson 3, Sally) - see Appendix G

Key summary point 1

Sally identifies the nature of the information she seeks her students to include in their posters about various parts of the mammalian digestive system.

Evidence

This is evident as she establishes various areas of information she wants them to incorporate including information about the structure of the part ('the structure' te/tc S 2), its function ('We need to look at what each of the parts of the digestive system does.' te/tc S 3-5), any digestive juices it produces ('What the digestive juices produced are.' te/tc S 7-8 'Juices and any contents of juices.' te/tc S 97), the stimuli for releasing these juices ('Whether the juices are produced by nerves or by hormones or both.' te/tc S 8-10), the function of these juices ('What the action of the digestive juices is' te/tc S 10-11).

Key summary point 2

Sally describes the 'information' as 'points' her students need to know about various parts of the digestive system.

Evidence

This is evident in the lesson when she tells her students that she wants them to produce information posters where the information comprises 'bullet point things' (te/tc S 14-15) 'bullet point pieces of fact' (te/tc S 108-109). Furthermore, in the post-lesson interview following this lesson she talks about assisting her students in 'picking out the *points* that they need' (plint 3 and 4 S 15-45 my emphasis), 'the relevant, the pertinent points' (plint 3 and 4 S 143-166), helping them to 'highlight the important *points*.' (plint 3 and 4 S 15-45 my emphasis).

Key summary point 3

Sally also describes the 'information' as diagrams.

Evidence

She also mentions that she wants her students to incorporate 'diagrams, where necessary' and specifies one occasion where diagrams are necessary - 'Villi. A diagram has to be done here.' (te/tc S 75-77).

Box B continuedKey summary point 4

For Sally, parts seem to be made up of 'points'.

Evidence

This is evident because Sally makes clear that to produce an information poster on a part of the digestive system (e.g. oesophagus, stomach etc.) requires establishing various 'points'.

Key summary point 5

For Sally, in addition to 'points' parts also on occasion seem to be made up of 'diagrams'.

Evidence

This is evident because Sally makes clear that to produce an information poster on a part of the digestive system requires, on occasion, diagrams too ('do sort of a bullet point things and diagrams, where necessary' te/tc S 14-16).

Key summary point 6

Sally identifies, for individual students, various specific pieces of information - 'points', 'diagrams' she wants them to include in their information poster on their particular part of the digestive system.

Evidence

Conversation with Eleanor about her poster on the mouth ('... the mouth ... obviously we talk about amylase, saliva with amylase in it.' te/tc S 43-46). Conversation with Owen about his poster on the oesophagus ('... oesophagus which will include obviously peristalsis ...' te/tc S 48-49). Conversation with student about villi ('A diagram has to be done here. ... Can you mention the hepatic portal vein because the hepatic portal vein is the vein that takes the end products of digestion from the intestines to the liver. te/tc S 76-83)

Box B continuedKey summary point 7

Sally considers the research and written presentation task to be a good way to cultivate her students' study skills - in this example, the development of note taking skills - by, for example, encouraging them to engage in questioning the text as they read it and encouraging them to use multiple sources.

Evidence*Questioning techniques:*

In the post-lesson interview following this lesson Sally talked about how she wanted to encourage her students to ask themselves questions when engaged in such an activity. For example, when they read textbook passages she wanted them to ask questions of the passages to help them extract and make sense of information relevant to the task. These questions included, for example: 'well does this actually answer what I'm supposed to be doing. Is it relevant?' (plint 3 and 4 S 143-166)

Using multiple sources:

In the post-lesson interview following this lesson Sally talked about how she wanted to encourage her students to use multiple sources when taking biological notes. In this activity the sources she wanted her students to use included several textbooks and also their syllabus. Using multiple sources she felt would help them to make more sense of the biological material they came across during the activity. An example from the interview transcript:

'The other thing I thought which was good out of what I'd asked them to do was-, because they couldn't find all the information in one textbook, or one textbook wasn't good enough to use because different textbooks do different things better than others, so they couldn't necessarily find a diagram they understood in one textbook and good enough notes and sort of vice versa, so I mean I do all my notes from a variety of textbooks and I think they should realise that and they should do the same. So they were able to do that. And it also meant because we were in here, if they couldn't find something I could say 'well let's look in the textbook' so we had a variety out.' (plint 3 and 4 S 15-45)

Analytical step 4: Grouping key summary points and writing propositions

As a result of engaging in analytical step 3, striking similarities between the key summary points of different teacher comment/teaching episode examples were observed. To start with, analytical step 4 began by loosely grouping these key summary points based on intuitive feelings that some showed noticeable similarities and others, distinct differences. Having completed this initial grouping an attempt was made to make clear why the key summary points had been grouped in this way. Given this project's desire to make cross case claims, only key summary point groups that contained material from all three teachers underwent this stage of the analysis. Making explicit why the key summary points had been grouped in the ways they had involved writing one or more propositions which encapsulated what all the key summary points in one group had in common. Each initial group contained a number of key summary points and so to begin with a small sample of these – one from each teacher – was used as a basis for the initial writing of propositions for each group. These propositions were statements designed to reflect the essence of, and be inclusive of, all the key summary points they applied to. Drawn up by myself, they were derived from and supported by the data. The following statement provides an example of a proposition:

- Knowing biological ideas for success at A level means knowing information in the form of 'points' about them.

Once written, a proposition was then tested. This involved assessing the extent to which it represented all the key summary points in the group. In order to achieve this, all the key summary points from the relevant group were reviewed and in light of this review, the following questions were posed:

- Does this proposition reflect the essence of all the key summary points in the group?
- Do any key summary points in the group contradict or refute this proposition?

If the proposition did reflect the essence of all the key summary points in the group it was accepted (see Box C). If any key summary point(s) in the group was found to contradict or refute the proposition, the proposition was either modified in some way in order to more genuinely reflect the complexity of the data (see Box D), or rejected (see Box E). Throughout the process of testing propositions, in addition to reviewing the key summary points from the relevant group, the entire data sets were scanned repeatedly for further data that might support, contradict or refute the propositions developed. In this way, data that might have been missed in earlier stages of analysis could be incorporated and used to shape the developing interpretation.

Box CAn example of a proposition that was accepted*Proposition:*

Knowing biological ideas for success at A level means knowing information in the form of 'points' about them

This proposition was taken to be representative of, and inclusive of, all the examples in one group and not contradicted or refuted by any other data and so was accepted. Key summary points from the teacher comment/teaching episode examples in Box B are amongst the supporting evidence for this proposition (e.g. key summary point 2 for Catherine, key summary point 1 for John and key summary point 2 for Sally).

Box DAn example of a proposition that was modified in order to genuinely reflect the complexity of the data

An early proposition attempting to encapsulate the way in which the teachers wanted their students to know 'points' for success at A level comprised the following:

One way of knowing information in the form of 'points' involves constructing an explanation of why something in the point is the case. For example, why a vein (something) has a valve in John's lesson 3 example.

Whilst, at the time, this proposition made some sense in relation to John's example, it did not adequately reflect the variety of examples within the key summary point group. Consequently, after much consideration, and a number of different revisions, the proposition was modified to produce a more abstract slant which was felt to reflect all the examples in the key summary point group. The proposition became:

One way of knowing information in the form of 'points' involves being able to consider the 'why' and/or 'how' of a particular 'point' in its wider biological context.

Box EAn example of a proposition that was rejected*Proposition:*

On occasions the teachers encouraged their students to explore content with little input from them.

This proposition was rejected outright when tested against all the examples in the group. As a deeper understanding of the data emerged it was felt that the initial understanding of the key summary points from which this proposition was developed was naïve and unsophisticated and did not represent the teachers' perspectives.

This process of grouping examples and then writing propositions to encapsulate the essence of those examples was fluid and flexible. As propositions were accepted, modified and rejected so the groupings underwent numerous revisions (see figure 4.1 on pp. 138-139 for an illustration of this process).

Analytical step 5: Developing a coherent framework

The completion of analytical step 4 resulted in the production of a series of groups of key summary points headed by written propositions encapsulating what all the key summary points in a particular group had in common. Having produced these groups and their associated propositions, there was a need to find an overall coherence to them. The purpose of analytical step 5 was to explore any links between the propositions and to see whether they fitted together into one or more frameworks. This was achieved by asking the following questions of all the propositions:

- Can any of these propositions be 'linked together'?
- If so, in what way(s)? What is the nature of these links? (e.g. what is the nature of the relationship?)

Asking and answering these questions encouraged the recognition of relationships between the different propositions and the construction of an overall framework tying all the propositions and their corresponding evidence together. Similar to analytical step 4, this was a fluid and flexible process. Numerous attempts were made to construct a framework that encompassed all the different propositions and after many revisions a suitable framework emerged which formed the basis for the development of the final written account.

The role of contextual information in the analytical process

Further to the two data sets described in the five analytical steps, contextual information about the teachers and their units-of-work collected during the preparatory phase helped to enrich the data generated and inform the analysis throughout. For instance, the unit-of-work interviews provided a useful source of information during the analysis of the lesson data and teacher interview data. As teacher comment/teaching episode examples were produced, each teacher's unit-of-work interview was re-read to see if any information in it might help to shape the developing understanding of the data or resonate with the developing understanding thereby providing further support and giving confidence to the evolving interpretation.

Furthermore, during the analytical process, when trying to make sense of the data in order to write key summary points and propositions, the contextual information was revisited to see if it provided any clues that might help the development and/or elaboration of the key summary points and propositions.

Finally, the teachers' discussions of their main aims as successful A level biology teachers in their exploratory interviews helped to inform the analysis by providing the backdrop to the production of the overall analytical interpretation of the data. All three teachers' main aim as successful A level biology practitioners was to encourage their students to achieve their full potential in their A level exams. Moreover, all three teachers argued that achieving such success would mean their students would need to acquire a considerably large body of biological knowledge. In light of this, the analytical interpretation presented in chapter six considers the ways in which the teachers conceptualised the biological knowledge they believed necessary to know for success at A level and how they represented it to their students. Furthermore, it considers the pedagogical strategies the teachers used in the classroom to bring about the development of these conceptualisations in their students.

Developing the written account

The final account reported represents my accumulative theoretical understanding of what successful teaching of biology at A level, for the three teachers in this study, comprises. In the same way that the data was analysed (i.e. cross-case) the written account was also formulated like this. The written propositions produced in analytical step 4 and the framework produced in analytical step 5 provided the starting point for the development of the final account. This involved a process of continual re-presentation of ideas in different written formats until an acceptable version emerged. Furthermore, it included on several occasions re-reading through the entire data and, in light of this, making any amendments deemed necessary.

Plausibility, credibility and trustworthiness in the final account

In this study, I have not sought to present the ultimate Truth in relation to these three teachers' characterisations of their successful teaching of biology at A level. Indeed, I do not believe that this is a viable pathway to pursue. Instead, I believe that the purpose of research is to 'identify critical elements and wring plausible interpretations from them' (Wolcott 1994, p. 366).

To this end, in this study I have sought to offer an interpretation of three teachers' characterisations of their successful teaching of biology at A level, one that has been grounded in the data generated and one that I hope is plausible and trustworthy. A variety of measures have been employed to help ensure the plausibility, credibility and trustworthiness of the account presented. These will be discussed next.

Describing the analytical process in detail

Miles and Huberman (1994) argue that one way of 'judging the goodness of conclusions' of a qualitative study is:

Describing our procedures clearly enough so that others can understand them, reconstruct them and subject them to scrutiny.

(p. 281)

In this study, the analytical process from which the interpretation presented has been reached and substantiated has been explicated in detail and is therefore open to scrutiny. Consequently, the reader is able to make his or her own

judgements as to the adequacy of proof and degree of confidence to be assigned the interpretation presented.

Approach to analysis

My approach to analysis was self critical and reflexive in order that I could keep an open mind and therefore not jump to conclusions too quickly. In the development of propositions, for example, I tried not to be persuaded by what, at first hand, seemed compelling evidence in support of a proposition until I had deliberately searched for contradictory or 'negative evidence' (Miles and Huberman 1994) and found none.

Including primary data in the final account

The final account presented in chapter six includes excerpts of primary data. Whilst this gives readers an idea of what the data is like it also helps to ensure the plausibility, credibility and trustworthiness of the account presented. By giving the reader access to primary data alongside the interpretation of the data offered, the reader is given the opportunity to judge the plausibility, credibility and trustworthiness of the interpretation presented.

Final account writing/checking process

Several times during the process of developing the final written account I read entirely through the data and contextual information generated. The purpose of this was to assess 'the extent to which the account I have created squares with the setting and individuals on which it is based' (Wolcott 1994, p. 354). Was I satisfied with the account produced? Did it adequately reflect the data generated by these three teachers? During this writing/checking process, revisions were made.

Respondent validation

Although I considered respondent validation a useful strategy to assess the plausibility, credibility and trustworthiness of the interpretation provided it was not practically possible in this study. Unfortunately the time consuming nature of the analytical procedure meant that within the time frame available it was not practicable to undertake respondent validation. However, it is worth mentioning that, to a certain extent, an element of respondent validation was built in to the interviews with the teachers during data collection. As described in chapter three, occasionally in 'short' and 'long post-lesson interviews' and vignette interviews in an attempt to check my developing understanding of a particular point a teacher was making, I fed back to the teacher what I thought s/he had been saying. In a small way this provided a check on my understanding of the teachers' lesson reflections and therefore contributed to the development of a plausible and credible account of their successful teaching of biology at A level.

Using multiple data sources

The use of different data sources such as non-participant observation, curriculum materials and interviews as well as pre-study contextual information not only helped to develop a rich picture of the teachers' characterisations of their teaching of biology at A level but also gave an element of trustworthiness to the conclusions drawn. For instance, if the teachers had discussed an aspect of their successful teaching of biology in the post-lesson or vignette interviews which had also been observed and, in addition, comments from the contextual information collected prior to the project also tied in with their discussion, this corroboration would give further weight to the interpretation offered.

Summary

This chapter has set out the ways in which the data of this study was analysed by giving an account of the principles that underpinned the analytical procedures and the analytical procedures themselves. Furthermore, it has described and discussed how the final account was written and the measures that were employed to help ensure the plausibility, credibility and trustworthiness of this final account.

Chapter Five

The Three Teachers and Their Contexts

Introduction

The aim of this chapter is to provide rich, descriptive accounts of the three case study settings by presenting details concerning the three teachers, their respective students, the schools in which they worked and the units-of-work they taught during the research period. The purpose of this is to encourage the reader to appreciate the contexts in which the three teachers worked and the factors they took account of in order to teach biology successfully at A level.

Furthermore, it is felt that presenting an overview of each teacher's unit-of-work will assist readers in making sense of the interpretations of the three teachers' successful teaching of biology at A level put forward in chapter six and, in addition, provide plausibility and credibility to the interpretations offered.

This chapter is written in three sections pertaining to each of the three case study settings. Each of these is subdivided further into two sub-sections. The first provides details about the teacher, their students, and the school and the second, provides details about the unit-of-work taught during the research period.

Case Study One

John

John followed what he described as 'a pretty wayward path' into teaching. He took A levels in biology, chemistry and physics with the original intention of studying medicine at university. He had always been interested in medicine and related disciplines. His mother was a dental nurse and he had often accompanied her, during school holidays, to the hospital where she worked. At the hospital he had always been 'fascinated by watching doctors and dentists'. Whilst in the sixth form he had become involved both in voluntary work at the hospital in Canterbury where he lived and also an old people's home. Consequently, a career in medicine had always been something he had wanted to pursue; however, he mentioned that getting the A level grades required to fulfil this ambition was 'a long shot' as he had 'never been a high flyer at A level'. He was not surprised, therefore, when he did not achieve his target grades and decided that, rather than re-sitting the examinations, he would find a place on another course through clearing. In addition to medicine he had always been interested in Marine Biology and got a place on a course of this nature at Cooke University. He really enjoyed the course having a 'fantastic three years'. During his time at Cooke he developed another interest, agriculture, which also had its origins in his schooldays. When he left Cooke he was offered and took up a summer job on a farm. He enjoyed this and consequently spent a year travelling abroad working on various dairy farms. He was never really confident, however, that farming would provide him with a career,

mainly because there was no farm in his family, and so before travelling he had got himself a place on a primary PGCE¹ course at Woodford University. Like medicine, education was also a vocational area in which John had always displayed a keen interest. His father had worked in education all his life and his contentment with his job was, in John's eyes, 'no doubt a great influence on [him]'. His choice of a primary PGCE resulted, as he mentioned, from being, at the time, 'scared of teenagers' not being much older than them himself. Having returned from his travels abroad he went down to Woodford to take up his primary PGCE place and 'just got cold feet at the eleventh hour'. Consequently, he resigned his place from the course and instead looked again at a career in farming. He took up a place at Gainbridge Agricultural College, Northwich studying a Post Graduate Diploma in Farm Management. From there he got a job as an assistant manager on a farm near Fronnerton, Dundasshire. Things did not go to plan, however, so he pulled out and became stock manager at Eastergate, Dundasshire. He worked there for four years, the next logical step being to move on and manage his own place. During his years in the farming business, however, he had married and was considering starting a family. He felt that farming was too stressful, did not provide the security he felt his family would need and also was not the sociable occupation he required in a job. As a result he made a career move and enrolled on a secondary PGCE course at OUDES². He chose secondary this time because,

¹ The Post Graduate Certificate in Education (PGCE) is a course for the professional development of beginning teachers.

² OUDES stands for the Oxford University Department of Educational Studies where John trained as a teacher.

being that much older he felt he would cope better with teenagers and he was delighted that he made that choice as he feels he gets 'so much out of teaching older kids'. He had 'a fantastic year' during his PGCE, 'like [he'd] never had before' and he felt that 'finally without a doubt [he had] found [his] vocation and [his] niche'. He described himself as a 'people person' being much happier working with people as a team, something that was lacking in farming but that he definitely found in the teaching profession ('at school there's ... one of the strongest teams'). He also enjoyed working with children ('I don't think I've ever laughed so much in a job') and playing, what he considered to be, an important role in shaping their future.

John was beginning his fourth year of full-time teaching when the research project began. He was teaching in a Local Education Authority controlled religious 13-18 co-educational comprehensive (St. Matthew's) where he had been since he qualified. The school was located in an academic city in the midlands and had approximately 650 students on roll comprising Year 9 to Year 13. It employed some 40 teaching staff. Many of the students on roll were from deprived social groups and had difficult home backgrounds. John characterised the students at St. Matthew's as 'tough kids'. He described St. Matthew's as having a supportive and forgiving ethos. He felt it was almost a 'shelter for kids' free from their domestic hassles where they could be encouraged, listened to and respected.

At St. Matthew's, John was employed to teach all three sciences to Year 9 and, in addition to biology, some chemistry and physics to lower sets at KS4³. He only taught biology at A level. In addition to his responsibilities as a biology/science teacher, John was also Assistant Head of Year 9 and had recently been appointed as a professional tutor⁴.

John was part of a small Science Department comprising seven full-time members and one part-time member of staff as well as two full-time technicians and one part-time technician. He felt the Science Department formed a cohesive unit with good relationships between the three sciences. The Biology Department was made up of one part-time and two full-time members of staff (John and Heather the Head of Biology). He described this department as well set up and organised with a 'superb Head of Department' providing 'good leadership and discrete support'.

St Matthew's had a small sixth form of approximately 50-60 students. Biology was a thriving subject with approximately half of the students in the whole sixth form studying it as one of their A levels. John taught two thirds of the A level biology course whilst the Head of Biology taught a third. This was the way the A level

³ KS4 refers to the year groups of students preparing to take GCSE examinations. GCSE stands for the General Certificate of Secondary Education, a qualification normally taken at 16, at the end of compulsory schooling, in many different subjects. GCSE's are two year courses and are usually begun by students aged between 14 and 15.

⁴ This refers to a school based teacher educator with responsibility for the management of student teachers' overall learning in school.

biology timetable had been split historically between the two full-time biologists in the department. Consequently when John took up his post at St. Matthew's he was happy to take over the greater part of the A level teaching freeing the Head of Biology for other commitments.

John had taught A level biology ever since he had begun teaching at St. Matthew's. In addition, he had also taught an A level biology module on Biotechnology during his teacher-training year. He had taught the same board, Associated Examinations Board (AEB) for all three years changing from linear to modular after his first year. He felt this change would help the sorts of students that attended St. Matthew's in the sixth form. He commented that many of the students did not have particularly supportive home-lives ('I had a lot more support at home than they do ... a different world'). Most had little or no experience of a parent who had studied. As a result, their parents/guardians were not as understanding or supportive of the needs (e.g. a quiet place to study) of their children when studying at A level. Many of his students also had jobs outside school hours which reduced their valuable study time. John felt that the change from linear to modular would reduce the pressure on his students allowing them to take exams in stages ('the students are put under far less pressure [than] in one go at the end of Year 13'). He felt this might possibly help them to achieve their target grades. John liked the AEB modular biology

A level course⁵ believing that it provided students with a good grounding in the subject. He felt that the content of the syllabus was appropriate for the students.

During the research period John's A level teaching consisted of one Year 12 and one Year 13 group. The study originated with John in June/July 1997, continued until Oct/Nov 1998 and involved a group of Year 13 students (11 girls and 5 boys) at the beginning of the 1997/1998 academic year⁶. Before the research project began these sixteen students had been in two separate groups but, because of budget difficulties, the groups were amalgamated into one larger group in the 1997 summer term.

John described the group as an 'incredible bunch of people' who had a 'general enjoyment and interest in the subject'. In terms of ability, the group was, according to John, 'very mixed'. He mentioned that he had 'quite a few at the lower end' that 'just don't believe for a minute what it's going to involve to do the course' and at the other end of the spectrum he had some 'extremely good students' who would get 'straight A's without a doubt'. John also mentioned that students taking A level biology at St. Matthew's tended to study a mixture of subjects at A level and the group observed during this research project was no exception. Several students were studying all three sciences and/or maths at A level with a view to a career in

⁵ The Associated Examining Board, General Certificate of Education – Advanced Level Biology – Modular A98/03, 0601, 1998 syllabuses for Biology/Human Biology.

⁶ The students were Year 12 in the summer during the preparatory phase and became Year 13 in September for data collection.

medicine or a science based degree whilst, for others, biology formed the only science subject they were studying at A level. In these cases biology was accompanied by more arts based subjects such as modern languages or geography.

Throughout the data collection period the size of the group and its great mixture of ability was a source of concern for John. He was keen to ensure that he stretched the brighter students and yet also supported those students who were struggling. He was also eager to develop a classroom rapport conducive to effective A level study, something he worked hard at and was sensitive to in his lessons.

John looked forward to his A level biology teaching as he indicates in the following quotation:

it's a breath of fresh air when you think, o gosh you have Year 9 and 10's this morning and I've got the Year 12's this afternoon, it just gives you a nice feeling.
(Expl Int J 161-3)

It was clear that he got a lot of enjoyment from this part of his teaching despite the large amounts of 'preparation, marking [and] assessment to do'. He liked the fact that A level groups were smaller and that he did not have to 'worry about classroom management skills'. He also enjoyed being able to work with adults and build up a good rapport with his class.

John's main aim as a biology teacher was to make sure his students achieved their potential in terms of their examination grades. He mentioned that not all of his

students were A grade candidates and so he was keen for his students to simply 'strive for the best grades they can get'. As he commented, he got 'as much pleasure from someone who is not so able as an A grade candidate getting a D or an E'. Furthermore, he explained that biology is a content laden subject and that his students would need to have 'a lot of knowledge at their fingertips' if they were going to be successful in their examinations.

In addition to the main aim of his teaching, John was also keen for his students to enjoy the A level course. He loved being able to share his passion for biology with a group of interested students as he indicates in the following quotation:

I've got a real chance to share my enthusiasm ... for the subject
(Expl Int J 185)

Moreover, John also felt that he had a pastoral role as a teacher of biology at A level. In addition to helping students develop their knowledge and understanding of biology, he also felt the need to help prepare them for their future lives outside school.

The unit-of-work

The observed unit-of-work for John comprised part of the AEB modular A level biology course taught at St. Matthew's. The course itself was composed of four modules (The Organisation of Living Organisms; Inheritance, Evolution and Ecosystems; Supply and Demand in Living Organisms; Response to the Environment) comprising 80% of the total marks and a 20% teacher assessed practical component. At the time of the research project, John was teaching

module 3 – Supply and Demand in Living Organisms. This module comprised four different sections: Levels of Organisation; Digestion; Gas Exchange and Transport. Each of these sections was further split into numbered subsections. The observed unit-of-work covered three out of the five numbered subsections associated with the Transport section of module 3 including:

- 3.9 The blood system of a mammal transports metabolites between exchange surfaces.
- 3.10 The heart and circulation continually adapt to meet the varying demands of the body.
- 3.11 Humoral and cell-mediated immunity play critical parts in the body's response to antigens.

A full outline of the subject content comprising these three subsections is found in Appendix A. This was the third time that John had taught this unit-of-work. The observed unit-of-work was planned roughly to span six to eight double lessons over a period of three to four weeks. It extended, however, to ten double lessons over a period of five weeks as a result of illness and other commitments during the research period. The following section provides a description of the overall shape of the unit-of-work John taught during the research period. All the curriculum materials and copies of the notes taken throughout this unit-of-work are found in Appendix H.

Lesson 1

Lesson 1 began with John asking his students if any of them would be interested in dissecting a pig's heart in the following lesson. Various students expressed concern about the use of animals and animal parts for scientific purposes, and a number of discussions ensued and were revisited by both John and his students at different points in the lesson.

John's introduction to the topic of Blood and Circulation began with a question and answer session exploring students' knowledge of the role of a circulatory system. Their thoughts included reference to surface area/volume ratio, diffusion and respiration and were pooled into a class definition, provided by John, which they all noted down.

Following on from this exercise, John encouraged his students to identify the major components of a circulatory system – that is, a pump, some vessels and a fluid. He then introduced them to the two types of circulatory system - single and double - and discussed the structures and functions of both. With John's guidance, the students made notes about each system as a series of bullet points. The notes incorporated information concerning where the systems are found, what they involve, various properties of them, and the advantages of a double circulation in comparison to a single circulation. The students also copied a diagram of a single circulatory system from their textbook and were given a handout which included a diagram of a double circulatory system.

The next task involved the students completing a worksheet on the mammalian circulatory system which comprised naming various blood vessels and colouring, on a diagram of the mammalian circulatory system, the arteries in red and the veins in blue. In addition, the worksheet also required the students to identify various aspects of the different blood vessels such as which vessel carries blood at the highest pressure and which vessel carries the most glucose after a meal. The students completed this task individually with support from John as he moved around the class interacting with individuals and small groups. Correct answers to the questions were provided through a whole class teacher-led question and answer session when the students had completed the exercise.

The lesson ended with John asking his students questions about the structure and function of various parts of the heart whilst they examined a generalised diagram of a mammalian heart from their textbook. For homework, the students were asked to copy this diagram into their notes and familiarise themselves with it before lesson 2.

Lesson 2

The Head of Biology (Heather) began lesson 2 by dissecting the heart of an ox for all the students to observe. During this dissection, both Heather and John engaged their students in a question and answer session reviewing their knowledge of the structure and function of the various parts of the heart covered in the previous lesson. This involved recalling information connected with the structure and function of different parts of the heart (e.g. atrium, ventricle, tendinous

cords). Instructions were also given to the students about how to do their own dissection.

The rest of the lesson was taken up with each student dissecting a pig's heart and labelling its constituent parts. John and Heather assisted the students individually with their dissection and identification. For instance, they helped the students to identify the right and left hand sides of the heart as well as suggesting the most appropriate places to cut the heart in order to open it up to observe its internal structure. Individual discussions with the students involved John and Heather commenting on the structure and function of various parts of the heart (e.g. what the parts look like, what they are made up of, what role they play in the overall function of the heart).

Lesson 3

A teacher-led discussion, note taking, and drawing activity concerning blood vessels – that is arteries, veins and capillaries – was the first activity of lesson 3. Through a whole class discussion activity, John guided his students to identify and note down, as a series of bullet points, information about each blood vessel including a description of its structure and function. The students also drew labelled cross sectional diagrams of each blood vessel to accompany their notes from their textbooks.

The next activity was a comprehension exercise. The students read a passage from their textbook - entitled "The Capillaries" – and answered the following questions:

- What is the relevance of pavement endothelium to a capillary?
- What is the relevance of the sphincter muscles to a capillary network?
- What is the relevance of shunt vessels to a capillary network?

During this task John discussed the textbook passage and the accompanying questions with individuals and small groups. Answers to the questions, involving descriptions of each of the structures (i.e. pavement endothelium, sphincter muscles and shunt vessels) and accounts of their role in mammalian circulation, were provided through a whole class question and answer session at the end of the activity.

The final lesson task began with John further discussing a capillary network with his students. He used an OHT of this structure to illustrate its various parts, such as arterioles, venules, sphincter muscles, shunt vessels and tissue fluid. Identification of the last part, tissue fluid, led to the sharing of students' personal experiences of tissue fluid as a result of skin cuts and grazes. Using the information on the OHT John described how tissue fluid is formed from the blood and how it is reabsorbed back into the blood. Following this, he gave his students a worksheet concerning the formation and fate of tissue fluid and spent a few minutes giving them clues to assist them in answering the questions. The students were then asked to complete the questions for their homework. 'Describe the structure of the surrounding layer of a capillary' provides an example of the sort of question asked on this worksheet.

Lesson 4

Lesson 4 began with a question and answer session reviewing information (i.e. properties, structure, function, location) regarding blood vessels and capillary networks. John continued by going through the students' homework on the formation and fate of tissue fluid set in lesson 3. In turn, each student was asked and answered one of the questions on the sheet. These answers were elaborated upon and discussed by John and the students.

Having accomplished this, John asked his students whether, in lesson 3, they had drawn a diagram of a capillary network to add to their notes. When he found that they had not, the second task of the lesson became the drawing and labelling of a simplified diagram of this structure from their textbook.

The third task comprised a research and presentation exercise. John identified the following research topics:

1. Haemoglobin structure and the carriage of oxygen.
2. Oxygen dissociation curve.
3. Other pigments.

The students were split into three groups and each group was allocated one topic to investigate and present to the class at the end of the lesson. John spent time with each group of students during the lesson helping them to identify what

information to include in their presentations. The last part of the lesson involved the groups presenting their respective topics to John and their peers.

Lesson 5

A test on Digestion, the previous topic the students had studied prior to the observed unit-of-work on Blood and Circulation, began lesson 5. As this topic area was not the focus of this research project it will not be discussed here.

The second part of the lesson comprised a talk about the immunological aspects of blood from one of the laboratory technicians (Bob) who had spent much of his career working for the blood transfusion service. Bob demonstrated agglutination, using human blood, and talked about the role of antigens and antibodies in this process. Both John and his students asked Bob questions after the talk.

Lesson 6

The first task of lesson 6 was a question and answer session reviewing knowledge about haemoglobin and the oxygen dissociation curve that the students could recall from their presentations in lesson 4. This task provided the basis for the next activity in which John guided his students in taking notes about the structure and function of haemoglobin and the oxygen dissociation curve.

The third task involved the students attempting some questions on the oxygen dissociation curve and Bohr effect. During this activity John engaged his students in one-to-one and small group discussions about the questions. As a whole

class, John and his students went through the answers to the questions set and, in addition, completed a past examination question together.

At the end of the lesson, John set his students an essay for homework with the following title:

‘The role of haemoglobin and hydrogen carbonate ions in the carriage of respiratory gases and the control of pH.’

Lesson 7

John was disappointed with his students’ digestion test results from lesson 5 and so lesson 7 began with a discussion about this test. The first activity of the lesson involved a question and answer session reviewing students’ knowledge of the oxygen dissociation curve and Bohr effect.

The next task comprised a teacher-led discussion and note-taking exercise concerning the function of the heart; how it pumps blood around the body. John identified the contraction (systole) and relaxation (diastole) phases of a heartbeat and then discussed the passage of blood through the heart. His students completed two flow diagrams illustrating the movements of heart valves on both the left and right hand side of the heart during a cardiac cycle. As the students were completing this activity, John discussed heart sounds with small groups of them. During these discussions an issue arose concerning the ethics of animal to human heart valve transplantation. John encouraged his students to express their views before reviewing, as a whole class, the students’ heart valve flow diagrams

and their understanding of heart sounds. A brief discussion about fitness during this review led John to instruct his students to put one arm above their heads and open and close the hand attached to that arm constantly for several minutes. The arm exercise resulted in cramp in the students' upper arms and John encouraged them to draw upon their knowledge of respiration and circulation in order to produce an explanation of the discomfort they were feeling.

The next task involved John discussing a diagram of the pressure and volume changes and associated valve movements during a cardiac cycle with his students. He identified each of the lines on the graph (e.g. ventricular pressure, atrial pressure) and discussed their shape in relation to the events of the cardiac cycle.

To finish off, as a whole class, John and his students went through a past paper examination question concerning pressure and volume changes and associated valve movements during a cardiac cycle.

In between lesson 7 and 8 the Head of Biology took another double lesson. This lesson focused on subject matter including the:

- myogenic stimulation of the heart and transmission of the wave of excitation;
- nervous and hormonal control of heart rate in relation to changing demands.

Although initially the plan was for John to take this lesson, unfortunately he was ill and so I was phoned and advised that the lesson had been cancelled. However, I was unaware that, in John's absence, the Head of Biology covered the lesson and so I was unable to observe it.

Lesson 8

Lesson 8 began with John going through the test on digestion. As this is not relevant to the unit-of-work observed during this research project it will not be discussed here. A teacher-led discussion and note-taking activity followed, the focus of which concerned examining the various mechanisms that humans have evolved to prevent the entry of microorganisms into their bodies. Various mechanisms, including the skin, blood clotting, mucus and lysozymes, were discussed and notes identifying certain information about these mechanisms, such as where they are found and what role they play in preventing the entry of microorganisms, were made.

The next task involved students working on a comprehension exercise concerning natural immunity. The students read a passage on phagocytosis and were asked to answer the following questions:

- State the function of neutrophils and macrophages.
- Why do skin infections swell and go red?
- What are the limitations?

Throughout this activity John interacted with individuals and small groups. The activity ended with a teacher-led discussion of the answers to the comprehension questions. John then introduced viruses into the conversation and this led to a discussion about the common cold, antibiotics and secondary infections.

The next activity involved a teacher-led note taking task concerning acquired immunity. The term 'acquired immunity' was defined and then various concepts such as antigen, antibody, B and T lymphocytes were discussed. Notes identifying information about these concepts, such as what they are and what they do, were taken.

The final activity of lesson 8 involved a whole class recap, through a question and answer session, of the subject matter knowledge learnt in the lesson. This included questions concerning the various mechanisms of preventing the entry of micro-organisms into the human body and the concepts associated with natural immunity such as lysozyme and phagocyte.

Lesson 9

The final lesson of John's unit-of-work began with a recap of the differences between natural and acquired immunity through a question and answer session. John then engaged his students in a discussion and note-taking activity concerning B and T cells adding further information to that identified in lesson 8. This information included a description of the different types of B and T cells and the roles they play in fighting infection. When this activity was complete, John talked to his class about an individual he knew who was unable to make his own

antibodies to fight infection. He then introduced the concept of monoclonal antibody. Using a handout, he described: what a monoclonal antibody is; how it is made; and the role it plays in modern medicine. At the end of this discussion, John emphasised that it was important that his students learnt about monoclonal antibodies as questions about this biological idea often come up in exams.

During the rest of the lesson John set his students two tasks to complete. The first task involved reading an article on organ transplantation and answering the questions that accompanied it. These questions focused, in particular, on the moral/ethical dimension of organ transplantation and sparked off many heated discussions amongst the students. The second task involved taking notes and answering questions about blood groups. Whilst the students were engaged in these activities, John and Heather discussed their individual reports. Every now and then, John moved around the class to talk to individuals and groups involving himself in their discussions.

Case Study Two

Catherine

Catherine was born in the West Indies. Unlike John, she knew from a very young age that she wanted to be a teacher. As far as she was concerned there was no question that she would do anything else as she indicates in the quotation below:

it was very easy for me. I always wanted to teach and here I am.

(Expl. Int 86-87 C)

At school she was particularly interested in science and maths and so studied maths, chemistry and zoology at A level. After taking her A levels she took a year out and worked as an assistant teacher in a local West Indian school as well as taking some adult evening classes before she took up her place to study Zoology at Ashhampstead University. She 'really enjoyed' this degree course and when she had finished she began a PGCE at OUDES. After completing her PGCE Catherine, who was only on a student visa, had to return home to the West Indies. Here, she took up the post of biology teacher at a boy's grammar school where she taught for three years. She was allowed a year's leave from the school in order to take up a Masters degree course in Education at OUDES and during this year she met her future husband. Having been awarded her Masters degree Catherine had to go back to the West Indies to return to her teaching post. Soon after this, however, she got engaged and in 1983 Catherine left the West Indies to come and live in England.

Catherine and her husband settled in the midlands. When she arrived in England she began by doing a term's supply teaching at a local school before she got a permanent job as a biology teacher at St. Matthew's. She stayed at St. Matthew's for ten and a half years. There, as well as teaching biology, she worked as a mentor⁷, a professional tutor and also for some time was acting Head of Biology. Catherine felt her work as a mentor had really helped her own development as a teacher. As a mentor she supported student teachers through their training year in school. The student teachers often asked many questions about what she was doing when teaching and why and Catherine believed this encouraged her to question her own teaching and become more reflective about what she did in the classroom. In particular she felt that mentoring helped her to be sure she was 'doing things for a reason'.

From St. Matthew's, Catherine was appointed as Head of Lower School at another Local Education Authority controlled co-educational 11-18 comprehensive: Culverhay School. It was at Culverhay that Catherine was teaching during this research project. She was beginning her fourth year of full-time teaching at Culverhay when the project began. In addition to being Head of Lower School, Catherine was also teaching science to Year 8 and biology to Year 9, KS4 and A level. Culverhay was located in a town on the outskirts of an academic city in the midlands and had approximately 1150 students on roll comprising Year 7 to Year 13. It employed 70 teaching staff.

⁷ This refers to a school based subject specialist working with student teachers.

The catchment area for Culverhay was very mixed. Catherine described it as being 'fully comprehensive' although 'slightly skewed by ability towards the bottom end'. She suggested this might result from the many independent schools in the city creaming off the high ability students. She also described the school as 'very white' with a multicultural element lacking. Catherine depicted Culverhay as having a very caring ethos. She felt the school went 'to great lengths pastorally' involving the families of students in school life and being very tolerant of students' problems.

Catherine described herself as being part of a large science department (ten full-time members of staff). She described the science department as being 'very talented' with 'good relations between the sciences'. She felt the overall department had 'strong leadership' and was very supportive, in particular with new staff. She described the Science Department as being noteworthy within the school for its strong ICT skills, record keeping and good target setting and monitoring. The Biology Department comprised three full-time biology specialists (including the Head of Department). Catherine described the department as being supportive with good relations between the teachers and an excellent technician.

Culverhay had a reasonably large (approximately 220 students) and growing sixth form which Catherine described as a 'tremendous strength of the school'. As well

as students who had been at Culverhay for KS3⁸ and KS4, students also came to Culverhay from other schools in the area specifically for the sixth form provision. Biology was a popular subject in the sixth form with, on average, about twenty-five students choosing to take the subject at A or AS level every year. This meant two new groups each year giving all three biologists the opportunity to teach either A level or AS level biology. The teaching of the groups was timetabled so that each group was shared between two of the three teachers.

At the time of the study Catherine had seventeen and a half years experience as an A level biology teacher. Although she had spent most of that time teaching the AEB linear biology course she also had experience teaching an Oxford⁹ A level biology syllabus as well as the biochemistry aspect of a Nuffield¹⁰ A level chemistry course. Catherine liked the AEB linear A level biology course. She felt the syllabus provided students with a good basis of knowledge and understanding of biology which, if required, they could build upon in future courses. She was not keen to change to the AEB modular equivalent. She felt that since the gap between the knowledge and understanding students have at GCSE and the knowledge and understanding students are required to have in order to pass A level is so big, changing to modular A levels would be detrimental to her students' achievement. She felt it

⁸ KS3 refers to a compulsory national programme of study for students aged 11-14.

⁹ The Oxford Examining Board; an examination board that provides syllabuses for many subjects at A level including biology.

¹⁰ The Northern Examining Board; an examination board that provides syllabuses for many subjects at A level, including chemistry.

would be difficult to get her students up to speed as quickly as she would need to if they had to take the modular examinations.

At the time of the study Catherine was teaching the A level linear biology course developed by the Associated Examining Board.¹¹ Her A level teaching during the research period consisted of two Year 12 (including the group observed for the research purposes) and two Year 13 groups.

The study began with Catherine in November 1997, continued until January 1998 and involved a group of nine Year 12 A level biology students – six girls and three boys – at the beginning of the 1997/1998 academic year. Catherine commented that the sixth form at Culverhay had an open policy and therefore took students with a wide range of academic ability. This was mirrored in the students who took biology at A level. She described the group that was observed in this research project in a similar way. She felt some of her students were extremely able, many having obtained As or A*s¹² in science, maths and English at GCSE. Others, however, were more inclined to struggle having not done so well at GCSE. Furthermore, similar to John's students, the individuals in the group taught for his research project were taking a mixture of subjects at A level. Some were studying

¹¹ The Associated Examining Board, General Certificate of Education - Advanced Level Biology - Linear A99/03, 0607, 1999 syllabuses for Biology/Human Biology.

¹² A* is a grade that has been introduced to provide additional discrimination within the body of students achieving this top grade.

all three sciences and/or maths whilst, for others, biology was their only science and it was combined with more arts based subjects such as English and history.

In addition, one student in Catherine's class had a severe disability. This individual (Paul), although 'an extremely strong GCSE candidate', was struggling as he had a brain tumour and, as a consequence of this, was losing his sight. Catherine felt the school was supporting him in every way it could. Paul had a learning support assistant in all of his lessons.

Like John, Catherine really enjoyed her A level teaching. For her, the relationships she built with her A level students were a refreshing change from the sorts of relationships she developed with younger students (e.g. disciplining and sorting out problems) in her role as Head of Lower School.

Similar to John, Catherine's major aim as an A level biology teacher was to ensure she got her students through their A level exams because she felt that in the long run 'that's what society is going to ask of them'. Furthermore, like John, she commented that in order to do well in their A level examinations, her students would need to acquire a:

considerable amount of biological knowledge ... there is so much on the syllabus that they have to know, biochemistry, cells, respiration, photosynthesis, different systems like the nervous system, there's so much to learn.

(Expl Int C 329-322)

An additional aim of Catherine's as an A level biology teacher was to ensure that her students enjoyed studying biology. She was keen to encourage them to

appreciate the wonder of the world around them, as this was something they could take with them throughout their lives.

The unit-of work

The observed unit-of-work for Catherine comprised part of the AEB linear A level biology course taught at Culverhay. The course itself was composed of four sections (The Organisation of Living Organisms; Variation and the Mechanisms of Inheritance and Evolution; The Biology of Ecosystems; Life Processes) comprising 80% of the total marks and a 20% teacher assessed practical work component. At the time of the research project, Catherine was teaching section 1 – The Organisation of Living Organisms. This section comprised seven subsections:

- 1.1 The cell is the basic structure of prokaryotes and eukaryotes.
- 1.2 The electron microscope and the techniques of cell fractionation may be used to study ultrastructure.
- 1.3 The properties of cell membranes are related to the passage of substances through them.
- 1.4 Large molecules are important in the structure and functioning of cells.
- 1.5 Enzymes are proteins which control biochemical reaction in cells.
- 1.6 Aerobic and anaerobic respiration produce ATP which is the immediate source of energy for all cell activities.
- 1.7 Photosynthesis is a method of utilising energy to synthesise organic molecules from inorganic sources.

The observed unit-of-work comprised subsection 1.6 - Aerobic and anaerobic respiration produce ATP which is the immediate source of energy for all cell activities.

A full outline of the subject content included in this section of the syllabus is found in Appendix A. Catherine indicated that she had taught this unit-of-work 'many times before.' The observed unit-of-work took place over 4 weeks and comprised four single and two double lessons. The following section provides a description

of the overall shape of this unit-of-work. All the curriculum materials and copies of the notes taken throughout Catherine's unit-of-work are found in Appendix I.

Lesson 1

The first lesson of Catherine's unit-of-work began with a teacher-led question and answer session exploring students' knowledge of the process of respiration. The question and answer session established several aspects of information about this process including its necessary raw materials (e.g. oxygen and glucose) and where it occurs (e.g. in all body cells). Furthermore, it established how these raw materials get into a mammalian body which involved reference to digestion, absorption, blood, cell membranes and breathing.

Following on from this exercise, Catherine encouraged her students to label a diagram of a section through a thorax. Whilst they completed this activity Catherine moved around the classroom interacting with individual students and small groups. When the majority of her students had completed this activity Catherine went through the answers to the exercise as a group. In addition to asking her students to provide names for the different parts of the thorax, Catherine discussed some of these various parts in more detail. For example, she described the structure of the trachea – made up of C shaped rings of cartilage – and encouraged her students to consider the relevance of this shape in the context of a living human.

Having finished this exercise, Catherine went on to point out the difference between the process of breathing and the process of respiration through a discussion of

each process's distinguishing characteristics. For example, breathing was defined as getting air in and out of the body and respiration was defined as a way of producing energy in all body cells using oxygen and glucose. Catherine went on to emphasise that respiration is a multi-stage process. She announced to her students that, in order to help them learn about it, she would break it up into different stages and one stage would be tackled at a time.

The rest of the lesson comprised a teacher-led discussion and note-taking task in which Catherine and her students explored the concept of ATP and the first stage of respiration: glycolysis. Various aspects of information were identified and noted down for each idea as well as several diagrams.

Lesson 2

Lesson 2 began with a teacher-led question and answer session reviewing the previous lesson's work on glycolysis. This question and answer session involved recalling information about this process that Catherine had identified in lesson 1 (e.g. its location, and what it involves, for example, phosphorylation).

In the second part of the lesson the students completed a practical investigating respiration in live maggots. Catherine demonstrated how to set up a respirometer using the equipment available to them. She then assisted her students in setting up and monitoring their own respirometers. As part of their experimental write up, Catherine encouraged her students to predict what they thought might happen to the level of the eosin dye in their respirometers over time. During this write-up, Catherine discussed her students' predictions with individuals and small groups.

In addition to this, through classroom discussion she encouraged her students to think about how they could improve their experimental control.

The final part of the lesson continued the previous lesson's discussion about glycolysis. In a teacher-led discussion and note-taking exercise, Catherine identified further information about this process including cleavage and oxidation. She summarised this on the board through bullet points and diagrams which her students copied into their notebooks.

Lesson 3

The third lesson of Catherine's unit-of-work began with her informing her students that the maggots used in the experiment in lesson 2 had all perished having fallen into the potassium hydroxide at the bottom of the respirometer. This led to a brief class discussion about pain and whether the maggots had suffered as a result of being part of the respirometer experiment. Following this discussion, a question and answer session explored what the students predicted might have happened if the maggots had not perished. They predicted that the eosin dye would move towards the respiring maggots. This question and answer session also explored the students' thoughts on improving the control used in the experiment. They suggested the use of disinfected dead maggots in a muslin bag rather than the use of glass beads.

The second and final task of the lesson comprised a teacher-led discussion and note-taking activity concerning two biological processes – the Link Reaction and the Krebs Cycle. Using an OHT and a handout, Catherine identified information

about each process (e.g. what each process involved, what sorts of things happened in each process). This information was summarised in diagrammatic form on the OHT. Catherine also annotated the OHT during the activity. Catherine's students copied the information on the OHT into their notebooks. The lesson ended with a question and answer session reviewing the information the students had learnt about the two biological processes, including, for example, where they are located and what they involve.

Catherine's commitments as Head of Lower School meant she was unable to teach the next lesson. She informed me in advance that the lesson would be cancelled. Despite this she still set her students work from their textbook on Respiratory Quotients which they had to leave in her pigeon hole at the end of their scheduled lesson.

Lesson 4

Catherine began lesson 4 by going through the assignment she had set her students on Respiratory Quotients. Each student, in turn, was asked to provide an answer to one of the assignment questions.

Next, through a teacher-led question and answer session, Catherine reviewed her students' knowledge and understanding of the Link Reaction and the Krebs Cycle. The question and answer session involved, for example, identifying various aspects of information about each process such as where each process is found.

Finally, in a brief teacher-led discussion and note-taking activity Catherine introduced the idea of the Electron Transport Chain identifying where the process takes place, its basic purpose and other names for it (e.g. Hydrogen Carrier System).

Lesson 5

Lesson 5 began with a teacher-led question and answer session reviewing the information about the Krebs Cycle Catherine's students had learnt in lesson 3.

Next Catherine led a discussion and note-taking exercise concerning the Electron Transport Chain. An OHT was used in order to emphasise various aspects of information about the Electron Transport Chain and some teacher dictation was also used in order to summarise key points (e.g. what the Electron Transport Chain involves - the Electron Transport Chain involves a series of oxidation/reduction reactions). Catherine then helped her students to identify where and how many ATPs are produced when one molecule of glucose is aerobically respired.

The subsequent activity involved Catherine taking her students through two handouts, one being a summary of cellular respiration and the other a sheet on ATP. The students were asked to highlight various sections on the handouts. For instance, on the ATP summary sheet, they were asked to underline various processes that require ATP including muscle contraction and protein synthesis.

The final part of the lesson involved a teacher-led discussion and note-taking exercise concerning anaerobic respiration. Teacher dictation was used in order to summarise various points such as what anaerobic respiration means (e.g. respiration without oxygen) and what it involves (e.g. sugar being converted, with the release of energy, to lactic acid in animals and ethanol in plants and fungi).

Lesson 6

The final lesson of Catherine's unit-of-work began with a question and answer session reviewing what the students had learnt about the Electron Transport Chain and anaerobic respiration in the previous lesson.

Following on from this recap, Catherine posed a problem for her students 'what kind of runners ... sprint or marathon are more likely to get cramp?' She encouraged them to produce an account to explain which type of runner they thought would be most likely to suffer from a build up of lactic acid by drawing upon their biological knowledge.

The final part of lesson 6 involved a teacher-led discussion and note-taking exercise concerning the respiration of alternative respiratory substrates (e.g. fat and protein). The students copied a diagram Catherine drew on the board illustrating the process of respiration using respiratory substrates other than carbohydrates. Catherine employed dictation to summarise, for example, the various processes involved in the respiration of fat and protein.

Case Study Three

Sally

Sally, like Catherine, had always wanted to become a teacher from a young age. Interested in the sciences, she took A levels in biology, chemistry, physics and general studies and was accepted at Brockenhurst University to study a joint degree in Botany and Zoology. During her four year undergraduate degree Sally had a slight change of mind about teaching as a career. Sharing a house with a PGCE student made her aware of the 'horrendous' workload of teaching. This encouraged her to consider other careers such as 'an Assistant Governess ... with the Prison Service', however, deep down she still felt that her heart was in teaching. Consequently, during the final year of her undergraduate degree Sally interviewed for a place on the PGCE course at Brockenhurst and the following year enrolled as a student teacher.

Sally's teaching career began at an all-girls Convent school in Hamilton where she was employed to teach biology. After two years she moved to an all-boy's school in Findle, Roster where she also taught biology. After five years she moved gaining a promotion as Head of Biology at a mixed comprehensive - Nailsea School - on the outskirts of Hamilton. During her time at this school she taught biology, general studies, personal and social education and chemistry up to Year 9 and also was promoted internally to become Head of Careers Education. In addition, at Nailsea School, Sally also completed a part-time Masters degree in Science Education at

Berry's College, Hamilton which she enjoyed despite holding down her full-time teaching job as she indicates in the following quotation:

I did enjoy it, the thought of going after a days teaching was sort of ough but you got a real buzz when you were actually there, I think you do on those sort of things.

(Expl. Int S 61-63)

Sally stayed for eight years at Nailsea School and then gave in her notice when she got married in order to move where her husband lived. When she arrived in the midlands she applied for various jobs that were on offer and, although it was a demotion from her previous job, she took the Head of Biology post at Beechencliff High School. At the time of data collection Sally had been at Beechencliff High School for ten years.

Founded in 1548 Beechencliff is a voluntary controlled co-educational comprehensive school located in the rural town of Camerton in the midlands. It had been designated with additional special provision for students with moderate learning difficulties. Beechencliff is a large school with 1232 students on roll, employing some 85 teaching staff. The school is located on two sites some four minutes walk apart. A mixture of old and new architecture, some of the buildings date from mediaeval times whilst others are twentieth century constructions. Sally felt that working in a split site school had its disadvantages. On days when she was teaching on both sites she felt she 'needed more energy'. Moving between the sites for different lessons meant, at times, that she was tired and even late for lessons. As she taught in a number of different rooms she also felt it difficult to

personalise her space. Sally's A level biology teaching, however, was always located in the same classroom.

Beechencliff was the only state secondary school in Camerton. Sally described the school as a rural comprehensive taking students across the ability range. Its catchment area incorporated Camerton, which was a growing town, as well as many rural villages. Sally described the school as being 'fairly friendly'. She felt there were good staff-student relationships as well as a strong work ethic. As Head of Biology, Sally was employed to teach biology at A level and Science at KS3 and KS4. She also had the special task of moderating Science 1 Investigations at KS4. In addition to this, Sally was also an experienced mentor and often worked with student teachers when they were attached to the school. Sally was very interested in mentoring and felt that her involvement in mentoring had, and continued to have, a positive impact on her teaching. Sally felt that mentoring provided her with the opportunity to develop professionally. She considered that her role as a mentor prevented her from becoming a 'staid' teacher and encouraged her to become more reflective about her practice because student teachers were always questioning her about her teaching (e.g. what she was doing in lessons and why). Sally also felt that mentoring encouraged her to read widely about science education. At the time of the research Sally was assisting OUDES in the development of a mentoring diploma.

Sally was part of a large Science Department comprising thirteen staff. She felt there were good relations between the different sciences. Overall she considered

the department to have a good team spirit where the individual teachers supported each other and were happy to share their expertise. Sally characterised the Biology Department in much the same way as the Science Department with good relations and communication between staff. She felt the Department worked well as a team 'towards the common goal of doing the best for students, you know, getting them the exam results they deserve'. Including Sally, the other members of the biology team were one part-time and four full-time teachers.

Beechencliff has a large sixth form comprising some 240 students. Biology was a popular subject to take at A level. It was the favourite of all the sciences and also a popular choice in the school across all the other A level subjects. On average between 20 and 30 students enrolled to take A or AS level biology every year ensuring two good-sized groups. This gave each of the full-time biologists in the Department the opportunity to teach biology at A level. Unless timetabling dictated something different, two biology teachers shared each A level group. Every year, therefore, each of the four full-time biologists shared one Year 12 and one Year 13 A level biology group.

At the time of the study, Sally had a wealth of experience as an A level science teacher; four years as an A level botany teacher, twenty-one years as an A level biology teacher and a few years as an AS human biology teacher. She had taught

several different boards including London¹³, AEB and NEAB. At the time of the study, Sally was teaching the A level biology modular course developed by Northern Examinations and Assessment Board¹⁴. She was teaching two A level classes during the research period, one Year 12 and one Year 13.

When Sally first took up her post at Beechencliff, the students were studying for the AEB linear A level biology course that she really liked. The Science Faculty, however, made a decision to change from linear to modular A level and decided on NEAB as the most favourable board. Sally seemed happy to change to the NEAB syllabus. She felt it was:

a good grounding in biology, it's got a lot of the concepts that are necessary but it's also got the extra little bits that make them interested like the Health and Disease, like some of the Behaviour so they can relate it to themselves, to what's going on.

(Expl. Int S 430-434).

She still had reservations, however, about the modular aspect of the course. She felt the modular course was not as good for the weaker candidates as they simply were not ready to take exams in their first year of A level. Doing badly in these first module tests she felt had a 'demoralising effect on them'.

¹³ The London Examining Board is an examination board that provides syllabuses for many subjects at A level including biology.

¹⁴ Northern Examinations and Assessment Board, General Certificate of Education - Advanced Level Biology - Modular 4164, 1999 syllabuses for Biological Sciences.

At Beechenclyff the biology A level course tended to attract a complete mix of students in terms of the combinations of other subjects they were doing. Some of the students taking A level biology were pure scientists, their other A levels in science or maths whilst others chose biology as their only science, their other A levels in arts subjects such as English or geography. In terms of ability, Sally indicated that the students taking A level biology were across the academic spectrum, with some definite A grade candidates and some who would struggle to get a grade at all. Timetabling had led to an interesting split between the two Year 12 A level biology groups, one (Sally's class) of which was observed during the research period. The other biology teacher, James, had been allocated a group who had done enormously well at GCSE. Sally described his students as 'very bright' and felt they were progressing extremely well in their A level studies. In contrast, Sally described her group as comprising mostly the weaker GCSE candidates who lacked confidence in their abilities and were really struggling at A level although she also had a few 'high flyers'. Sally called this group 'the plodders' but remained positive that through hard work in the end they would 'get there'. The study began with Sally in June 1998, continued until July 1998 and involved a group of thirteen Year 12 A level biology students, six boys and seven girls, at the beginning of the 1997/1998 academic year.

Similar to both John and Catherine, Sally's overall aim as a biology teacher at A level was to get her students through their exams to the best of their ability ('to get them to get their best mark possible for them ... because we are in an exam orientated world'). She also mentioned that in order to be successful in their

examinations, her students would need to develop a considerable knowledge of biological subject matter ('they need to know so much stuff to do their exams, so much biology').

In addition, however, she was also keen for her students to enjoy the subject and wanted them to 'go home and talk about it' and 'want to find out a bit more'. She hoped that with some of her students she would 'create a little spark'.

Sally really enjoyed her A level biology teaching because of the sorts of relationships she was able to develop with her students ('you can have more adult conversations') as well as the opportunity it gave her to engage more with her subject ('you talk more about your subject'). She also really enjoyed watching her students' understanding of the subject develop over the two year course. In her words:

you start off with a group and when you get to the end of Year 12 the start of Year 13 things start slotting into place and they start giving you the right answers back, they start to see the light.

(Expl. Int S 570-573)

The unit-of-work

The observed unit-of-work for Sally comprised part of the NEAB modular A level biology course taught at Beechencliff High School. The course was composed of six modules, two compulsory and a choice of a further four from a selection of seven (see figure 5.1 for further detail).

Figure 5.1 The compulsory and option modules comprising the NEAB modular A level biology course taught by Sally

MODULE

- BYO1 Processes of Life (compulsory)
- BYO2 Continuity of Life (compulsory)
- BYO3 Physiology (option)
- BYO4 The Biological Basis of Behaviour (option)
- BYO5 Ecology (option)
- BYO6 Microorganisms and Biotechnology (option)
- BYO7 Biology and Food Production (option)
- BYO8 Health and Disease (option)
- BYO9 Social Biology (option)

Each module was allocated $16\frac{2}{3}\%$ of the total marks: 3% allocated to teacher-assessed practical skills (in the form of an investigation related to the module studied) and $13\frac{2}{3}\%$ to the end of module test. At the time of the research project, Sally was teaching module BYO3 Physiology. The module comprised eight numbered sections:

- 3.1 Relationship between surface area and volume
- 3.2 Gaseous exchange
- 3.3 Ventilation
- 3.4 Obtaining food
- 3.5 Digestion in mammals
- 3.6 Exchange of water and ions in plants
- 3.7 Transport systems
- 3.8 Exchange and transport of wastes

The observed unit-of-work covered a large proportion of section 3.5 Digestion in mammals. A full outline of the subject matter included in the unit-of-work is found in Appendix A.

This was the third time Sally had taught this particular unit-of-work although she commented that she had taught the ideas involved in it many times before. The observed unit-of-work spanned a total of two and a half weeks involving two double and six single lessons. The following section provides a description of the overall shape of the unit-of-work Sally taught during the research period. All the curriculum materials and copies of the notes taken throughout Sally's unit-of-work are found in Appendix J.

Lesson 1

The first lesson of Sally's unit-of-work began with a brainstorm about digestion. The students were given several minutes to write down anything they could think of that was related to the process of digestion such as particular enzymes involved in it or specific organs associated with it. The students then shared their ideas and Sally collated them on the board. Drawing upon their ideas, Sally summarised what the students would learn about digestion during this unit-of-work. The summary included knowledge of the structure and function of the digestive system and the secretions associated with the process of digestion.

The second activity involved Sally talking through a handout she gave students on the anatomy and microanatomy of the gut. First, in the style of a lecture, Sally identified and spoke about each of the labelled parts (e.g. stomach and gall bladder) on a cut away diagram of the human digestive system from mouth to anus. Her dialogue involved describing the structure of the different parts (e.g. what they look like, what they are made up of) and discussing the role they play in mammalian digestion (e.g. whether they produce specific enzymes important in the

process of digestion, whether they are the site of digestion of a particular type of nutrient). Interspersed with this discussion, the students asked Sally various questions relating to personal experiences of their own digestive systems (e.g. why when you are sick does it burn the back of your throat?). Sally drew upon her biological knowledge to answer these questions. In addition, Sally talked through a further diagram on the handout showing the main regions of the gut wall. Each region was described by identifying what it looked like and what role it plays in digestion. For example, the mucosa region was described as:

- comprising connective tissue, blood vessels, glands and lymph vessels;
- important for the secretion of enzymes and the absorption of digested food.

Finally, Sally asked one of her students to describe how food moves along the gut (i.e. by peristalsis).

Lesson 2

Lesson 2 began with a discussion of the process of digestion. Sally identified various bits of information about the process (e.g. what it involves) which her students copied into their notebooks. Sally then gave each student a handout which described a practical she wanted them to complete on the digestion of starch. The students were instructed to read through the practical and then Sally showed them the equipment they would be using and gave them some tips on safety. At this point Sally provided them with instructions, which she subsequently wrote on the board, setting out how she wanted the experiment written up. During the practical, Sally moved around the class discussing with individual groups of

students what results they might expect from it. Furthermore, during these conversations she reviewed various biological ideas connected to the digestion of starch (i.e. polysaccharides, disaccharides, hydrolysis and enzymes) that the students had covered in an earlier module. This review involved the students recalling specific bits of information about the biological ideas such as what they are made of (e.g. disaccharides) or what they involve (e.g. hydrolysis). Having helped her students pack away their equipment, Sally initiated a plenary in which she and her students discussed their experimental results and drew some conclusions.

Lesson 3

In lesson 3, Sally engaged her students in individual research projects. Each student was assigned a digestive structure and/or secretion to investigate. The purpose of this investigation was to produce an information sheet incorporating specific details about the structure/secretion and any appropriate diagrams of it. Sally assisted her students in this research task by suggesting to the whole class, and also on an individual basis, what sorts of details and diagrams might be appropriate to include in their information sheets. For example, for students assigned a digestive structure, such as stomach, Sally suggested they focused on details concerning its structure and function. For students assigned a digestive secretion, such as bile, she suggested they focus on details concerning the contents of the juice, the required stimulus to get the juice flowing, and the site of its production.

The majority of the lesson was spent with students investigating the particular structure and/or secretion assigned to them. At one point in the lesson, however, Sally stopped her students working on their individual projects in order to introduce various biological ideas connected with protein digestion. She discussed endopeptidases and exopeptidases, identifying various bits of information about them including where they are produced and what role they play in protein digestion.

Lesson 4

Lesson 4 began with the students finishing off the research projects they started in lesson 3 with Sally providing assistance if required.

The second activity involved the students observing microscope slides of various parts of the gut, including the oesophagus, duodenum, stomach and rectum, and producing tissue plans of them. For homework, Sally gave her students a series of questions on the topic of digestion. The idea was for the students to use each other's information sheets to help answer the questions. The questions covered the structure and function of various parts of the gut and the contents of different digestive juices, their stimulus for secretion, place of production and site of action.

Lesson 5

Sally spent all of lesson 5 going through the answers to the homework questions on digestion set in lesson 4. Each student, in turn, was asked to provide an answer to one of the homework questions. When they reached question 6, concerning the main regions of the mammalian gut wall, Sally gave out two sheets.

The first identified the four basic layers of the gut wall and the second identified the main function and adaptations of these layers in different regions of the gut (e.g. oesophagus, stomach, ileum, colon). Together, Sally and her students read through the two sheets. She identified for her students what they needed to know, in particular the structures and functions of the four layers of the gut and what sorts of adaptations they display in various regions of the gut for their end of module exam. The lesson continued with the students providing answers to the homework questions on digestion.

Lesson 6

Lesson 6 began with Sally demonstrating a practical on protein digestion she wanted her students to complete. The first part of the lesson was taken up with the students setting up this practical. When this was done, the students followed Sally's instructions for the write-up including an introduction and the preparation of a results table. As it was near the end of term, the class then had a break in which Sally provided each student with a cake to eat. After the break, the students individually recorded the results of the protein digestion experiment. Sally engaged some of her students in a question and answer session about their results. The final task involved Sally continuing to go through the homework questions on the structure and function of the digestive system set in lesson 4. The format was similar to lesson 5 where each student, in turn, provided an answer to a specific question.

Lesson 7

The seventh lesson of Sally's unit-of-work began with her talking individually to her students about the results of their protein practical. The students then packed away their apparatus.

The second activity involved Sally going through a summary sheet on digestion and absorption with her students, discussing the digestion and absorption of carbohydrates, proteins and fats. The summary sheet, for example, covered things like the enzymes involved in breaking down carbohydrates, proteins and fats, the end products produced, the site of absorption and the processes involved in absorption.

In the third activity, the students were given a worksheet on the role of nervous and hormonal stimulation in digestion. Sally gave her students 10 minutes in which to read the sheet and answer the questions on it. When they had completed the questions, Sally discussed the answers with them in a whole class question and answer session.

Following on from this activity, Sally provided her students with a handout on the large intestine that she asked them to read. She then discussed with them the role of the large intestine in digestion (e.g. reabsorption of water and ions). Sally then posed her students a problem 'why is it that cholera causes chronic diarrhoea in humans?'. She gave her students some contextual information about what cholera does to the lining of the large intestine and then encouraged them to solve the

problem posed by drawing upon their biological knowledge from the digestion topic and other topic areas. The final lesson activity involved working through some past paper examination questions with the students.

Lesson 8

The final lesson of Sally’s unit-of-work began with a written test on the digestion topic. The students were given a sheet covered by a grid containing information in each box about either an organ or secretion, the effect of an organ or secretion, the contents of a secretion, the stimulus required for a secretion or the site of action of a secretion. The test involved the students reorganising the information into a table with the following structure:

Organ/secretion	Contents	Effect	Site of action	Stimulus
-----------------	----------	--------	----------------	----------

When the students had finished this test the rest of the lesson was spent with Sally giving the students an oral assessment where, for example, they had to name particular parts of the gut or particular processes based on the information given to them (e.g. one student was asked what term referred to the process of breaking down fat into smaller droplets).

Summary

This chapter has sought to present rich, descriptive accounts of the three case study settings by providing information about the three teachers, their respective students, the schools in which they worked and the units-of-work they taught during the research period. Interestingly, despite their different backgrounds and the different schools in which they taught, all three teachers shared the same basic aim to their A level biology teaching – to get their students through their examinations to the best of their abilities. Through these descriptive accounts this chapter has suggested that, in order for these teachers to achieve this aim they took account of a variety of factors within the contexts in which they worked including their students, the resources available to them and the curriculum. All three teachers conceptualised the A level curriculum - as manifest in their respective syllabi - as content laden. Furthermore, they believed that to be successful in their examinations their students needed to acquire a lot of biological knowledge. In light of this, the following chapter will examine the ways in which these three teachers conceptualised the biological knowledge they believed was needed to be successful in A level exams and how they represented this knowledge to their students to encourage them to encode, store and retrieve it when necessary.

Chapter Six

Constructing the A Level Biology Curriculum for Student Success in A Level Examinations¹

Introduction

In the previous chapter it was argued that the overriding aim of all three teachers' teaching of biology at A level was to prepare their students for examination success. Further, it was suggested that to be successful their students needed to acquire the vast amount of biological knowledge that would form the basis of their assessment. The purpose of this chapter is to examine the ways in which the three teachers believed their students needed to know the A level biology curriculum for examination success and how they worked to bring about the development of such knowledge in their students. A distinction first proposed by Schwab in 1964 (see 1964a and 1964b), and discussed in chapter two, provides a useful analytical framework for exploring the conceptions of biology that the three teachers believed their students needed to develop to ensure successful examination results. To remind the reader of this distinction a brief description is given here. Schwab's distinction classifies subject matter content knowledge into two dimensions: substantive knowledge and syntactic knowledge. Substantive knowledge is composed of two aspects. The first embodies a subject's facts, concepts, principles and theories. The second comprises the conceptual frameworks or knowledge structures of a subject. Syntactic knowledge is defined as comprising the methods and modes of inquiry a discipline

¹ Whilst for all three teachers the A Level examination in biology comprised both written tests and coursework, they seemed to separate these two methods of assessment and preparation for examinations appeared synonymous with preparation for written tests. Consequently, in this thesis the term examination is considered in its narrowest sense as a written test under timed conditions.

develops as well as the canons of evidence and warrantability it draws upon in order to verify its knowledge claims.

In this chapter, it will be argued that, in relation to the three topics taught during this research project, these teachers believed that, to achieve A level success, their students only needed to know the substantive dimension of biological knowledge. Indeed, it will suggest that the teachers did not consider knowing the syntactic dimension of biological knowledge to be a prerequisite to examination success. Further, it will argue that the teachers believed that their students needed to conceptualise this substantive biological knowledge in several patterned ways. Moreover, it will suggest that the pedagogical strategies the teachers used in the classroom were carefully selected and managed in order that the specific conceptualisations of substantive biological knowledge they considered critical to know were developed and reinforced in their students.

This chapter is split into five sections. The first three sections will consider the substantive aspect of biological knowledge. The first section will explore the conceptualisations of substantive knowledge the three teachers sought to develop in their students. In essence it will consider what, to these teachers, it means to 'know' substantive biological knowledge for success at A level. The second section will consider how these three teachers encouraged their students to conceptualise substantive biological content in these ways – that is how they assisted their students in developing and retaining these conceptions of biology. The third section will explore how the teachers decided what substantive biological knowledge their

students needed to know and in what ways it needed to be known for examination success.

The fourth section will show how developing students' knowledge and understanding of the syntactic aspect of biology was not considered an important feature of the teachers' successful teaching of biology at A level. Moreover, it will provide suggestions to account for the lack of emphasis given to developing students' understanding of the nature of biology/science.

The fifth and final section will present a summary of the chapter's main findings and consider their relationship to those of previous studies.

Conceptualising substantive biological knowledge for success at A level

This section begins with three quotations from the teacher interviews. These quotations give rise to the major finding upon which the first three sections of this chapter are based. In post-lesson interview 6, John identifies his teaching as successful because he feels that, at the end of lesson 6, his students have developed knowledge of the oxygen dissociation curve. In his words:

I got through, my plan was the dissociation curve ... I think they grasped it amazingly quickly ... it was another difficult concept.

(plint 6 J 17-38)

Similarly, in post-lesson interview 4, Catherine identifies her teaching as successful because she feels her students have acquired knowledge of respiratory quotient when she says:

I felt ... that by the time I was finished they knew what a respiratory quotient was.

(plint 4 C 48-50)

Finally, in post-lesson interview 6, Sally identifies her teaching as successful because she feels confident that her students have developed knowledge of exopeptidases and endopeptidases. In her words:

It was good ... so I think they've grasped those ideas [exopeptidases and endopeptidases].

(plint 6 S 37-42)

Although the three quotations above relate to three very different topic areas, what is common to them is that in each the teachers identify their teaching as successful

because they feel that their students have acquired knowledge of what John refers to as a 'concept', and Sally refers to as 'ideas'. Across the teachers' interviews, they repeatedly identify their teaching as successful if they perceive their students to have acquired knowledge of what they variously refer to as 'concepts', 'ideas', 'things' and 'bits'.

But what is a 'concept', 'idea', 'thing' or 'bit'? In explicating what is meant by a 'concept', 'idea', 'thing' or 'bit' it is useful to draw upon the work of Ogborn *et al* (1996). These researchers studied videotapes of a number of teachers teaching science in order to try to make sense of the role that explanation plays in science teaching. They identified a key aspect of producing an explanation as constructing the entities from which the explanation is developed. These entities are defined as 'things to think with'. In this chapter it is proposed that what the teachers variously refer to as 'concepts', 'ideas', 'things' and 'bits' are synonymous with Ogborn *et al*'s entities.

But what is meant by a 'thing to think with'? Although Ogborn *et al* give many examples of entities in their work, they refrain from categorising them definitively in any other way than as 'things to think with'. Though they suggest that some entities might be considered as material things (e.g. teeth) whilst others might be considered as conceptual things (e.g. density) and yet others might be considered as processes² (e.g. evaporation), no robust definitions for these possible classifications are offered. They appear to refrain from offering definitive classifications because they acknowledge the inherent difficulties in achieving them. Indeed, the problems associated with drawing definitive distinctions between the entities of science have been acknowledged by philosophers such as Ruse (1973) who argues that:

there seems to be no one absolute way of drawing a distinction between the entities of science

(p. 16)

Instead, he suggests that there are several ways of distinguishing between the entities of science including the dimensions of:

- observable–non-observable;
- really existent–hypothetical;
- non-theoretical–theoretical.

² Ogborn *et al* (1996) point out that a process – such as evaporation – might not, at first glance, be considered as an entity. They argue, however, as do Halliday and Martin (1993), that 'Scientific texts are well known for their high concentration of events and processes presented as if they were things' (p. 51). Indeed, they suggest that processes 'exist in text and in talk as entities because they exist in the thinking of scientists as entities. They are things with which to think' (*ibid.*, p. 51). In essence it seems that they believe one of the characteristics of science is that it examines processes in detail and in doing this turns them into something like 'things'. In putting forward this argument they justify their reasons for considering processes as entities.

He points out, however, that whilst these dimensions:

are all in their own way informative, despite a considerable amount of overlap, each division has boundaries peculiar to itself, and indeed, the methods of division themselves are not entirely unambiguous.

(*ibid.*, p. 16)

It seems, then, that whilst entities have been referred to loosely as material things, conceptual things and processes, what unites them definitively is that they are all knowledge objects. They are all tools that scientists use to think with. They are the things that scientists investigate. In this chapter it is proposed that each 'concept', 'idea', 'thing' or 'bit' that the teachers refer to across their units-of-work and interviews is a 'thing to think with', a knowledge object, a tool of thought. In drawing on the work of Ogborn *et al* in this thesis, the term entity has been chosen to refer to what the teachers variously call 'concepts', 'ideas', 'things' or 'bits'. In addition, however, the term biological will be added in front of the term entity to signal the focus of this study on the subject of biology rather than science in general.

Arising from the above discussion, it is suggested that these teachers perceive their successful teaching of biology at A level to be any teaching that encourages their students to acquire knowledge of 'biological entities'. Consequently, it can be inferred that knowing substantive biological content knowledge for success at A level means knowing various 'biological entities'. In light of this interpretation, it is important to consider what, to these teachers, it means to know a 'biological entity' for success at A level.

Knowing ‘biological entities’

The evidence suggests that for these three teachers, what it means to know a ‘biological entity’ for success at A level comprises two elements: knowing various features of it, and knowing, where possible, any representations of it. Each element will be discussed and illustrated in turn.

Knowing features

In order to have knowledge of a particular ‘biological entity’ for success at A level, it is suggested that these teachers believe it is necessary to know various features of it. The data indicates that a feature comprises a proposition that embodies meaning about a particular ‘biological entity’ – meaning that is well substantiated and about which there is a consensus within the scientific community. A feature appears to be an expression of a particular characteristic of the ‘biological entity’ in question. It might communicate, for example, something about the ‘biological entity’s’ structure or function or if the ‘biological entity’ is a process, it might indicate where the process takes place or what it involves. The work of this thesis suggests that there are a number of different sorts of features that contribute to the meaning of the plethora of ‘biological entities’ that comprise biology. For example, some of the features that emerged during analysis include:

- structural features which are features that embody meaning concerning the structure of a particular ‘biological entity’ - that is what it is made up of or what it looks like. John’s reference to ‘veins’ having ‘valves’ in lesson 3 provides an example of such a feature. The proposition ‘veins have valves’ provides

information concerning the structure of the 'biological entity' vein, i.e. it is composed of, amongst other things, valves.

- functional features which are features that embody meaning concerning the function of a particular 'biological entity' - that is what role the 'biological entity' plays in a living organism. Sally's reference in lesson 3 to 'the action of the [digestive] juices' provides, at an abstract level, an example of such a feature. Whilst this statement itself tells us nothing about a specific 'biological entity', Sally uses it in the lesson to encourage her students to identify the functional features of various 'biological entities' i.e. digestive juices such as gastric juice. Establishing 'the action of the juices' would require students to identify the functional features of the juices, that is what role they play in the living organism in question. For example, do the juices contain specific enzymes to catalyse the break down of various substrates into products? Or is their function simply to provide the right pH conditions for the action of other juices?
- locational features which are features that embody meaning concerning the location of a particular 'biological entity', that is where a 'biological entity' is found or, if the 'biological entity' is a process, where it takes place. Catherine's reference to the Krebs Cycle taking place in 'the mitochondrial matrix' in lesson 3 provides an example of such a feature. This proposition provides information concerning the location of this 'biological entity'³.

³ One of the outcomes of this thesis is a realisation that some useful follow up work to this project might involve a detailed analysis of substantive biological knowledge in order to produce a typology of features.

The first example of relevant evidence to support the proposal that these teachers believe that in order to have knowledge of a particular 'biological entity' it is necessary to know various features that embody the meaning of it can be taken from the transcript of lesson 3 of John's unit-of-work and the post-lesson interview following this lesson. Part of the subject matter focus of this lesson concerns developing students' knowledge of three 'biological entities' – that is artery, vein and capillary. In the post-lesson interview following this lesson, John indicates – with certainty – that he feels his students have acquired knowledge of these 'biological entities' when he says:

I would be confident enough to say that if you stopped anyone walking out of the door they would know the difference between an artery and a vein and a capillary
(plint 3 J 114-116)

Moreover, he qualifies why he believes that they have acquired knowledge of these 'biological entities' when he goes on to say 'they'd be able to give you some points about them' (plint 3 J 116). It is reasonable to infer that John's use of the term 'points' refers to the features that the students have been introduced to in this lesson about the 'biological entities' artery, vein and capillary.

John's use of the term 'points' during lesson 3 itself, lends further support to this inference. In this lesson, John develops his students' knowledge of the three 'biological entities' artery, vein and capillary through a teacher-led discussion and note-taking task. At the beginning of the task he says:

We are going to look at the structure and function of each type of vessel, arteries, capillaries and veins. OK. So let's start off with arteries. And if we just make some points. Um. Transports blood away from heart.

(L3 J 92-94)

It seems from this lesson excerpt that the task involves identifying various 'points' about the three 'biological entities' artery, vein and capillary. As before, it appears that John's use of the term 'points' refers to features of these three 'biological entities' because immediately after he mentions the term 'points' in this quotation he provides an example of a 'point' – that is 'Transports blood away from the heart'. This 'point' is a statement about an artery, it identifies the function of an artery – it is a feature of this 'biological entity'.

Comments from the interview following lesson 3 of Catherine's unit-of-work suggest that she also believes that to have knowledge of a 'biological entity' for success at A level means to know various features of it. Part of the subject matter focus of this lesson concerns developing students' knowledge of the 'biological entity' the Krebs Cycle. Immediately after the lesson, Catherine identifies her teaching of this 'biological entity' as successful. It seems that she perceives this to be successful because she feels that during this part of the lesson she has clarified for her students what she refers to throughout the interview as the 'main points', 'important parts', 'important bits' and 'important aspects' of this 'biological entity' that they need to acquire in order to know it for success at A level. She makes this clear when she says:

I wanted, I felt I got across the main points, the important bits of biology. That's what they need to know for this, [referring to the Krebs Cycle], you know, for A level.

(plint 3 C 34-36)

In this interview, she identifies some of these 'main points' as including things like, for example, 'removal of carbon to form carbon dioxide' and 'removal of hydrogen'. This implies that these 'main points' refer to the various features of the Krebs Cycle that Catherine introduces her students to in this lesson.

Finally, comments from Sally in lesson 1 of her unit-of-work imply that she believes knowing a 'biological entity' for A level success also means knowing various features of it. Towards the beginning of this lesson, Sally provides an overview of what her students will cover during their study of the topic area of digestion. In her words:

We need to look at ... function ... like the oesophagus, the colon, the small intestine and the stomach ... what each of the bits do ... including the enzymes which are produced

(L1 S 92-98)

This quotation suggests that Sally's use of the term 'bits' refers to the various 'biological entities' - including oesophagus, colon, small intestine and stomach - that her students will learn about during the topic area of digestion. Furthermore, her comments 'what each of the bits do', 'function', 'the enzymes which are produced' seem to refer to the various features of these 'biological entities' that her students will come to know as a result of participating in this series of lessons.

So far, it has been suggested that to know a 'biological entity' for success at A level means, in part, to know various features of it. But what does knowing a feature for

success at A level mean? In light of the evidence available, it can be speculated that, for these teachers, knowing a feature for success at A level involves knowing it at a surface level and, in addition, in some cases also knowing it at a deep level⁴.

Surface level knowing

It appears that to know a feature at a surface level means to be able to remember and recall it. Evidence to support this proposal can be found in lesson 8 of John's unit-of-work. At the beginning of this lesson, John introduces his students to various 'biological entities' relating to the human body's defence mechanisms against disease. At the end of the lesson, he conducts a question and answer session where he reviews various features of these 'biological entities'. In this question and answer session, one student gets confused between two similar sounding 'biological entities'. These are lysozyme (introduced in this lesson) and lysosome (studied in an earlier topic area). In the process of clarifying the difference between them, John establishes a feature of a lysozyme and encourages his students to do the same with lysosome. They respond in unison by recalling a feature of a lysosome as can be seen in the following extract from the lesson transcript:

⁴ In this thesis, it is important to point out that the use of the terms 'surface' and 'deep' in relation to knowing 'biological entities' is not meant in any way to reflect the meaning of these terms as used in relation to learning in the Higher Education literature e.g. Prosser and Trigwell 1999.

J: what's an additional feature of the body which stops invading micro-organisms?

Clare: Um, the lysosomes [^]

J: Lysosomes or lysozymes?

Euan: Lysozymes.

J: Lysozyme. Lysozyme is an enzyme, what's a lysosome?

Students in unison: It's a membrane bound organelle.

J: You're like parrots aren't you, very good like parrots! Um, it's a membrane bound organelle which contains the enzyme lysozyme, ok?

(VI1 J 796-810)

In this quotation, John's reference to parrots suggests that his students know the feature – lysosome is a membrane bound organelle – at a surface level. They can remember, recall and recite it. This is further corroborated by John's reflections in vignette interview 1. In this interview, he heard the above passage and commented that this part of the lesson was successful because his students 'remembered the right information'. It is plausible to propose that John's reference to 'information' refers to the feature of the 'biological entity' lysosome that they recalled.

Similarly, evidence from lesson 6 of Sally's unit-of-work also suggests that knowing a feature at a surface level means to be able to remember and recall it. During this lesson, Sally engages her students in a question and answer session. In this, they review various features of the 'biological entities' endopeptidase and exopeptidase. In the interview following, Sally identifies this question and answer session as successful because her students are able to recall features of these 'biological entities'. In the following quotation, she identifies one feature of endopeptidases

(‘endopeptidases attack in the middle of a protein’) that she was pleased her students had remembered and could recall. In her words:

they certainly remembered it today, not bad, you know, they remembered that *endopeptidases attack in the middle [of a protein]*

(plint 6 S 124-125 my emphasis)

A further example of this surface level knowing arises in vignette interview 2 of Catherine’s unit-of-work. Here she is reflecting on a question and answer session that involves reviewing features of the ‘biological entity’ electron transport chain. She comments that this activity provides her with an opportunity to assess whether her students have remembered and therefore can recall these. In particular, she identifies one feature about the electron transport chain (‘the electron transport chain involves electrons being passed between carrier molecules’) that she wants to make sure her students have remembered. In her words:

making sure that she said ... what happens ... *the taking and handing on [of electrons between] the carriers*, so looking for detail, making sure that your students are, have gone and learnt it

(VI2 C 583-586 my emphasis)

The previous three examples highlight one feature that each teacher wanted his/her students to remember and recall about a specific ‘biological entity’. They were for John a feature embodying meaning about the ‘biological entity’ lysosome – a lysosome is a membrane bound organelle – for Sally, a feature embodying meaning about the ‘biological entity’ endopeptidase – endopeptidases attack in the middle of a protein – and, for Catherine, a feature embodying meaning about the ‘biological entity’ electron transport chain – the electron transport chain involves electrons being

passed between carrier molecules. Although these three features embody meaning about three very different 'biological entities' they have a characteristic in common; the propositions that embody the meaning of the particular feature of the 'biological entity' in question include reference to one or more 'biological entities' than the 'biological entity' that the feature concerns. For example, the feature about a lysosome, i.e. lysosome is a membrane bound organelle, refers to membrane bound organelle and organelle which are both 'biological entities'. The feature about endopeptidases, i.e. endopeptidases attack in the middle of a protein, refers to protein which is a 'biological entity'. The feature about the electron transport chain, i.e. the electron transport chain involves electrons being passed between carrier molecules, refers to electrons and carrier molecules, both of which are 'biological entities'. In light of this, it can be tentatively suggested that knowing a feature at a surface level involves appreciating and remembering the relationship(s) between the 'biological entity/ies' signified in the explication of the feature and the 'biological entity' that the feature is about.

Deep level knowing

There is evidence to suggest that whilst all features can be known at a surface level – that is all features can be remembered and recalled – some can also be known at another level – what has been termed a deep level⁵. From the evidence available, it appears that knowing a feature at a deep level involves being able to explain the

⁵ Acknowledging that 'some' features can be known at a deep level leads one to ask which ones? What is it about the nature of these features that mean they can be known at both a surface and a deep level? In light of these questions, a further outcome of this thesis is a realisation that some additional follow up research to this project might involve investigating whether features that can be known only at a surface level share characteristics and whether features that can be known at both surface and deep levels share characteristics. Teasing out commonalities based on the nature of features might provide interesting extension work to this thesis.

‘why’ and/or ‘how’ of a feature in its wider biological context. In this thesis, a biological context is taken to mean any context in which the ‘biological entity’ to which the feature is connected is found. So, for example, a biological context might be a biological structure such as a cell, tissue, organ, system or a biological process such as digestion, respiration, reproduction. Explaining the ‘why’ of a feature seems to entail being able to consider the significance of it in its wider biological context. This might involve examining its importance, relevance or usefulness. For example, in lesson 3 Sally encourages one of her students to explain the ‘why’ of a feature of villi – ‘the villi are made up of many microvilli’. The student finds this difficult and so Sally draws upon various ‘biological entities’ such as surface area, absorption, diffusion, amino acids and glucose to help explain the relevance and significance of this feature of the villi.

Explaining the ‘how’ of a feature seems to entail being able to consider how the meaning encapsulated in a feature is achieved. For example, in lesson 3 John encourages his students to explain the ‘how’ of a feature of an artery – ‘arteries carry blood at high pressure’. He encourages them to come to know how carrying blood at high pressure is achieved through reference to various ‘biological entities’ including collagen, elastin and pressure.

Evidence to support this interpretation of what, for these three teachers, knowing a feature at a deep level means can be inferred from lesson 3 of John’s unit-of-work. The major purpose of this lesson is to encourage students to develop knowledge of the ‘biological entities’ artery, vein and capillary. When John is discussing the

'biological entity' vein, his students recall a feature of a vein that they have already come across – that is 'veins have valves'. John seems pleased that they remember this feature (i.e. they know it at a surface level) but he also appears to want them to know it at a deep level as he encourages them to explore, in this case, the 'why' of this feature – that is its importance in the wider biological context of the mammalian blood circulatory system. This is clear in the following quotation where his question ('what is the relevance of-, what is the point of veins having valves, why do veins have valves?') encourages one student to explore the usefulness that this feature of a vein plays in the overall working of the mammalian circulatory system.

J: Now there is something that veins have if you remember that arteries don't.

Sarah: They've got valves.

J: Valves, well done. Right. So what is the relevance of-, what is the point of veins having valves? Why do veins have valves?

Chloe: Because veins take blood back to the heart and cause they have to go up and the blood is at low pressure, it isn't pumped there, and so some blood might go back the wrong way, so the valves keep the blood going the right way and stop it going backwards.

J: Exactly that. What Chloe is saying for those who couldn't hear was that veins have valves because the blood really needs, it's not under pressure being forced through, it's draining if you like, that's how I always remember veins go back to the heart, they drain, veins are drains and they are draining back. Now if you're not pumping this blood through there's a good chance that it's going to slip back the wrong way, so you've got valves.

(L3 J 163-172)

Further corroboration of this interpretation is provided in the post-lesson interview following lesson 3. In this interview John makes clear that he wants his students to remember the feature 'veins have valves' (i.e. surface level knowing) but, in addition, he wants them to go beyond 'just remembering' and, in this case, be able to explore the 'why' of this feature of a vein – that is consider its significance in the wider

biological context of the mammalian circulatory system (i.e. deep level knowing). In his words:

Rather than just remembering parrot fashion 'veins have valves', you actually work back and think, 'why do they need valves?' 'Surely that blood's going fast enough, oh no hang on, there's nothing pushing it cause it's been through all the capillaries. What's happened in the capillaries to make it lose its pressure?'
(plint 3 J 132-136)

His reference to blood, pressure and capillaries in the previous quotation appears to form, in part, an exploration of the importance of valves to the 'biological entity' vein. These 'biological entities' seem, to John, to be integral to knowing this feature at a deep level. John refers to the ability to explore the significance of a feature in its wider biological context as 'reasoning behind things'. It seems that being able to reason behind things involves drawing upon other 'biological entities'. In the above quotation, John cites various 'biological entities' including blood, capillaries and pressure as necessary to any consideration of the significance of the feature 'veins have valves' in its wider biological context.

Comments from Sally also suggest that knowing a feature at a deep level means being able to explain the 'why' or 'how' of a feature in its wider biological context. In post-lesson interview 3 and 4, Sally reveals that she believes developing her students' knowledge of the two 'biological entities' endopeptidase and exopeptidase involves 'a lot of understanding'. It seems that the meaning of this phrase is similar to the meaning of John's phrase 'reasoning behind things' i.e. knowing at a deep level – being able to go beyond remembering and recalling a feature to explain the 'why' or 'how' of a feature. In this example, Sally's reference to 'understanding'

seems to be referring to being able to consider the 'why' of a feature, that is to consider its significance in a wider biological context. The evidence for this comes from lesson 3 of Sally's unit-of-work. In this lesson, Sally develops her students' knowledge of the 'biological entities' endopeptidase and exopeptidase by talking to them as a whole class. Through this teacher exposition, Sally identifies various features she deems her students need to know about the 'biological entities' endopeptidase and exopeptidase for success at A level. Two of these are:

Endopeptidases are used in the first stage of protein digestion.

(L3 S 128-129)

Exopeptidases are used in the second stage of protein digestion.

(L3 S 132-133)

Having stated these features, Sally goes on to consider the 'why' of these features, that is their significance in the wider biological context of protein digestion – why it is relevant that endopeptidases are used first in protein digestion and exopeptidases are used second. As is indicated in the excerpt from the lesson transcript below, Sally finds the 'biological entity' surface area useful in her exploration of the relevance of these features:

S: So if you do endo first, you just break it down to lots of smaller pieces, you are creating a greater surface area, if you think about it if you break it down into a smaller piece then you have got two ends haven't you? You have got more ends to work on. So without endopeptidases, the digestion of protein would take a long time because you are chopping it up into lots of smaller bits, its much quicker, it's more efficient.

(L3 S 133-138)

Observations of Catherine's teaching and comments in post-lesson interviews indicate too that, for her, knowing a feature at a deep level also means being able explain the 'why' and/or 'how' of the feature in its wider biological context. In lesson 1, when reviewing and developing students' conceptions of various 'biological entities' related to the gross structure of the human respiratory system, Catherine states the following feature of a trachea – the trachea is composed of C shaped rings of cartilage ('what you have is rings of cartilage around it [trachea] ... those rings are C shaped'). Catherine goes on to encourage her students to consider the why of this feature, that is its significance in the wider biological context of a functioning organism. She asks them why the rings of cartilage are C shaped ('Why is that?'). In order to consider the relevance of this, the students are encouraged to draw upon the 'biological entities' oesophagus and bolus as is evident in this lesson excerpt below:

C: those rings are C shaped, why is that?

Tanya: [^]

C: No, the oesophagus is behind it. Here is your trachea in the front, here is the oesophagus. What happens when you swallow, what are you swallowing?

Paul: Food.

C: Food, and what's the food called, that ball of food?

Paul: A bolus.

C: Is the food bolus going to be, what's it going to do as it goes down the collapsed tube?

Nerissa: Push it out.

C: Exactly, it's going to push it out and where's it going to have room to push into?

Peter: Into the C shape.

C: Into the C shape, into the trachea.

(L1 C 239-263)

In the post-lesson interview following this lesson Catherine spoke about this aspect of the lesson as successful because she felt her students had 'got to grips with the trachea, you know, the C shape rings and things. I think they really understood that after we'd talked about it' (plint 1 C 153-155). Her reference to 'getting to grips' and 'understanding' seems to resonate with John's phrase 'reasoning behind things' and Sally's reference to 'understanding' suggesting that Catherine's phrase similarly refers to being able to explain the 'why' or 'how' of a feature – that is knowing it at a deep level.

What is common to all these examples is that explaining the 'why' and/or 'how' of each feature in its wider biological context involves drawing upon one or more 'biological entities' other than the one to which the feature is connected. Indeed,

John articulates this when, reflecting on the part of lesson 3 where he encourages his students to explain the ‘why’ of the feature – capillaries are thin – by considering the relevance of this feature in the context of a functioning organism. He says:

reasoning behind things ... that’s one of the reasons I referred back to Fick’s Law ... and that’s why the capillaries are thin because they need to get a lot of things diffusing through

(plint 3 J 140-144)

In this quotation, John seems to be emphasising that the ‘biological entities’ Fick’s Law and diffusion are necessary to knowing the feature ‘capillaries are thin’ at a deep level.

Furthermore, Sally implies that explaining the ‘why’ and/or ‘how’ of a feature in its wider biological context involves drawing upon one or more ‘biological entities’ other than the one to which the feature is connected when she indicates the usefulness of ‘biological entities’ – what she refers to as ‘concepts’ and ‘ideas’ – in ‘understanding ... other things’. It is plausible that her reference to ‘other things’ refers to drawing upon ‘biological entities’ when developing biological knowledge at a deep level.

Finally, comments from Catherine suggest that she also feels that knowing at a deep level involves being able to draw upon ‘biological entities’ from different areas of biology. In post-lesson interview 1, reflecting on her discussion with students about the structure of the trachea, referred to earlier, Catherine indicates that her students needed to know other ‘biological entities’ including the oesophagus and bolus in order to develop deep level knowledge of the particular feature of a trachea discussed (i.e. the trachea is made up of C shaped rings of cartilage). In her words:

You see in order to get to grips with that, you know, understand the whole C shape and everything they needed to know things about digestion, you know, they needed to know about the shape, the bolus and about the oesophagus, you know where it is, how it sort of all connects in

(plint 1 C 155-157)

So far it has been proposed that knowing a 'biological entity' for success at A level involves knowing features of that 'biological entity' at a surface level and in some cases also at a deep level. Furthermore, establishing and appreciating the relationships between 'biological entities' is an integral part of coming to know the features of a 'biological entity' at either level. Indeed, knowing features of 'biological entities' at both levels seems to involve building networks of meaning between 'biological entities'. Consequently, 'biological entities' are represented not as discrete knowledge objects but instead as related to and interconnected with a huge network of other 'biological entities'. However, whilst the teachers perceive all 'biological entities' to be interrelated, the evidence suggests that they do not perceive all 'biological entities' to have equal status. It seems that the teachers believe there to be a core set of 'biological entities' (referred to as 'the basics', 'the important principles of biology', 'concepts that go all the way through biology' and including 'biological entities' such as enzyme, water potential and surface area) which are drawn upon time and again when developing knowledge of other 'biological entities'. Indeed, these core 'biological entities' appear integral to developing surface and deep level knowledge of features of many 'biological entities'. Sally indicates this when she talks of the significance of 'the basics' (i.e. core 'biological entities') in developing conceptions of other 'biological entities' (i.e. 'things') in the following quotation:

you can't forget the basics ... doing that helps in understanding some of the other things

(VI1 S 583-586)

Similarly, Catherine suggests the centrality of certain 'biological entities' (e.g. enzymes) to developing knowledge of many other 'biological entities' (e.g. living processes such as digestion, photosynthesis and homeostasis) when she says:

you remind them that yes there's an enzyme here because enzymes are involved in all living processes

(VI1 C 664-666)

Finally, John suggests the importance of the 'biological entity' specificity to the comprehension of 'biological entities' from differing topic areas in biology. In vignette interview 1, John makes clear that his students' understanding of specificity has up to lesson 8 of his unit-of-work manifested itself through the lock and key metaphor in relation to the 'biological entity' enzyme. In his words:

lock and key, there you are a concept they've had rammed into them since Year 9

(VI1 J 182-183)

In lesson 8, however, John is able to show the concept of specificity in another context, that of immunology. It appears that he draws upon his students' understanding of specificity in relation to enzymes – that is lock and key (i.e. shapes fitting together) – in order to help them develop their conceptions of the 'biological entity' antibody. It seems that, for John, one of the features of an antibody that he seeks his students to develop knowledge of is that 'an antibody has a specific shape

in order to bind to a specific antigen' (i.e. specificity). He makes this clear in the following quotation:

linking back to the lock and key concept ... it is so visually effective cause they can ... visualise in their mind shapes fitting together which they have actually been doing for years since they've been tiny kids, putting round things through round holes and they'll get, hopefully, you know, that concept [i.e. lock and key] is reinforcing the idea of these antibodies.

(VI1 J 197-202)

Knowing representations

In addition to features, the data indicates that, for these three teachers, knowing a 'biological entity' for success at A level involves a second element: knowing representations. It appears that a representation is a graphical or 3D depiction – e.g. a model – of one or more features concerning a particular 'biological entity'. A representation might depict, for example, certain characteristics of a particular 'biological entity'. It might represent certain features concerning the structure of a particular 'biological entity', or, if the 'biological entity' is a process, it might depict certain features concerning what the process involves.

It is suggested that these teachers believe in order to have knowledge of a particular 'biological entity' for A level success it is necessary to know certain representations of it. The first example of relevant evidence to support this proposal is evident in lesson 4 of John's unit-of-work and the interview following it. In this lesson, John develops his students' knowledge of the 'biological entity' capillary network through a drawing and discussion exercise. The students copy a diagram of a capillary network from an OHT as John identifies various features of this 'biological entity'. He

identifies this part of lesson 4 as successful as he believes that to have acquired knowledge of the 'biological entity' capillary network the students need to be familiar with a representation of it. In his words:

they need to know *what the capillary network looks like* with loads of cells in it and they'll need to know the arteriole and venule so they'll need to know the structure of it really

(plint 4 J 301-303 my emphasis)

The data also implies that Sally considers that knowing a 'biological entity' for success at A level requires knowing representations of it. Introducing the topic area of digestion in lesson 1, Sally emphasises that throughout this unit-of-work, her students will examine 'the structure of the digestive system ... what the parts *look like*' (L1 S 95-96 my emphasis). Whilst knowing the structure of various 'biological entities' might mean knowing various features concerning their composition, Sally's emphasis on 'what the parts *look like*' indicates that the students also need to know representations of these 'biological entities'. This suggests that, for Sally, part of knowing a 'biological entity' means knowing representations of that 'biological entity'. A comment made by Sally in post-lesson interview 1 provides further support for this claim. In this interview, Sally indicates that part of learning 'new concepts' requires being able to 'visualise them' (any new concepts ... they've got to sort of ... visualise them plint 1 S 95-99).

Finally, comments from Catherine in post-lesson interview 3 also suggest that she feels that knowing a 'biological entity' for success at A level requires knowing representations of it. In lesson 3 she introduces her students to the 'biological entity' the Krebs Cycle. They copy down a simplified diagram of the Krebs Cycle that she

produces on an OHT and are also given a handout with a diagram of the Krebs Cycle on it. She is very keen, as the following quotation suggests, for her students to come to know the basic representation of the Krebs Cycle that the scientific community offers. In her words:

Now, I want them to learn this diagram, but I also-, I gave them a handout of Krebs from another book, I want them to see that it might have different names in it and things but what it looks like is really the same. They need to know, you know, what it looks like. They need to recognise it.

(plint 3 C 254-259)

From the evidence and interpretation presented so far, it appears that to 'know' substantive biological knowledge for success at A level means to know various 'biological entities'. Furthermore, to know a 'biological entity' for success at A level comprises knowing various features of it and, where appropriate, knowing one or more representations of it. All features need to be known at a surface level – that is they need to be remembered so that, when appropriate, they can be recalled. However, certain features can also be known at a deep level. Knowing at a deep level involves being able to explain the 'how' or 'why' of a feature in its wider biological context. Knowing features at both levels involves being able to appreciate the relationship between the 'biological entity' the feature is connected with and one or more other 'biological entities'. Indeed, this interpretation suggests a characteristic of 'biological entities' – that is they are inter-related. It is not possible to know about one 'biological entity' without knowing about many others too. Finally, the interpretation presented suggests that the teachers wanted their students to appreciate the different status of 'biological entities' – that is that some 'biological entities' would be met over and over again when developing knowledge and

understanding of new 'biological entities' throughout the biology course. Such 'biological entities' have high status and are central to developing meaning in many different contexts.

To summarise, this analysis has suggested that these three teachers sought their students to conceptualise substantive biological knowledge as a network of related 'biological entities' (of differing status) where a 'biological entity' is conceptualised as comprising a constellation of features and, where appropriate, one or more representations. The next section will consider how these teachers encouraged their students to develop and retain such conceptions.

Encouraging students to conceptualise substantive biological knowledge in particular patterned ways

The last section outlined the particular conceptions of substantive biological knowledge these three teachers sought their students to develop across their units-of-work. The focal point of these conceptions is the concept of 'biological entity'. Consequently, the focus of the teachers' attempts to develop such conceptions of substantive biological knowledge concerned encouraging students to develop and retain knowledge of 'biological entities'.

All three teachers employed subject matter tasks⁶ to encourage their students to develop and retain knowledge of 'biological entities'. Across their units-of-work the teachers used a variety of subject matter tasks to introduce their students to various 'biological entities'. In lesson 2 of her unit-of-work, for example, Catherine engaged her students in a teacher lecture and student note-taking task to develop their knowledge of the 'biological entity': glycolysis. In lesson 4 of his unit-of-work, John engaged his students in a drawing exercise to develop their knowledge of the 'biological entity': capillary network. In lessons 3 and 4 of her unit-of-work, Sally engaged her students in a research and written presentation task to develop their knowledge of various 'biological entities' related to the topic of digestion.

⁶ In the context of this thesis a subject matter task is defined as a combination of: the 'biological entities' of which knowledge is to be developed; and the medium through which knowledge of these 'biological entities' is developed. An example of a subject matter task is the group research and oral presentation (medium) that John set his students in lesson 6 of his unit-of-work in order to encourage them to develop knowledge of various 'biological entities' related to circulation, including the oxygen dissociation curve and haemoglobin.

However, all the subject matter tasks employed during the three teachers' units-of-work shared one characteristic – they were carefully structured by the teachers so that during each task one or more of the following events were enacted:

- features were identified;
- representations were identified;
- opportunity was given to explore the 'why' or 'how' of a feature in its wider biological context.

It seems that by structuring the tasks such that one or more of the events outlined above were enacted, the teachers encouraged their students to come to know 'biological entities' in the particular sort of way they deemed appropriate to ensure A level success – that is as:

- a constellation of features;
- related to a wider network of 'biological entities';
- one or more representations, where relevant.

The sorts of subject matter tasks the teachers employed, therefore, might best be described as 'teacher centred' since even when the students seemed, on the surface, to be given some freedom (e.g. the research and written presentation task Sally set in lesson 3 of her unit-of-work) the teachers carefully controlled the ways in which their students explored the substantive biological content such that they encouraged them to come to know it in specific ways. What follows is a description

of a task from each teacher's unit-of-work and a discussion of how it was structured so that their students came to know specific 'biological entities' in the particular sort of way outlined above.

In lessons 3 and 4, Sally wants to develop her students' knowledge of various 'biological entities' related to the topic of digestion⁷. She selects a research and written presentation subject matter task as the medium through which this knowledge will be developed. This involves allocating each student one or more 'biological entities' to investigate. The purpose of this investigation is to produce an 'information poster' which will be displayed in the classroom and drawn upon in future activities.

Sally structures this subject matter task so that she can encourage her students to come to know these various 'biological entities' as a constellation of features, as related to a wider network of 'biological entities' and also, in some cases, as specific representations. She does this by giving strict instructions at the start of the exercise as to the format of the 'information poster'. In her words the 'information poster' has to include 'bullet point things and diagrams where necessary' (L3 S 7). It is plausible to suggest that Sally's reference to 'bullet point things' refers to the fact that she wants her students to identify and develop knowledge of various features of the specific 'biological entities'. Furthermore, it is likely that her reference to 'diagrams where necessary' refers to the fact that, where appropriate, she wants her students to identify and come to know specific representations of these 'biological entities'. Moreover, implicit in the process of developing knowledge of various features of

⁷ These include mouth, oesophagus, mucosa, sub mucosa, muscularis externa, serosa, stomach, gall bladder, bile, pancreas, villi, intestinal wall, colon and caecum.

‘biological entities’ is the building of networks between the ‘biological entity’ to which the feature is connected and other ‘biological entities’. The reason for this was explained earlier – knowing a feature of a ‘biological entity’ at a surface or deep level involves being able to appreciate the relationships between the ‘biological entity’ the feature is connected with and one or more other ‘biological entities’.

To summarise, it seems that by limiting the format of the ‘information poster’, Sally encourages her students to develop a certain sort of knowledge of the ‘biological entities’ that are the focus of the task. But how do her students know which features and which representations to select for their information poster? The variety of textbooks available present them with a considerable amount of detail. How are they to make decisions about what information to include and what information to leave out?

Sally clearly had no intention of abandoning her students to make such decisions themselves. Instead, she encourages them to select what she believes to be the appropriate features and representations to know of the ‘biological entities’ in two ways. First, she provides the students with a verbal framework at the start of the lesson. This signposts the areas the students should focus on when selecting features to include in their information poster (see Box A overleaf for an outline of this verbal framework).

Box A

Sally verbally proposes the following framework for her students in the research and written presentation exercise in lesson 3. It suggests the areas the students should focus on when identifying features about the particular 'biological entities' they are investigating. These areas include:

- Structural characteristics connected with mammalian digestive structures
(‘What the basic layers of each of the parts are like. Why they are different’ - L3 S 2-3, ‘structure if it’s a structural thing’ – L3 S 41)
- Functional characteristics connected with mammalian digestive structures
(‘what each of the parts of the digestive system does’ – L3 S 2)
- Structural characteristics of digestive secretions connected with mammalian digestive structures
(‘What the digestive juices produced are’- L3 S 3, ‘Juices and any contents of juices.’ – L3 S 42)
- Functional characteristics of digestive secretions connected with mammalian digestive structures
(‘the action of the juices’ – L3 S 44)
- Stimulus of digestive secretions
(‘Whether the juices are produced by nerves or by hormones or both.’ – L3 S 3-4, ‘whether they are stimulated, whether it’s nervous, whether it’s hormonal or whether it’s a mixture.’ – L3 S 44-45)
- Site of production of digestive secretions
(‘What the juices are produced by, which particular bits’ – L3 S 43)

This framework indicates, for example, that if a student is researching a digestive structure such as the stomach s/he should investigate:

- what it is made of;
- what role it plays in the body;
- whether it produces any digestive juices and if so:
 - what the components of these juices are;
 - what role they play in digestion;
 - what stimulates their production.

Second, Sally personally identifies particular features for individuals to include in their respective information posters. For example, she gives quite specific information to one of her students when allocating her the 'biological entity' mouth. In her words:

S: Right, Eleanor, you do the mouth ... obviously we talk about amylase, saliva with amylase in it. Mechanical digestion. Right, that's your task.

(L3 S 40-43)

In this quotation, Sally establishes the function of the mouth as 'Mechanical digestion'. Furthermore, she identifies the important secretion connected with the mouth, that is saliva, and also one of its key components, amylase.

Similarly, when talking individually to the student researching the colon, Sally identifies one of the features she feels this student ought to know about it, namely it's function. In this quotation from the lesson transcript, Sally directly establishes the particular function of this 'biological entity' as, in her words, 'reabsorption of water'.

you want to talk about the colon ... the colon being involved in reabsorption of water

(L3 S 73-74)

In both of these examples, through identifying a specific feature of the 'biological entities' mouth and colon, Sally is also highlighting relationships between these 'biological entities' and a number of other 'biological entities'. For example, the 'biological entity' mouth is identified as related to the 'biological entities' saliva and amylase and the 'biological entity' colon is identified as related to the 'biological entity' water. Sally is beginning the process of building a network of relationships between each 'biological entity' and other related 'biological entities'.

To summarise, it is suggested that Sally's explicit instructions at the beginning of the subject matter task encourage her students to develop a certain sort of knowledge of the 'biological entities' that are the focus of the task, i.e. knowledge of features of them, knowledge of other 'biological entities' to which they are related and, in some cases, knowledge of representations of them. Furthermore, Sally's verbal framework and her self identification, in individual conversations with students, of particular features and representations associated with specific 'biological entities' encourages her students' selection of what she believes to be the essential facets of knowledge they must learn about these 'biological entities' for success at A level.

Similar to Sally, Catherine also carefully structures her subject matter tasks to encourage her students to come to know 'biological entities' in a particular sort of way. In lesson 3 of her unit-of-work, Catherine introduces her students to the 'biological entity' the Krebs Cycle. She chooses a teacher lecture and student note-taking subject matter task as the medium through which knowledge about this 'biological entity' will be developed. Catherine structures this task in a number of ways to encourage her students to come to know the Krebs Cycle as a constellation of features, as related to a wider network of 'biological entities', and as a specific representation. The different ways in which she structures the subject matter task are outlined below.

First, Catherine identifies features of the Krebs Cycle herself as can be seen from the following excerpt from lesson 3:

C: And the next stage in the process, step three, also takes place in the mitochondrial matrix and is aerobic. If you remember we haven't used any oxygen and it's called Krebs Cycle. ... Now it is a cycle so things are going to go round and round and round

(L3 C 229-241)

In this quotation she identifies for her students the following features of the Krebs Cycle:

- that it takes place in the mitochondrial matrix;
- that it is a cycle;
- that it is aerobic.

The students note these features down. In this example, as in all examples given below, not only are features of the 'biological entity' the Krebs Cycle identified but also through this identification relationships between the 'biological entity' the Krebs Cycle and other 'biological entities' are established. For example, in the above quotation, the Krebs Cycle is identified as related to the mitochondrial matrix. In this way the identification of features is coupled with encouraging students to appreciate that the 'biological entity' in question is related to a wider network of 'biological entities'.

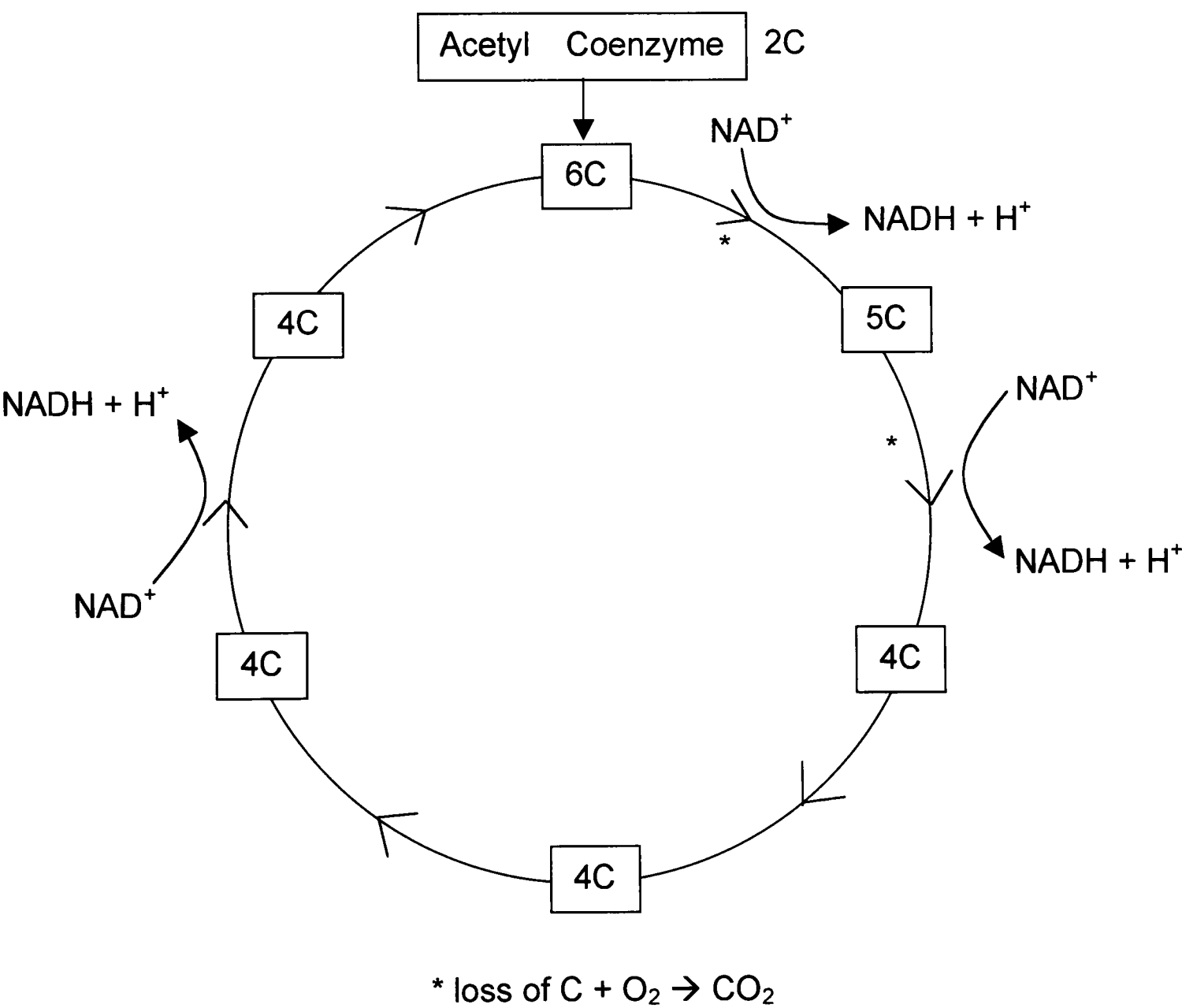
Second, Catherine introduces her students to a representation she has produced of the Krebs Cycle on an OHT (see figure 6.1 overleaf for a reproduction of this representation). This representation is a very simplified version of an exceedingly complicated cyclical process. The students copy the representation into their notes.

Catherine uses this representation to identify further features of the Krebs Cycle. For example, in the following quotation from the transcript of lesson 3 Catherine identifies the feature – the Krebs Cycle involves the removal of hydrogen at different points. In her words:

C: Hydrogen is being lost there, there and there [Catherine is pointing to the parts of the diagram where the following is written – $NAD^+ \longrightarrow NADH + H^+$] and is being picked up by the hydrogen acceptor ... It picks up two H's and goes off again. ... the basic principle of all this ... is the loss of hydrogen at different points.

(L3 C 252-283)

Figure 6.1 A reproduction of the representation of the Krebs Cycle that Catherine uses in lesson 3 of her unit-of-work



Third, using this representation, Catherine identifies additional features of the Krebs Cycle. She annotates the diagram to illustrate these new features (see figure 6.2 for a reproduction of this annotated diagram) and the students note down these annotations. This involves identifying various features concerning the production of intermediate compounds during the Krebs Cycle. At this point, a handout of the Krebs Cycle is also given to the students to assist with this identification process (see figure 6.3 for the handout).

Figure 6.2 A reproduction of the annotated representation of the Krebs Cycle that Catherine uses in lesson 3 of her unit-of-work

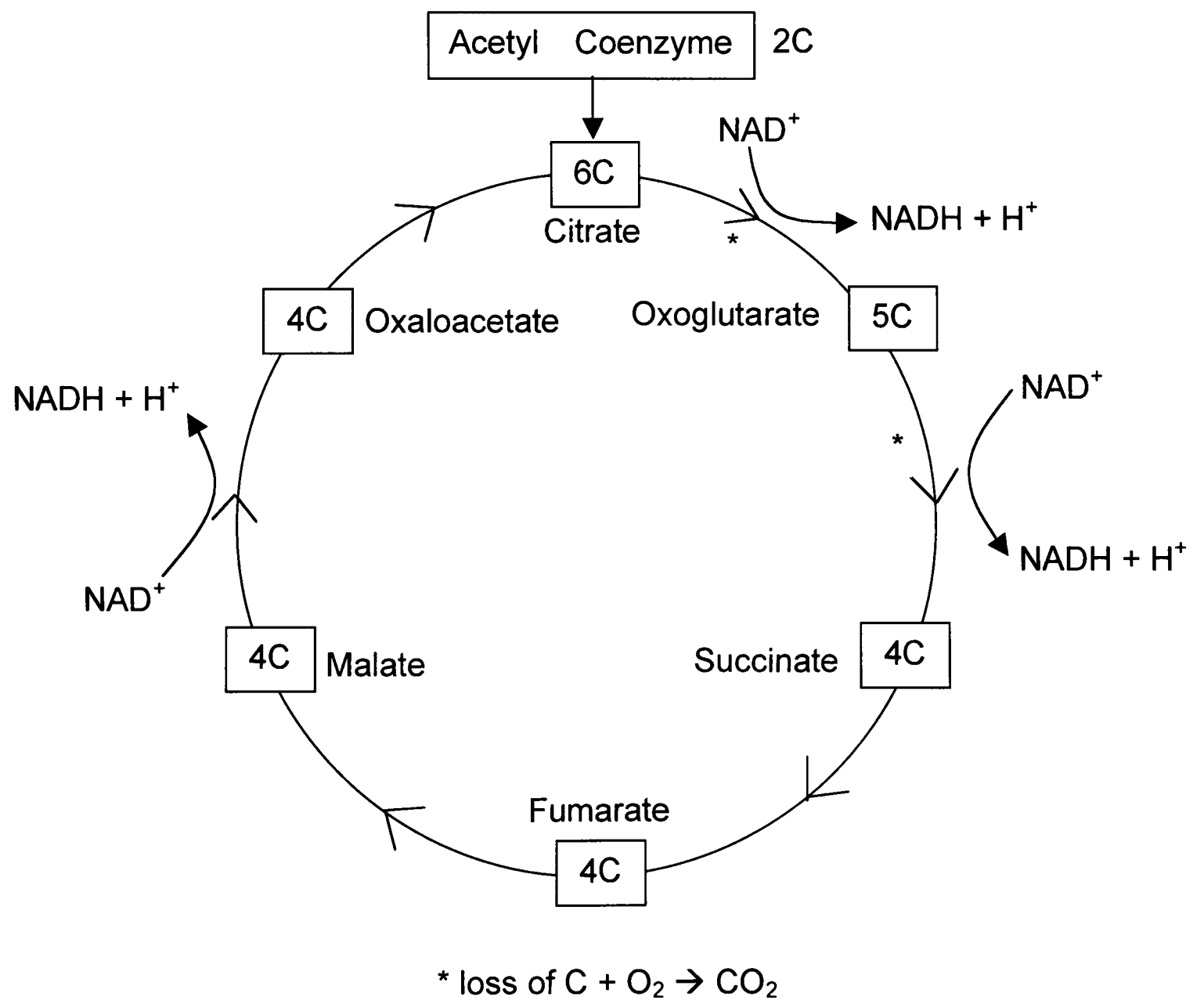


Figure 6.3 A reproduction of the handout Catherine gives her students to accompany them in this task

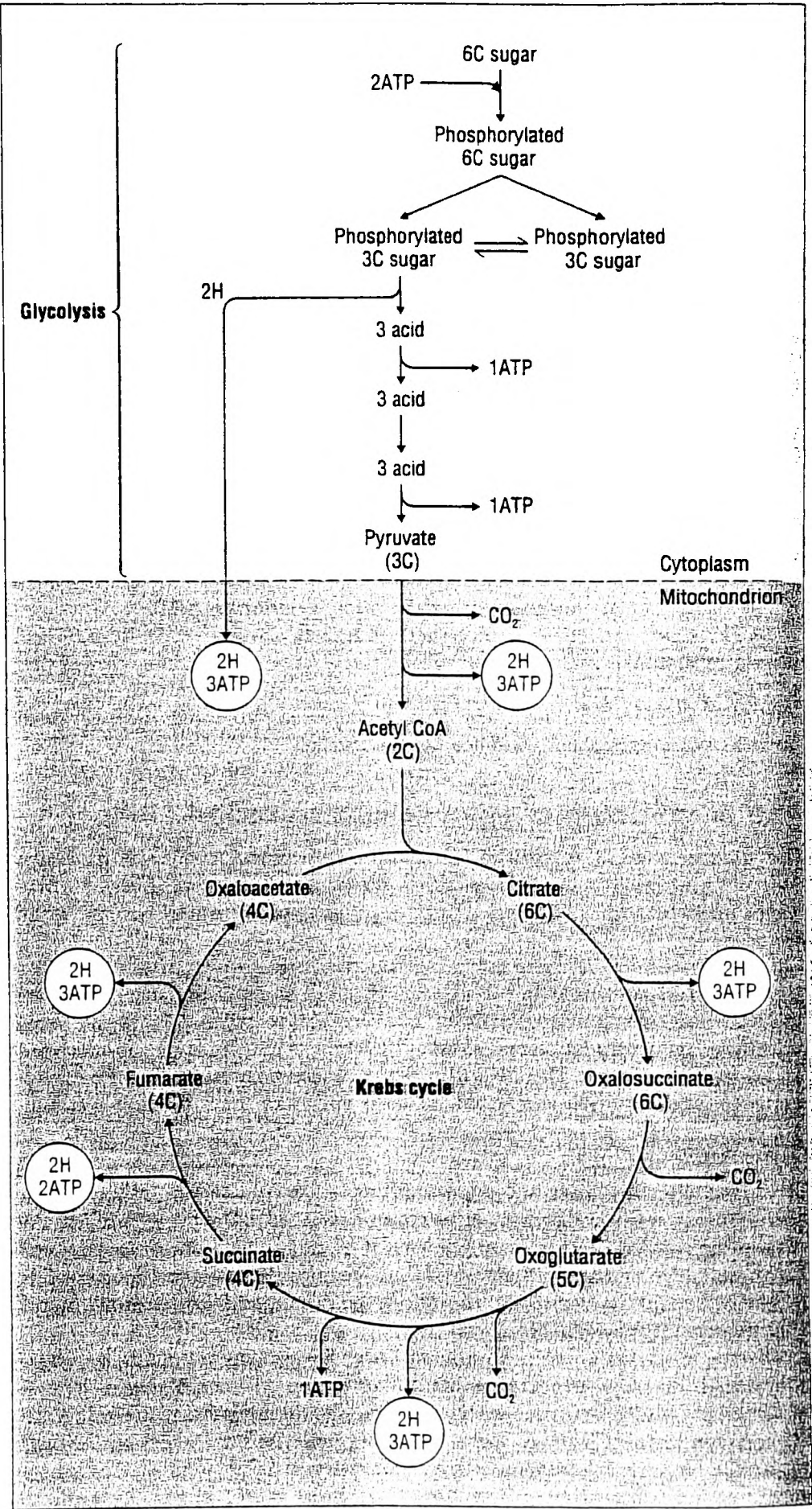
The release of energy

Figure 14.5 The metabolic pathway in which sugar is broken down in respiration. The process starts with phosphorylation of 6-carbon sugar (glucose). In the diagram this is shown happening in one step but in fact it involves several steps. In the first a phosphate group is added to the glucose molecule, resulting in the formation of **glucose 6-phosphate**, so-called because the phosphate group is attached to the glucose molecule at position 6 (see page 126). A second phosphate group is then attached to the sugar which is subsequently split into two molecules of 3-carbon sugar. These are in equilibrium with each other and normally both are converted into pyruvic acid and fed into the Krebs cycle.

The overall function of the pathway is to produce ATP molecules. Energy is transferred to ATP mainly as a result of the removal of pairs of hydrogen atoms from intermediate compounds in the pathway. The diagram shows the stages at which hydrogen atoms are removed, together with the numbers of ATP molecules synthesised. The ATP molecules circled are produced via the hydrogen carrier system which is explained on page 234. Usually three ATP molecules are synthesised every time two hydrogen atoms pass through the carrier system. However, in the conversion of succinate to fumarate only two ATPs are produced because in this case the initial carrier (NAD) is absent.

One of the most important intermediates in the pathway is acetyl CoA because it links glycolysis with the Krebs cycle. Coenzyme A is a complex molecule derived from the vitamin pantothenic acid (see page 149). Its function is to transfer an acetyl group (CH_3CO) from pyruvate to oxaloacetate. In this way two carbon atoms are added to the oxaloacetate with the formation of citrate.

The process outlined here is called **oxidative phosphorylation**. It is oxidative in the sense that hydrogen atoms are removed from certain compounds and combined with oxygen. It is phosphorylation in that phosphate groups are added to ADP to give ATP. The process also involves **decarboxylation**, the removal of carboxyl groups with the formation of carbon dioxide.



Fourth, using the representation reproduced in figure 6.1, Catherine asks her students specific questions in order to assist them with identifying certain features of the Krebs Cycle themselves. For example, she asks them the following question:

C: Now all I've shown on there is something is happening. What is happening?

Amanda: The carbon is being taken away.

C: So the carbon is being lost between steps one and two there.

(L3 C 246-251)

In this case, one student interprets the representation and identifies the very feature of the Krebs Cycle that Catherine seems to want to elicit from them.

To summarise, Catherine uses a variety of techniques to structure this subject matter task to encourage her students to come to know the Krebs Cycle in a particular sort of way. The production of her own simplified representation of the Krebs Cycle seems to play a key role in the structuring process. She uses this diagram to:

- identify features of the Krebs Cycle herself;
- represent the Krebs Cycle in an uncomplicated way;
- encourage students to identify features of the Krebs Cycle themselves.

It seems that Catherine has a clear idea of the basic features of the Krebs Cycle she wants her students to know. She thoughtfully constructs a simple diagram to assist in the identification of many of these features. In conjunction with this diagram, she carefully selects a diagram from a textbook which she photocopies for her students and uses to identify further features. Thus, by structuring the task in this way Catherine encourages her students to construct the meaning of the 'biological entity'

the Krebs Cycle as a constellation of various features, as related to a wider network of 'biological entities' and as a particular representation.

Finally, there is evidence to suggest that John also carefully structures his subject matter tasks to encourage his students to come to know 'biological entities' in a particular sort of way. In lesson 3, John wants his students to acquire knowledge of various 'biological entities' including capillary, capillary network, sphincter muscle, pavement endothelium and shunt vessel. He employs a comprehension subject matter task to encourage his students' development of this knowledge. In this task, the students read a passage from the textbook and answer three questions written by John on an OHT. Throughout this task, John circulates around the classroom speaking to students individually (see Box B overleaf for a reproduction of this text and questions).

John structures this subject matter task in two ways to stimulate his students' acquisition of knowledge of these 'biological entities' as a constellation of features, as particular representations, and as related to a wider network of 'biological entities'. First, he carefully selects the text that will form the basis of the comprehension. This text contains reference to the relevant features of each 'biological entity' he wants his students to know as well as an exploration of the 'how' and 'why' of some of the features in their wider biological context.

Box B**A reproduction of the text and comprehension questions***The capillaries*

As a transport system, the job of the circulation is to take up materials in one part of the body and deliver them to another. There must therefore be an intimate relationship between the circulatory system and the tissues. This is achieved by the **capillaries**.

Figure 19.20⁸ shows a small part of a capillary network. In contrast to arteries and veins, the capillaries are narrow (an average of 10 μm in diameter) and thin walled. The wall consists of a single layer of very thin **pavement epithelium** which allows rapid diffusion of dissolved substances into or out of the capillary. The cells are bathed in tissue fluid derived from the blood plasma which provides a medium through which diffusion can take place. The close proximity between the capillaries and the tissue cells, and the thinness of the barrier between them, facilitates this exchange of materials.

The flow of the blood through the capillaries can be regulated. Rings of muscle surround the ends of the arterioles at the points where they break up into capillaries. Under the influence of nerves, hormones or local conditions, these **sphincter muscles** contract or relax, thereby decreasing or increasing the flow of blood through them.

In some parts of the body larger vessels form a direct connection between arteries and veins, thereby bypassing the capillaries. By constricting or dilating, these **shunt vessels** can regulate the amount of blood which flows through a particular set of capillaries at any given time. This occurs in parts of the body where the blood flow needs to be adjusted according to the external temperature (see page 400).

The capillaries are like a vast irrigation system, different parts of which can be opened or closed according to local needs and conditions. This coupled with the fact that the heart can vary its rate of beating, makes the mammalian circulation a highly adaptable transport.

Questions written by John on the OHT

What is the relevance of pavement endothelium to a capillary?

What is the relevance of sphincter muscles to a capillary network?

What is the relevance of shunt vessels to a capillary network?

⁸ This figure is reproduced in Appendix H (see p.414).

Second, he carefully words the three questions. On the face of it, constructing answers to these three questions appear to encourage students to develop knowledge of various features of a capillary and a capillary network at a deep level (i.e. being able to consider the 'why' of various features of a capillary and a capillary network in the wider context of the mammalian circulatory system.). However, a prerequisite to exploring the significance of these features would be to know, at a surface level, various features of the 'biological entities' pavement endothelium, shunt vessel and sphincter muscle. Indeed, it appears that implicit in being able to answer these questions is the first step of identifying particular features of the 'biological entities' pavement endothelium, shunt vessel and sphincter muscle. This is apparent when John introduces the task to his students. In the following quotation, he highlights the two aspects to the task, that is first identifying features of pavement endothelium, sphincter muscles and shunt vessel and then moving on to consider the significance of these three features to a capillary and a capillary network. In his words:

J: I'd like you to do a bit of reading ... read the paragraph called the capillaries, the three new terms, newish terms, pavement endothelium, sphincter muscles, shunt vessels ... I want you to find out some stuff about the three terms and then think about their relevance to capillaries and capillary networks by answering these three questions, ok?

(L3 J 317-327)

Being able to answer the three questions requires first identifying various features of pavement endothelium, shunt vessel and sphincter muscle and then being able to consider the significance of each of these structures to their respective 'biological entities' (i.e. pavement endothelium to a capillary and shunt vessel and sphincter muscle to a capillary network). Implicit in engaging in both of these processes is

appreciating and recognising the relationships that exist between different 'biological entities'. Answering these questions, therefore, encourages John's students not only to come to know various 'biological entities' as a constellation of features but also as related to a wider network of 'biological entities'.

So far it has been argued that these teachers carefully structure their teaching so their students develop and retain biological knowledge in a particular sort of way. However, it appears that the teachers also used an additional strategy to encourage their students to retain biological knowledge for retrieval when necessary (i.e. examinations). This strategy comprises the frequent rehearsal ('recap', 'recall', 'going ... over things', 'revisiting') of knowledge.

Catherine indicates this when she says in the following quotation:

Recap and recall ... that's helping just the learning

(VI1 539-541 C)

Similarly, Sally reiterates this point when in post-lesson interview 6 she comments that:

the more you tell them ... the more likely it is to sink in

(plint 6 120-122 S)

Sally's use of the metaphor 'sink in' implies that the more times her students come into contact with knowledge about 'biological entities' the more likely they are to remember this knowledge.

Finally, John indicates, in vignette interview 1, that the frequent review of 'biological entities' leads to retaining knowledge about them. In this interview, he expresses delight that, in lesson 9 when learning about the 'biological entity' monoclonal antibody, his students remember knowledge about the 'biological entity' enzyme that he refers to as having been 'rammed into them since Year 9'. The use of the metaphor 'rammed' suggests that they have come across knowledge relating to this 'biological entity' on many occasions and, as a result, have retained it.

These quotations suggest that the teachers held certain beliefs about the nature of learning assuming that frequent contact with the same information eventually leads to its internalisation and easy retrieval. Furthermore, given that developing knowledge of 'biological entities' is so dependent on drawing upon knowledge of other 'biological entities' this frequent revision process is likely to ensure that knowledge and understanding about certain sorts of 'biological entities' (in particular those deemed to be central to the subject or key to a particular topic area) is constantly kept at the forefront of students' minds so it can be used when necessary.

The teachers employed a variety of strategies to rehearse the biological knowledge they introduced to their students. The most common strategies were question and answer sessions at the beginning or end of lessons reviewing features of 'biological entities' and, on occasion, also reviewing representations of 'biological entities'.

In this section, it has been argued that these three teachers carefully structure their subject matter tasks to encourage their students to come to know substantive

biological knowledge as a network of related 'biological entities' where a 'biological entity' is conceptualised as a constellation of features and, where appropriate, also one or more specific representations. Indeed, it has been suggested that the pedagogical strategies they use in their teaching encourage the development and retention of this desired conception of substantive biological knowledge in their students.

How do the teachers decide what substantive biological knowledge needs to be known and in what ways it needs to be known for success at A level?

In light of the fact that these teachers believe that to learn substantive biological knowledge for success at A level their students need to conceptualise this knowledge in particular sorts of ways, it is plausible to suggest that they have to make a series of decisions concerning:

- what 'biological entities' are important to study within a specific topic area;
- what features of these chosen 'biological entities' need to be known and at what depth they need to be known;
- what representations of these chosen 'biological entities' need to be known.

Indeed, the evidence indicates that these three teachers do make decisions concerning which 'biological entities' they believe important to study within specific topic areas for student success at A level. Catherine, for example, clearly regards respiratory quotient to be an important 'biological entity' to study as part of the respiration topic she teaches during this research when, in post-lesson interview 4, she states that:

they simply have to do respiratory quotients

(plint 4 C 31-2)

In addition, John implies that he considers the 'biological entities' oxygen dissociation curve and Bohr effect to be important to study as part of the blood and circulation topic he teaches during this research. This is clearly indicated when he states that

his aim for lesson 6 was to develop his students' knowledge of these two 'biological entities'. In his words:

my plan was the dissociation curve ... and the Bohr effect

(plint 6 J 18)

Finally, Sally indicates that she deems the 'biological entities' endopeptidase and exopeptidase important to study as part of the digestion topic she teaches during this research when she says:

this [referring to endopeptidase and exopeptidase] is something that they need to know

(plint 6 S 118-119)

Furthermore, there is evidence to support the proposal that these teachers make decisions regarding which features and representations they consider need to be known about specific 'biological entities' for A level success. In lesson 3 of John's unit-of-work, for example, he engages his students in an exercise that involves them copying a diagram of a cross-section of an artery, vein and capillary from their textbook. John indicates to his students what knowledge he seeks them to acquire about capillaries from this exercise. In his words:

All you need to show is that it's very thin ... the capillaries are very thin, single celled vessels.

(L3 J 274-275)

This remark suggests that the students need to acquire knowledge of two features of the structure of a capillary – 'a capillary is made of a single layer of cells' and 'the walls of a capillary are very thin'. Furthermore, John's comment, 'All you need to

show' (my emphasis), implies that the students need to become familiar with the textbook's representation of these two features. John's statement, '*All you need to show'* (my emphasis), suggests also that there are more features concerning capillaries, and possibly further representations of those features, that the students could learn about. Indeed, there are. They could learn, for example, that the cells that constitute a capillary are not attached tightly to each other but rather are separated by narrow spaces filled with tissue fluid. They could then familiarise themselves with a more appropriate representation of a capillary in light of this knowledge. For the students' purposes – that is success at A level – however, it seems that John perceives the two features and the representation of these features, in the form of the cross-section illustrated in the textbook, as sufficient.

Similarly, comments from Catherine indicate that there are certain features she wants her students to know about the 'biological entity' the Krebs Cycle. In lesson 3, Catherine develops her students' knowledge of this 'biological entity'. It is clear from the interview that follows this lesson that there were a number of features that Catherine wanted her students to learn about this 'biological entity'. Catherine summarises some of them in the following quotation:

good biology teaching ... was showing them ... getting the important parts of the Krebs Cycle ... reducing the carbon, showing that oxygen for the first time was coming in cause we said it was an aerobic process ... and then ... these hydrogens

(plint 3 C 44-49)

Moreover, the data suggests that Catherine recognises her students could learn more about the Krebs Cycle than the features she establishes in this lesson. This is

implied by her use of the word 'detail' in the following quotation from post-lesson interview 3:

here was a good opportunity, a great opportunity to colour it with detail
(plint 3 C 122-123)

She decides, however, that the features she establishes in the lesson – implied by her use of the phrase 'the important bits of biology' in the following quotation – are enough for her students to know for success at A level. In her words:

the important bits of biology. That's what they need for this, you know, for A level.

(plint 3 C 35-36)

Comments from Sally's interviews also suggest that she makes decisions about what sorts of features and representations she wants her students to know about the various 'biological entities' that form the basis of her subject matter teaching. For example, in post-lesson interview 3 she identifies an aspect of her successful teaching as talking individually to each of her students about their research of various 'biological entities' involved in digestion. It seems that these conversations involve Sally identifying the specific features (referred to in the following quotation as 'points') of the 'biological entities' they have been assigned that she considers they need to know for success at A level. In her words:

I thought it's good to be able to talk to each person about what they have to-, what information they have to include ... I went round and talked to them I was able to highlight the important points.

(plint 3 and 4 S 17-24)

Finally, there is evidence to tentatively suggest that these teachers also make decisions concerning the level at which they deem their students need to know various features for success at A level. This can be seen in lessons 3 and 8 of John's unit-of-work. Evidence from lesson 8 and the interview following it implies that John wants his students to know a particular feature of a lysosome – that is 'lysosome is a membrane bound organelle' – at a surface level. In the lesson, when in unison his students recall this feature he says 'You're like parrots aren't you, very good like parrots'. His reference to parrots seems to imply that they have committed this feature to memory. They can remember and recall this exact feature when necessary. They know this feature at a surface level.

In contrast, in lesson 3, it is apparent that John wants his students to know a feature of a vein – that is 'veins have valves' - at a deep level. In the interview following this lesson, he makes this clear when he says:

Rather than just remembering parrot fashion 'veins have valves', you actually work back and think, 'why do they need valves?' 'Surely that blood's going fast enough, oh no hang on, there's nothing pushing it cause it's been through all the capillaries. What's happened in the capillaries to make it lose its pressure?' So as they go on they're ... reasoning behind things

(plint 3 J 132–141)

In this quotation, John stresses that he wants his students to go beyond remembering the feature veins have valves. Instead, it seems he has decided he wants his students to know this feature at a deeper level – i.e. consider its significance in a wider biological context - as implied by his reference to 'reasoning behind things'.

In light of these observations, it might be inferred that, for these teachers, part of their expertise lies in being able to select which 'biological entities' they consider their students need to know, within a given topic area, for success at A level. In addition, a further part of their expertise might comprise an awareness of the ways in which they believe their students need to know these 'biological entities' for examination achievement. This seems to involve identifying which features and representations of a specific 'biological entity' are important to know and deciding at what level – surface and/or deep – these features need to be known.

But, how do these teachers select which 'biological entities' – out of the many within the discipline – they consider their students must know for success at A level when studying specific topic areas? Furthermore, how do these teachers select which features about and representations of them they deem necessary for their students to know? Moreover, how do they select at which level these features need to be known? In short, what decision-making processes underpin the content selections they make?

An additional outcome of this thesis is a recognition that some further follow up research to this project might involve exploring the decision making processes that the teachers employ when selecting 'biological entities' to be studied for success at A level and deciding in what way they need to be known. The evidence available, however, does make it possible to conjecture the likely factors that inform such decision making.

Comments from the teachers indicate that two factors inform their decision-making in this area: knowledge of the syllabus; and experience of past examination questions. It seems that syllabuses themselves can suggest directly which ‘biological entities’, within a specific topic area, need to be studied. This is indicated in vignette interview 1 when John says that the ‘biological entity’ monoclonal antibody is directly stated in his syllabus. In his words:

It came up in the syllabus, sorry, it’s in the syllabus, and they do specify it ...
Monoclonal antibodies

(VI1 J 327-328)

Experience of past examination papers also seems to inform the teachers’ decision-making regarding what ‘biological entities’ to include in their teaching of various topics. John, for example, suggests that the ‘biological entity’ oxygen dissociation curve is important to study as students are frequently assessed on this part of the course in their examinations. In his words: ‘questions are guaranteed to come up’ (p1int 6 J 73).

Similarly, Sally also outlines exopeptidases and endopeptidases as two ‘biological entities’ her students ‘need to know’ for success at A level. Her experience both as a classroom teacher and examiner has led her to conclude that questions concerning these two ‘biological entities’ are often found on examination papers and that students are rarely able to distinguish between them. In her words:

I was plugging it a lot [that is the difference between endopeptidases and exopeptidases] because having I suppose read the exam papers where people hadn't a clue about the differences between them and this is something that they need to know

(plint 6 S 116-119)

Experience of past examination questions also seems to inform the teachers' perceptions of the ways in which they deem their students need to know a particular 'biological entity' for success at A level. Catherine illustrates this. When deciding which features her students need to know about the 'biological entity' the Krebs Cycle, Catherine's experience of past examination questions suggests they need to know various features concerning the intermediate compounds formed in the Krebs Cycle. In her words:

in terms of the names of the substances they do need to know some names, they do, you'll see it in the ... questions that they get in a biology exam

(plint 3 218-223 C)

Consequently, she includes various features concerning intermediate compounds when constructing the meaning of the Krebs Cycle in lesson 3 of her unit-of-work.

In addition to the two factors already discussed, it is possible to speculate that there might be a further tool that Sally uses to help her select the features and representations she considers her students need to learn in order to know a specific 'biological entity' for success at A level. This tool seems to be a guiding framework that assists Sally in her selection process. Whilst there is no direct evidence from Sally's interviews that she uses this tool, she was observed using it with her students in lessons 3 and 4. In these lessons, as was described earlier on in this chapter,

Sally engages her students in a research and written presentation task. The students are allocated certain 'biological entities' relating to the topic area of digestion and they have to investigate these and produce an information poster about them. To assist her students in their selection of features about, and representations of, the specific 'biological entities' they are investigating, Sally provides them with a verbal framework at the beginning of the lesson (this is outlined in Box A on p. 246). This framework provides the students with a general guide as to what to include in their written presentations. It suggests, for example, that if they are investigating a digestive organ, they should include some information about what the digestive organ is made of, and what role the digestive organ plays in the mammalian body. In short, the framework suggests that, with respect to digestive organs, the students must include features (and possibly representations) about the organ's structure and function. In lesson 3 then, Sally used this guiding framework to help her students select the features and representations she considered they needed to learn in order to know specific 'biological entities' related to the topic of digestion for A level success. It is possible that guiding frameworks similar to the one exemplified here might help Sally when she is selecting which 'biological entities' need to be known and in what ways they need to be known in topic areas across the entire A level biology curriculum.

Finally, although there is no direct evidence from the observations of the teachers or the interviews with them, it is possible to conjecture several further factors that might influence their decision making in this area. It is probable that examiner reports on past A level examinations, the textbooks the teachers use to prepare and set work for

their students and discussions with colleagues might also have an impact on their decision making regarding which 'biological entities' they consider their students should study within a specific topic area and the depth to which they should be studied to ensure A level success.

To summarise, so far this chapter has argued that these teachers sought to encourage their students to conceptualise substantive biological knowledge in particular sorts of patterned ways. This involved viewing substantive biological knowledge as a network of related 'biological entities' – of differing status – where a 'biological entity' is conceptualised as comprising a constellation of features – to be known at a surface and/or deep level – and, where appropriate, one or more representations. Furthermore, it has been suggested that these teachers considered that viewing substantive biological subject matter knowledge in these patterned ways would help their students to develop and retain the vast amount of knowledge they would need to retrieve in order to be successful in their A level examinations. Moreover, it has been proposed that the teacher-centred pedagogical strategies the teachers used in the classroom served to develop and reinforce these conceptualisations of substantive biological knowledge in their students. Whilst it has been pointed out that the decision-making processes that the teachers employ when selecting these 'biological entities' and deciding in what ways they need to be known for success at A level is beyond the scope of this thesis, there has been some speculation about the likely factors that might inform this decision-making. These include knowledge of the syllabus, experience of past examination papers, 'guiding frameworks', examiner reports, textbooks and discussions with colleagues.

Developing students' understanding of the nature of biology/science: an unnecessary feature of students' preparation for A level biology examination success?

So far, this chapter has argued that the major focus of these teachers' perceived successful teaching of biology at A level concerns developing their students' knowledge and understanding of substantive biological content. There is little evidence to show that developing their students' understanding of syntactic knowledge – that is Schwab's second dimension to subject matter knowledge – is considered to be a feature of their successful preparation of students for A level biology examination achievement. Reflections in post-lesson and vignette interviews are not dominated by this concern. In fact only a handful of comments seem to relate in any way to developing students' understanding of the nature of biology/science. Furthermore, direct attempts, through lesson activities, to develop their students' understanding of syntactic biological knowledge are not apparent to any great degree.

One of the ways in which it could be argued that biology/science teachers might encourage their students' development of knowledge and understanding of the nature of biology/science is through experimental work. Experiments, however, did not play a central role in these teachers' respective units-of-work. For example, laboratory experiments did not feature in any of John's lessons, although, in lesson 2, one of his colleagues performed a dissection of an ox heart for the class to observe and then later in the same lesson all students dissected a pig's heart themselves. Catherine's students performed one laboratory experiment across her unit-of-work involving setting up and using a respirometer. And finally, Sally's students performed

two short experiments during her unit-of-work: the first, in lesson 2, concerned the digestion of starch and the second, in lesson 6, concerned the digestion of protein.

Furthermore, only a few comments made by the teachers about these experiments could be perceived as tentative evidence of them considering successful teaching of biology at A level to involve developing students' understanding of syntactic biological knowledge. For instance, all three teachers did mention an aspect of their successful teaching as providing opportunities for their students to develop various practical skills. In post-lesson interview 2, Catherine mentioned that the respirometer practical was successful because her students were able to develop their skills in using particular laboratory equipment. In her words:

another good bit was the getting used to the apparatus, practical skills, learning how to use different bits and things.

(plint 2 C 71-72)

Similarly, Sally makes clear in the following quotation that she felt the practical involving the digestion of starch in lesson 2 of her unit-of-work encouraged her students' development of experimental skills:

I think there were good bits of practical sort of involvement in it, using equipment, doing tests, measuring, all things you expect them to be able to do but they have to practice I suppose, you know, to get better.

(plint 2 S 48-51)

Finally, John was pleased most of his students had attempted the dissection of a pig's heart in lesson 2 as he felt this gave them the opportunity to practice using

scientific equipment – e.g. scalpels – thereby developing their laboratory skills. In his words:

It's good for them to have a go at using the scalpel and things.

(plint 2 J 52-53)

In addition to the above comments suggesting that successful teaching of biology at A level involves providing students with opportunities to develop their practical skills, Catherine also argued that the respirometer experiment provided her students with the opportunity to develop their capacity to make predictions concerning the outcome of an experiment ('the technique of biology there is important, predicting and saying why you predict, explaining your own prediction.' VI1 C 437-439) and to improve their ability to critically evaluate the methods used in an experiment ('what I try to do with this every time is to get them to improve the method which was the business of how the control was better, so improving the very thing that they were doing within that.' plint 2 C 48-51).

Parallels could be drawn between the three teachers' reference to practical skills and abilities, Catherine's reference to predictive and evaluation skills and elements of Schwab's reference to the syntactic structures of a subject - that is 'the methods and modes of inquiry that a discipline develops'. Indeed, practical skills and abilities such as accurately measuring, learning how to use specific equipment and performing dissections could be considered examples of methods used in scientific endeavours. Furthermore, both the skills of prediction and evaluation could be interpreted to be examples of modes of inquiry in science. However, the scarcity of evidence makes

any such parallels highly speculative. Indeed, much more evidence would be required to substantiate any claims of this sort.

Other ways in which it could be argued that biology/science teachers might encourage their students' development of knowledge and understanding of the nature of this discipline include historical discussions concerning the development of scientific knowledge. For example, in the Blood and Circulation topic John could have drawn upon the work of William Harvey (1628) (cited in Roberts *et al* 1993) to illustrate how, until his research - based on dissections and experiments - was published it was thought that blood was pumped from the heart and subsequently drawn back into it via the same vessels. However, such a technique was not used by any of the teachers.

Since the aim of analysis in this research is to produce an account of three teachers' perspectives of what teaching biology for success at A level comprises using their comments in interviews (as described in chapter four) to shape an understanding of observed classroom practice, findings that might result simply from my interpretation of their observed teaching have not been explored. However, it is worth noting here that whilst developing their students' knowledge and understanding of the nature of biology/science did not appear to be a conscious aim of their successful teaching of the subject at A level it is possible to speculate that implicit in the teachers' predominant focus on the teaching of substantive content and their presentation of this content was a representation of the nature of their subject. This representation seemed to involve presenting biology as comprising a fixed and unchanging body of

knowledge to be learnt in order for examinations to be passed successfully. Whilst this might not have been the intention of the teachers, the combination of not consciously or directly developing their students' understanding of the nature of biology/science and their major focus on developing students' knowledge and understanding of a set body of unchanging facts as set out by their respective syllabuses could have achieved this outcome.

The lack of evidence concerning developing students' understanding of the syntactic aspect of biological knowledge leads us to ask the following question – how can we account for the fact that all three teachers did not consider developing their students' understanding of the nature of biology/science to be a feature of their successful teaching of biology for A level examination achievement? Indeed, why did these three teachers not consider developing students' understanding of the syntactic structures of biology to be necessary for A level examination success? In the following section, various possible explanations will be suggested and explored in an attempt to account for this finding.

The first possible suggested explanation to account for this finding relates to the nature of the three syllabuses taught by the teachers in this research project. The nature of the syllabuses can be considered along three dimensions: subject content; nature of assessment; and method of assessment. The subject content dimension outlines in statements the biological knowledge and understanding that will be assessed at the end of a course - in the case of a linear course (e.g. Catherine's course) - and during a course - in the case of a modular course (e.g. Sally's course

and John's course). The nature of assessment dimension outlines in what ways the students will be assessed, for example, by the recall of facts, concepts, principles, theories or by the interpretation and analysis of data. The nature of assessment dimension is embodied in each syllabuses aims and objectives. These are outlined in detail in chapter one (pp. 6-8). Finally, the methods of assessment dimension outlines the various ways in which the subject content will be assessed. This involves a number of written papers taken under examination conditions and coursework. For all three syllabuses the coursework element comprises one or more 'investigations'. These involve students planning and executing (e.g. making observations, recording measurements) an experiment; presenting, analysing and drawing conclusions from the experimental data; and finally, evaluating the experiment.

In the following sections all three dimensions will be considered in turn and their contribution to account for the finding that the teachers did not consider developing their students' understanding of the nature of biology/science necessary for A level examination success will be discussed.

Analysis of each syllabuses subject content dimension (see Appendix A), that is the biological knowledge and understanding taught during this research project, reveals an overwhelming emphasis on substantive content. The statements defining the content of each syllabus section set out specifically what facts, concepts, principles and theories the students need to know and understand for the examination. No statements indicate the need for students to know and understand the nature of their

subject in relation to the three topic areas taught during this research project. Indeed, the only suggestion that one of the topics taught during this research might provide the opportunity to encourage the development of students' understanding of the nature of biology/science comes from the 'possible learning experiences' that, in conjunction with the syllabus statements, are suggested by Sally's syllabus. Various suggestions are given and all include the word 'investigate'. For example, next to the section outlining the biological subject matter concerning the digestion of carbohydrate, protein and fat, the following possible learning experience is suggested:

Investigating protein digestion using photographic film or egg albumin
(NEAB 1999, p. 24)

It is possible to interpret the meaning of the word 'investigate' in two ways. To begin with, in science education, the term 'investigate' has historically been used to refer to laboratory experiments – that is 'investigations' – which are designed, executed and evaluated more or less entirely by students themselves in order to solve practical problems (Watson 2000; Woolnough 1994; Woolnough and Allsop 1985). Indeed, in certain science education circles 'investigations' are seen to be a way of encouraging students' development of understanding of the nature of science (Woolnough 1991). However, an alternative interpretation of the term 'investigate' in relation to laboratory experiments might lead a teacher to provide students with the opportunity to perform an experiment that has already been designed and tested by other teachers and/or curriculum developers. In this case the students simply follow a set of instructions, presented by the teacher, and, providing they do this correctly, *should* produce a

particular set of results. It seems that Sally interpreted the term 'investigate', as found in the 'possible learning experiences' in her syllabus, in the latter way. She incorporated two out of the five recommended 'possible learning experiences' in her unit-of-work. However, for each, her students followed a set of instructions the purpose of which seemed to be to verify knowledge and understanding already developed. For example, the experiment investigating protein digestion using photographic film or egg albumin involved her students verifying that the optimum pH for the enzymatic action of pepsin is 2 and trypsin is 8. In Sally's case then, the possible hint from the syllabus section to encourage teachers to develop students' knowledge and understanding of the nature of biology/science was not borne out in the classroom.

It seems then, that the emphasis of the subject content sections of each of the syllabuses is on outlining substantive content thereby giving the impression that there is much substantive content to be covered. Indeed, all three teachers mentioned the content-laden nature of their syllabuses suggesting they had a lot of substantive content to cover and their students had a lot of substantive content to acquire. Given that these syllabus sections are probably one of the most vital sources for the teachers in their lesson planning it is perhaps not surprising that they tended to focus, almost exclusively, on developing their students' understanding of substantive biological content in the particular topics taught during this research project.

Across all three syllabuses the nature of assessment is very similar. Indeed, the assessment objectives for the three syllabuses can be loosely grouped into three

areas: knowledge and understanding; application and analysis; and investigation. Although these assessment objectives are discussed in detail in chapter one, for overall coherence for the reader they are also described briefly here. The knowledge and understanding objective is described as referring, in the main, to assessing students' knowledge and understanding of facts, theories, concepts and principles. The application and analysis objective is defined as assessing a candidates' ability to apply knowledge and understanding of substantive biological content to solve problems in familiar and unfamiliar situations as well as to analyse and interpret scientific information that is presented in a variety of forms. The investigation objective includes assessing a students' ability to: formulate hypotheses and design feasible experiments to test them; implement an experimental design making accurate observations and recording results; analyse, evaluate and draw conclusions from the outcome of an experimental investigation and finally write up an experimental investigation in an appropriate manner making good use of grammar, punctuation and spelling.

When the assessment objective descriptors are analysed it is worth noting that each tends to focus its attentions on assessing either predominantly substantive biological content or predominantly syntactic biological content although for one objective – application and analysis – there is some degree of overlap. For example, the knowledge and understanding objective appears to assess students' substantive biological knowledge, that is knowledge and understanding of facts, theories, concepts and principles. The application and analysis objective appears, in part, to assess students' knowledge and understanding of substantive biological content but,

in addition to this, it also seems to assess, in some way, students' understanding of the nature of biology/science. For example, being able to analyse and interpret scientific information suggests some level of knowledge and understanding of the syntactic structures of science since analytical and interpretive skills are part of the armoury of practising scientists. Finally, the investigation assessment objective seems to focus almost exclusively on assessing students' knowledge and understanding of the nature of science. For example, being able to formulate hypotheses, record results, analyse and draw conclusions from data seems to resonate with some basic knowledge and understanding of the syntactic structures of science.

Analysis of the three syllabuses assessment objectives therefore suggests that only two out of the three – that is knowledge and understanding, and application and analysis – assess students' knowledge and understanding of substantive biological content. Furthermore, it also suggests that only two out of the three – that is application and analysis, and investigation – assess in some way students' understanding of the nature of biology/science. These findings are important when the nature of assessment is considered in conjunction with the three syllabuses methods of assessment.

Across all three syllabuses the methods of assessment are very similar. For all courses, as mentioned earlier, assessment takes the form of either written tests, taken under examination conditions, or coursework. Table 6.1 overleaf outlines the three major assessment objectives for each syllabus and the percentage of the

Table 6.1 A table to show the % of each syllabuses overall A level marks devoted to the assessment of the three assessment objectives as well as the assessment component through which the majority of each assessment objective is assessed.

Assessment objectives and % of overall A level devoted to their assessment for the different syllabuses	Assessment component through which the majority of the assessment objective is assessed (e.g. between 90-100%)
Knowledge and understanding AEB 45% (linear) ABE (modular) NEAB 50%	Written test Written test Written test
Application and analysis AEB 35% (linear) AEB 35% (modular) NEAB 30%	Written test Written test Written test
Investigation AEB 20% (linear) AEB 20% (modular) NEAB 20%	Coursework Coursework Coursework

overall A level marks devoted to their assessment. Furthermore, it also outlines the assessment component through which the majority of the assessment objective is assessed.

When nature of assessment is considered with method of assessment various findings emerge. To begin with, it seems for all three syllabuses the assessment of substantive biological content (i.e. assessed through the assessment objective ‘knowledge and understanding’ and to some degree also through the assessment objective ‘application and analysis’) is achieved almost exclusively through written tests. Furthermore, it appears that for all three syllabuses the assessment of

syntactic content (i.e. assessed through the assessment objective 'investigation' and in part through the assessment objective 'application and analysis') is achieved in large part through coursework. Given these facts, it is possible that these three teachers tended to develop their students' understanding of the nature of biology/science predominantly when they were engaged in coursework activities. Since none of the units-of-work observed involved any students doing coursework this might help to explain why developing students' knowledge and understanding of the nature of biology/science was not a major feature, if a feature at all, of the three teachers' successful teaching of biology at A level.

It has been argued above that the A level biology curriculum and its representation in the three syllabuses taught during this research might help to explain why, for these three teachers, successful teaching of biology at A level comprised an almost exclusive focus on developing students' knowledge and understanding of substantive biological content with little, if any, emphasis on developing students' knowledge and understanding of the nature of biology/science. An additional factor that might help to explain why developing students' knowledge and understanding of the nature of biology/science was a peripheral feature, if a feature at all, of the three teachers' successful teaching of biology at A level is the teachers' assessment of the suitability of the topic areas taught during their respective units-of-work for developing this sort of understanding. It is possible that the three teachers did not consider the subject content of their topics conducive to achieving this sort of understanding in their students. Indeed, judging by the syllabus subject content statements, only Sally's, through 'possible learning experiences', makes any hint to suggest that the particular

topic area chosen might be suitable for developing this sort of knowledge and understanding in students. For John and Catherine two later topic areas in their syllabuses - genetics and ecology - do provide subject content syllabus statements that seem more geared to encourage teachers to develop their students' understanding of the nature of biology/science in addition to their knowledge and understanding of substantive content. For example, the following notes that accompany Section 2.1 of Section 2 (Variation and the Mechanisms for Inheritance and Evolution) of both the linear and modular AEB syllabus suggest, through the use of terms such as analysis, deduction and evidence from experimental work, an opportunity for teachers to develop students' knowledge and understanding of the nature of biology/science:

These sections provide the opportunity to examine the work of a number of biologists such as Griffith and Avery, Macleod and McCarty on *Pneumococcus*, Hershey and Chase on the T2 bacteriophage and *E.coli* and Beadle and Tatum on *Neurospora crassa*. Candidates will not be expected to study all these examples or to link workers' names with particular pieces of work or to be familiar with details of techniques. The exercise for the candidates should be one of analysis and deduction using evidence derived from the experimental work.

(AEB 1997, p.21)

Moreover, it is possible that the three teachers might have felt that the subject content of their units-of-work was conceptually demanding enough for their students to cope with and that introducing another dimension in the form of developing an additional sort of knowledge and understanding would make things too difficult for their students.

In addition, it might be the case that the teachers consider developing students' knowledge and understanding of the nature of biology/science to be a time

consuming process. Consequently, given the pressure they feel to ensure they get through the subject content syllabus statements in an appropriate time frame they do not embark on achieving this aim in the classroom.

Finally, it might be the case that the teachers do not consider developing students' knowledge and understanding of the nature of biology/science a possible aim of their teaching or do not consider it a possible aim to achieve through explicit teaching methods. Perhaps they believe that the nature of biology/science can only be modelled through their own practices and therefore inferred indirectly by students rather than intentionally taught by them.

Summary of the chapter's main findings and their relationship to previous studies

In light of the suggestion in chapter five that the overall aim of all three teachers' teaching of biology was to prepare their students for examination success, this chapter has investigated the ways in which the three teachers believed their students needed to come to know the A level biology curriculum in order to achieve this objective. Schwab's classification of subject matter content knowledge into the two dimensions of substantive knowledge and syntactic knowledge has been particularly useful in assisting the exploration of the conceptions of biology the teachers deemed necessary for their students to know in order to be successful in their A level examinations.

This chapter has suggested that, for all three teachers, the major focus in preparing their students for A level examination success involves developing their knowledge of substantive biological content. Indeed, this finding resonates with the anecdotal assertions made about A level biology/science teaching by a variety of other researchers including Yan Yip (2004), Ryder *et al* (2003) and Lock (1997).

This chapter has argued that, for students, coming to know substantive biological content for success in examinations involves conceptualising it in several patterned ways since these ways help them to develop and retain the knowledge they need to retrieve for examination achievement. This proposal concurs with findings from other studies. In a study of four English and history teachers' teaching, for example, Gudmundsdottir (1991) found that the teachers she worked with wanted their

students to come to know either literary texts or historical topics in particular patterned ways. Nancy – one of the English teachers – for example, wanted her students to come to know a literary text in three ways. She wanted them to:

- know the literal meaning of the text;
- be able to interpret the text;
- be able to relate the text to their own lives.

Similarly, David, one of the history teachers, wanted his students to come to know history in three ways. He wanted them to:

- know specific historical facts and events;
- be able to interpret these facts and events;
- be able to link these interpretations to current events.

Further, this chapter has explored the nature of the conceptions of substantive biological knowledge the teachers considered critical for their students to know for A level examination achievement. It has been argued that these conceptions involve viewing substantive biological content as a network of related ‘biological entities’ and ‘biological entities’ as comprising a constellation of features (which can come to be known at either a surface and/or deep level) and, where appropriate, one or more specific representations. Whilst the teachers believe all ‘biological entities’ to be interrelated they do not perceive all ‘biological entities’ to have equal status. Indeed, it has been argued that the teachers consider there to be a core set of ‘biological

entities' that are integral to developing surface and deep level knowledge of features of 'biological entities' across the discipline.

A number of studies accord with aspects of the conceptions of biology the teachers considered necessary for their students to know for A level success. Findings from a study by Gess-Newsome and Lederman (1995), for example, suggest that it is not unusual to seek to represent biology as a network of related subject matter. In this study Gess-Newsome and Lederman described the conceptual structures – what they referred to as Subject Matter Structures – of five experienced biology teachers from observations of their classroom practice. For three of these teachers a feature of their Subject Matter Structure comprised representing to their students the integrated nature of biological content through their teaching.

Elements of Ausubel *et al*'s (1978) work on meaningful learning resonates with aspects of the patterned way of knowing 'biological entities' the teachers in this study sought their students to develop. In *Educational Psychology: A Cognitive View*, Ausubel *et al* discuss a number of different types of learning including concept learning. They define a concept as an object, event, situation or property suggesting that their 'concepts' are similar in nature to the 'biological entities' described and discussed in this thesis. They argue that learning a concept involves learning its identifying or distinguishing criterial attributes. Whilst the definition of an identifying or distinguishing criterial attribute is never given it is possible to infer that it might be similar to this thesis' definition of a feature - that is an expression of a particular characteristic of a specific 'biological entity'.

Furthermore, aspects of Wilson's (1989) analysis of the subject matter knowledge of history teachers also accords with some elements of the patterned way of knowing 'biological entities' that the teachers in this study sought their students to develop. Wilson identifies four constructs to substantive historical knowledge. They are: differentiation; elaboration; qualification; and integration. Two of these - differentiation and integration - resonate with elements of knowing 'biological entities' as suggested by this research. Differentiation, for example, refers to the ability to identify the characteristics of a particular topic, a construct that shares similarities to this thesis' definition of a feature of a 'biological entity'. In addition, integration refers to comprehending the connections between historical facts. This construct bears resemblance to the suggestion that learning about 'biological entities' involves appreciating the connections between them.

It is possible also to draw parallels between various aspects of the patterned way in which the three teachers in this study sought their students to come to know 'biological entities' and the findings of Gudmundsdottir's study discussed earlier. For instance, it seems that knowing features at a surface level shares similarities with the sort of knowing her English and history teachers sought to develop in their students. Remembering and recalling features seems comparable with knowing the literal meaning of a text or knowing specific historical facts and events. Furthermore, knowing at a deep level seems to resemble Gudmundsdottir's teachers' 'interpreting'. Being able to explain the 'how' and/or 'why' of a feature in its wider biological context

resonates with being able to interpret a text in English and being able to interpret facts and events in history.

Literature from psychology suggests support for the teachers' desire to encourage their students to appreciate that whilst all 'biological entities' are inter-related not all 'biological entities' are of equal status, indeed, some play a more central role in connecting with 'biological entities' than others. Ausubel *et al* (1978), for example, suggest that there are always concepts in any knowledge structure that are more 'central' than others as they are linked to many other concepts.

In addition, this finding also concurs with results from a study by Hoz *et al* (1990). In this study, the researchers explored the conceptual structures of seven biology and six geography teachers and suggested that experienced teachers have hierarchically arranged conceptual structures suggesting that some aspects of biological subject matter are more central to developing knowledge and understanding than others.

The findings presented in this chapter also suggest that through the careful structuring of subject matter tasks and the frequent rehearsal of knowledge the teachers believe their students will develop and retain the specific conceptions of substantive biological subject matter knowledge that they consider necessary to have for A level examination success. Research from cognitive psychology supports the teachers' beliefs in the value of frequently reviewing knowledge. Indeed, a number of studies have shown that rehearsal leads to improved memory recall (Eysenck and Keane 2000; Eysenck 1993; Benjafield 1992).

Moreover the findings presented in this chapter suggest that the decision-making that the teachers employ in order to decide what substantive biological knowledge needs to be known and in what ways it needs to be known is shaped by a variety of factors. These include knowledge of the syllabus, experience of past paper examination papers, examiner reports, textbooks, discussions with colleagues and 'guiding frameworks'. The variety of factors discussed signal the importance of context in shaping and guiding the decisions teachers make that inform their practice. A number of studies illustrate the significance of context in shaping teaching. For example, Delpech (2002) suggests the significance of the curriculum and methods of assessment on teaching whilst studies such as Brown and McIntyre (1993) suggest the importance of a wider range of factors including pupil, time and material conditions.

Finally, this chapter has argued that, for these three teachers, preparing their students for A level examination success does not seem to involve developing their knowledge of syntactic biological content. This finding concurs with findings from a number of other studies (Lederman 1999; Abd-El-Khalick *et al* 1998; Lederman *et al* 1994; Gess-Newsome and Lederman 1993; Duschl and Wright 1989). These studies show that even in projects where the research participants are both very knowledgeable about the nature of biology/science and highly experienced teachers they rarely consider the nature of science when planning for instruction or making instructional decisions. In short, they do not intentionally attempt to teach in a

manner that is consistent with their perceptions of the nature of science (Lederman 1999).

The arguments offered in this chapter to account for this finding suggest that contextual variables such as the curriculum and the teachers' perceptions of the cognitive demand of the content taught might explain why the teachers did not consider it appropriate to develop their students' knowledge and understanding of the nature of biology/science in their classrooms. Previous research has also consistently alluded to contextual factors such as these as significantly inhibiting teachers' attention to the nature of science in their classroom teaching (Roberts and Gott 2000; Brickhouse 1990; Duschl and Wright 1989; Lederman and Zeidler 1987).

In the next chapter the findings reported in this thesis will be related to the study's three research questions. Furthermore, there will be a critical reflection upon the design and conduct of the study. Finally, the implications of these findings for policy, practice and research will be discussed.

Chapter Seven

Conclusions

Introduction

To conclude this thesis the final chapter will relate and discuss the findings presented in chapters five and six to the three research questions posed in chapter three. Furthermore, it will critically reflect upon the design and conduct of the research study, and finally, discuss the implications of the findings for policy, practice and research.

Answering the research questions

What are the teachers' characterisations of their successful teaching of biology at A level?

The findings presented in chapters five and six suggest that given the contexts in which the teachers worked, there are three central features that comprise a characterisation of their successful teaching of biology at A level. The first feature concerns an overwhelming focus on developing students' knowledge and understanding of substantive biological content. The data indicates that preparing students for A level examination achievement in biology involves developing this aspect of subject matter knowledge almost to the exclusion of the direct development of other content based aims such as fostering knowledge and understanding of the nature of biology/science.

This is an interesting finding because it does not seem to resonate with the intentions of the curriculum developers of the three syllabuses that the teachers were following. Indeed, the aims and objectives of the three syllabuses, as laid

out in chapter one and discussed in chapter six, suggest a balance of both substantive and syntactic content based aims ranging from assisting students to acquire knowledge and understanding of biological concepts and principles (a substantive content based aim) to assisting students in developing a scientific approach to the solving of problems including, for example, forming hypotheses and predicting outcomes (a syntactic content based aim). Moreover, although it has not always been the case, more recently science curricula rhetoric has tended to emphasise a balanced curriculum with a focus on both substantive and syntactic content aims (Roberts 2001; Miller and Driver 1987).

It is possible that the teachers are not interpreting the syllabus documents as the curriculum developers intended because they are having to take account of an additional national policy driver which, in conjunction with the variety of factors they take account of in their immediate classroom contexts, means they are unable to fulfil all of the aims outlined in the syllabuses. Increasingly education is being seen as a commodity. There is an emphasis, for example, on setting and reaching targets, on restructuring the workforce by encouraging more students into higher education (Phoenix 2003) and on encouraging competition between schools through the publication of league tables. This national context constantly reinforces the importance attributed to examination results as, for example, they can be important in target setting, they are a requirement for entrance into higher education and they are the key component in the construction of league tables. Certainly, the three teachers in this study seemed affected by this national context since the main aim of their successful teaching of biology at A level was not, for example, to develop their students as inquiring

and creative biologists, but *to get their students the best results they could in their examinations*. In light of the immediate contexts of their classrooms and the variety of factors of which they had to take account, it is possible that prioritising the teaching of the substantive aspect of biology over the syntactic aspect became a necessity. Within the topics taught during this project, the teachers might have perceived it as impossible to achieve both the teaching of substantive and syntactic content knowledge. Furthermore, it might be the case that *in their experience* having knowledge of the substantive aspect of biology is more likely to achieve successful examination results than having knowledge of the syntactic dimension.

It is also possible that the teachers did not emphasise syntactic subject matter issues in their successful teaching of biology at A level because they did not possess the knowledge, understanding and skills to do this. Indeed, Ryder *et al* (2003) suggest that teaching about the nature of science is 'a new area of expertise for many teachers' (p. 2). It is unlikely that biology teachers will ever have had explicit instruction in the syntactic dimension of science through science degree courses or professional development and training, and unless they are highly motivated and interested in this aspect of science – perhaps they have undertaken scientific research themselves – it is doubtful they will have developed sophisticated knowledge and understanding of this dimension of biology. In light of this, it is perhaps expecting a great deal of biology teachers to be able to teach explicitly about this aspect of subject matter knowledge.

There is a likelihood that since the teachers did not focus on developing knowledge and understanding of the syntactic dimension of biology, their

students might well emerge from their school education with truncated conceptions of the nature of biology/science. As is argued in chapter six, it is possible that implicit in the teachers' predominant focus on the teaching of substantive content and their presentation of this content was a representation of the nature of their subject. This representation seemed to involve presenting biology as comprising a fixed and unchanging body of knowledge and truths about the world.

It could be argued that one of the aims of science education is to develop scientifically literate citizens. However, it is unlikely that holding views about the nature of biology/science such as those described above would be beneficial in achieving this aim. How, for example, do individuals who consider science to be a fixed body of knowledge and truths about the world reconcile the different findings and conclusions of competing scientific theories concerning issues pertinent to them? Furthermore, if the pressure of examinations encourages the development of such a truncated conception of biology/science this might have implications for the role that examinations play in the overall aim of developing scientifically literate citizens.

The second feature of the three teachers' successful teaching of biology at A level concerns the fact that, to help their students develop and retain knowledge and understanding of large volumes of substantive content, they represented this content in patterned ways.

As discussed in greater detail in chapter two, the work of Shulman and his colleagues at Stanford led to the suggestion that in addition to knowledge of

subject matter *per se*, teachers develop a special sort of knowledge – pedagogical content knowledge – that blends their knowledge of subject matter with their knowledge of pedagogy (including, for example, knowledge of learners and knowledge of curricula). It is argued that this knowledge develops from a teacher's re-evaluation of his/her own understanding of subject matter for the purposes of teaching it – that is it involves developing ways of transforming subject matter in order to foster the development of subject matter knowledge in the minds of students (Wilson *et al* 1987).

The teachers in this study provide strong support for this early formulation of pedagogical content knowledge. Indeed, the evidence suggests that they transform their knowledge and understanding of substantive biological content into specific patterns of knowledge that they represent to their students in order to encourage them to develop what they consider appropriate knowledge and understanding for success in A level biology examinations.

The third and final feature of the teachers' successful teaching of biology at A level concerns the fact that they tended to use carefully structured and controlled teacher-centred approaches to teaching, including the frequent use of repetition, in order to encourage their students to develop knowledge and understanding of specific representations of biology. This certainly seems to be a familiar picture since the anecdotal assertions of other writers have highlighted the use of such methods as a characteristic feature of A level biology teaching (Yan Yip 2004; Lock 1997).

This is an interesting finding since one of the major criticisms levelled at the original conception of pedagogical content knowledge is that it suggests a transmission model of teaching and a didactic role for the teacher (Calderhead 1996; Pendry 1994). It assumes that teachers understand subject matter and through appropriate tasks, explanations and demonstrations they develop this understanding in their students. This assumption tends to dismiss other possibilities for learning such as students constructing their own knowledge within a social context or problem-based inquiry type learning. Indeed, researchers adopting more constructivist conceptions of teaching and learning have questioned whether Shulman's concept of pedagogical content knowledge is a necessary prerequisite for teaching (Calderhead 1996).

The use of teacher-centred approaches to teaching does not resonate with much of the extant literature in science education on teaching and learning. Indeed, the use of such methods in the teaching of A level biology has often been criticised (e.g. Hall *et al* 2003; Lock 1998; Purchon 1998). The predominant use of these methods suggests that the teachers' major conception of what learning in biology/science comprises is the accretion of new knowledge. The highly controlled classroom environment they engendered gave little opportunity to students to play an active role in the development of their own knowledge. Indeed, one of the only ways they contributed was when they were presented with the opportunity to develop deep level knowledge of features of 'biological entities'. In these cases the students were encouraged, under the watchful eyes and prompting of their teachers to connect 'biological entities' together in an attempt to construct accounts to explain the 'why' or 'how' of a feature. In this way they began to actively construct networks of meaning

themselves. Since, however, this was quite a time consuming process it was not an overly frequent feature of the three teachers' teaching.

This picture of science teaching and learning contrasts with the views of what many (e.g. Jenkins 2000; Tao and Gunstone 1999; Banet and Nunez 1997) consider to be the dominant paradigm in science education: the 'Constructivist Movement'. Constructivists argue that learning in science 'ought' to comprise learners constructing their own meaning for events and phenomena having addressed any prior ideas or conceptions they might have about biology/science topics. The role of teachers in this process is to provide the right conditions for the students' reconstruction of meaning.

The findings of this thesis, however, indicate that within the contexts in which the teachers worked they did not consider constructivist approaches to be either appropriate or practicable. They adopted a teacher-centred approach to teaching because of the contexts in which they worked and the various factors they took account of in their practice. They adopted this approach because they truly believed that given the primary aim of their A level biology teaching – to ensure examination success for all their pupils – and their conceptualisation of how best to achieve this aim – by developing their students' knowledge and understanding of substantive biological content – a carefully structured and controlled teacher-centred mode of teaching was the most fruitful and effective. Nevertheless, if one were to judge the three teachers according to a great deal of the science education literature (academic writing that is predominantly of constructivist origin) they would be deemed lacking. However, what this thesis has tried to do is show that the teachers' use of teacher-centred methods and

repetition was not thoughtless but instead *thoughtful*. The teachers in this study are highly skilled practitioners. They have a clear rationale for the ways in which they act everyday in their classrooms. The decisions they make and the actions they take are a reflection of their priorities (in particular their desire to encourage student success in examinations), their perceived student needs (in particular to view substantive biological knowledge in specific ways) and their knowledge and understanding of the subject matter of biology. It seems that this finding, therefore, highlights a much broader issue: the discrepancy in science education between academic writing about practice and practice itself.

Furthermore, there is a possibility that the teacher-centred approaches to teaching these that teachers adopted might, in part, be a response to this country's constant drive for students to achieve examination success. Indeed, other researchers seem to support such a conjecture (Yan Yip 2004; Delpech 2002; Slingsby 2003; Purchon 1998; Lock 1997). It might be interesting then to consider that if we did not have such a drive for examination achievement other aspects of subject matter knowledge could be prioritised over the acquisition of substantive biological content or at least considered by teachers to be appropriate goals of their teaching and, in light of this, possibly alternative teaching and learning approaches might find a place in the enactment of the A level biology curriculum.

In what ways and to what extent do these characterisations vary between the teachers?

The evidence from this research indicates that the characterisations of successful teaching of biology at A level do not vary between the teachers, in fact they are extremely similar. As has already been suggested, the prevailing

assessment driven culture in England is likely to help us, in part, explain these huge similarities. Indeed, the commonalities between the teachers' teaching might arise from their wealth of experience concerning how best to assist their students in achieving A level examination success.

Further to this, however, it is possible that the logic of the subject of biology itself might also help us to explain the similarities observed. Analyses of the nature of biology/science suggest parallels with the conceptions of biology the teachers sought to develop in their students. There is general agreement, for example, that biology/science is populated by a wide variety of entities (Ogborn *et al* 1996; Halliday and Martin 1993; Ruse 1973). Indeed, Ogborn *et al* refer to these entities as an 'ontological zoo' giving examples that include such things as water, energy and animals. Furthermore, academics concur that these entities are often related to one another. Halliday and Martin (1993) argue that an aspect of scientific discourse is that the technical terms of science tend to accumulate information – a feature they refer to as the condensing power of scientific language. They argue that technical terms are consistently used to define other technical terms. To understand a term, therefore, it is important to have knowledge of all the technical terms that are referred to in its definition as well as knowledge of the relationships between them. Moreover, academics argue that defining entities, that is constructing knowledge and understanding of them involves establishing things like what they can do – functional statements – (Ayala 1974; Ruse 1973; Beckner 1971; Munson 1971) and what they are made of (Ogborn *et al* 1996).

Given the three aspects of the logic of biology/science suggested by the various scholars referenced above it makes sense that the teachers represented their subject in the ways they did and developed their students' knowledge and understanding of it by using predominantly didactic pedagogic techniques and the frequent use of repetition. An analysis of the teachers' conceptions of biology suggests that these teachers had developed highly sophisticated knowledge of aspects of the logic of their subject and drew upon this knowledge and understanding in their teaching. Teaching for them became developing ways in which they could get across the logic of their subject to their students.

At a more tentative level it is possible that several factors the teachers had in common might help to explain their strikingly similar characterisations of successful A level biology teaching. To begin with, all three teachers were teaching classes where the students were of varying levels of prior attainment – that is some students were considered particularly academic whilst others were considered much less academic. It might be the case that the similar features observed between them, therefore, assisted them in catering for this spread of ability in their classes.

An additional similarity between the three teachers concerned the fact that the students they taught were a combination of those where biology was their only science at A level (i.e. they were studying other more arts based subjects such as history or English alongside it) and those where biology was being studied alongside all the other sciences and/or maths. It is possible that the congruity in their characterisations of their successful teaching of biology at A level took this factor into account – that is the features of their teaching they shared in

common enabled them to accommodate students in their classes who had a definite scientific flair as well as students who were more artistic in their talents and therefore had no support from understanding in other scientific subjects.

What subject matter knowledge and understanding shapes and accounts for these characterisations?

The evidence from this research suggests that the subject matter knowledge and understanding that shapes and accounts for the characterisations described and discussed in relation to research question one comprises various specific conceptions of biology. These conceptions involve:

- viewing biology as a network of 'biological entities' where each 'biological entity' is related to every other 'biological entity' in some way;
- viewing 'biological entities' as made up of features, which can be known at different levels and in different ways, and representations;
- viewing some 'biological entities' as having a higher status than others, thereby holding a hierarchical conception of the network of 'biological entities'.

It is suggested that the three teachers' conceptions of biology share two characteristics. First, they display an overall structure to biological subject matter knowledge. For example, biology is viewed as a network of inter-related 'biological entities'. Furthermore, 'biological entities' are viewed as comprising features and, where appropriate, representations. Features are viewed as attributes of a 'biological entity' that can be known at a surface level, and sometimes also a deep level. Finally, the structure is conceived as hierarchical,

not flat. Thereby a core set of 'biological entities' help to draw the huge network of 'biological entities' together.

Second, the overall structure is determined by guiding principles. For example, the guiding principle that shapes the conception of biology as a network of inter-related 'biological entities' is 'All biological entities are inter-connected'. Several guiding principles shape these teachers' conceptions of a 'biological entity'. The first is 'all 'biological entities' comprise features and, where appropriate, representations'. The second is 'all features can be known at a surface level and some can also be known at a deep level'. The third is that "biological entities' can be common or core depending on how significant they are at giving meaning to other 'biological entities". The more significant they are the more they are used to give meaning to other 'biological entities' and therefore the more likely they are to be core 'biological entities'.

Given that all three teachers shared similar subject matter conceptions of biology, this thesis suggests a subject matter conception that teachers consider useful for successful A level biology teaching as well as the value of subject matter conceptions *per se*. The three teachers' subject matter conceptions appeared to provide a framework to structure large amounts of substantive subject matter knowledge. It is likely that this framework assisted in making the enormous volume of biological content both easy to retain for the teachers (Berliner 1987) and useable for their pedagogical purposes.

Critical evaluation of the study

Advanced level study comprises only a small part of a student's educational career and since it is not a compulsory element large numbers of students do not study at this level at all. Given this context, it could be argued that the sole focus of this study on the teaching of biology at A level is too narrow. However, as discussed in chapter three, the choice of A level was dictated by the purpose of this research – to explore in detail the teaching of biological subject matter. Since A levels are not compulsory and tend to be studied by students who are well motivated and interested in the subject area, it was felt that classroom management issues would be minor, if not absent altogether, thereby ensuring the purest sample available to investigate the teaching of biological content.

A further criticism that could be levelled at this research relates to the fact that only the teaching of three areas of biology – Digestion, Blood and Circulation, and Respiration – were investigated. There is no evidence of the teaching of other topics which might have suggested additional features to the teachers' characterisations of the successful teaching of biological subject matter or might have resulted in the modification of the characterisations presented. However, as with other studies, this project was limited by time constraints. The overall time scale of the research only permitted the intensive investigation of three topic areas.

Time constraints also meant that it was not possible to engage in respondent validation when analysis had been completed. Whilst elements of respondent validation had been woven into the research design – for example, through the

use of confirmatory probing in interviews as discussed in chapter three – the feeding back and discussion with the research participants of complete analytical accounts would have been a desired feature of the investigation. Given more time and increased proficiency in the analytical process respondent validation at the end of analysis in an additional project might become a real possibility.

A number of researchers (e.g. Rickinson 1999; Cooper and McIntyre 1996) have suggested that there is much value to be gained from classroom studies that simultaneously explore the perspectives of teachers and their students. Another way in which this study could be criticised, therefore, is for focusing on only one of the perspectives of these two groups of actors in the classroom. Nevertheless, looking at both would have widened the scope of the study beyond the reserves of time available.

The focus of this study on only the successful practice of classroom practitioners could also be criticised although there were a number of methodological grounds for focusing on just the positive aspects of the teachers' teaching as discussed in chapter three. First, the positive emphasis provided the teachers with a point of focus to the accounts they gave of their subject matter teaching. Second, previous research (e.g. Cooper and McIntyre 1996; Brown and McIntyre 1993) had suggested that encouraging teachers to talk about the successful aspects of their practice gives them confidence and assists them in explaining their classroom actions. Third, research exploring the successful aspects of teachers' teaching was felt to be most useful to the recipients of the research.

During the course of this study the quality of interviewing improved. Although careful preparation was instigated through the reading of methodological texts before data collection began it was only when engaging in the interview process itself that the practical skills of interviewing were developed. As data collection proceeded and there was time to reflect upon my conduct as an interviewer I became a better listener, I was able to probe more effectively and I was less likely to ask leading questions. Since improvements in the quality of interviewing might lead to improvements in the quality of data generated this is another area in which this study might be criticised. However, during analysis, steps were taken to minimise the effect of any examples of poor interviewing on the interpretation produced. On occasions where, for example, a leading question was asked and the teacher's response supported a particular claim of the developing analytical interpretation, further corroborative data from the same teacher (under conditions where interview practice was good) was sought before the evidence was accepted as trustworthy.

The small number of case studies in this investigation ensured a richness and detail to the accounts produced. However, given the small-scale nature of this research, it is difficult to know, with confidence, the extent to which the findings and implications of this study might be applicable to settings beyond the three investigated. At this juncture, it would seem most useful if the conclusions of this study are considered as ideas that are valid *in relation to the contexts in which they were generated*. However, in addition to this, the ideas could also be considered as potential frameworks used to explore further settings. Consequently, any generalisations arising from this study should be

constructed in a 'naturalistic' form. These are generalisations, not of a statistical nature, but instead, generalisations that 'form the basis of hypotheses to be carried from one case to the next' (Brown and McIntyre 1993, p. 50). Further investigation in different settings, therefore, would enable the potential generalisability of the findings of this study to be explored.

Implications of the study

Implications for policy and practice

The findings of this thesis suggest a number of implications for policy and practice. To begin with the finding that developing students' knowledge and understanding of the syntactic dimension of biology was not an intentional aim of the teachers' successful teaching suggests that there is a real need for initial teacher training to encourage the development of student teachers' conceptions of the nature of biology/science as well as assist them in considering ways in which their conceptions could be translated into their practice. A study by Gess-Newsome (2002) suggests the value of explicitly teaching the nature of science to pre-service teachers since through a specifically designed course her student teachers developed more sophisticated conceptions of this dimension of subject matter knowledge. The study, however, did not explore the effects of this explicit teaching on the pre-service teachers' classroom practice.

Furthermore, it is suggested that it might be beneficial to give practising teachers the time (away from their school teaching commitments), resources and support through in-service training to develop and extend their knowledge and understanding of the syntactic dimension of biology/science and encourage them to reflect and share their thoughts and experiences on how to successfully integrate this aspect into their classroom practice.

The suggestion that teachers interpret syllabus documents according to the national and local contexts in which they work, and not necessarily in the sorts of ways the writers intend, indicates that much more account needs to be taken of

the ways in which teachers work and what they consider possible in their classrooms in the formulation of such documents. It would certainly be beneficial to involve teachers in a consultative process when new curriculum documents are being developed.

The finding that teachers draw upon highly sophisticated conceptions of biology in order to teach it successfully suggests that initial teacher training would also benefit from encouraging pre-service teachers to develop, discuss and reflect upon their substantive subject matter structures and consider how they might assist their teaching of biology. Moreover, it is also suggested that it might be advantageous for practising teachers to be given the time (away from their teaching commitments), resources and support to reflect upon and share their conceptions of biology with other teachers. In this sort of format they might be encouraged to extend their subject matter conceptions and consider how they do use them and can further use them to develop their own subject matter teaching.

Moreover, this finding holds significance for a feature of science teaching in England – teachers of science frequently teach outside of their subject specialism in the lower school years (for example in Years 7, 8 and 9) and sometimes also through to GCSE (for example in Years 10 and 11). It is unlikely that non-subject matter specialists will have the depth of knowledge and conceptions of a specific science discipline that subject matter specialists have developed. Indeed, this might help to explain the well-documented difficulties that teachers teaching outside of their specialism experience (e.g. Sanders *et al* 1993). Given the problems in this country with recruiting and retaining science

teachers (Parliamentary Office of Science and Technology 1996) it is likely that teaching outside of ones specialist area will remain an aspect of a science teachers' job for some time to come. Consequently, it is suggested that both pre-service and in-service support that encourages science teachers of different subject specialisms to share the conceptions they have of their subjects with other non-specialists, and that offers the opportunity for specialists to explore with non-specialists how these conceptions shape their teaching might help non-specialist teachers to feel better prepared and more confident when teaching outside their subject area.

Finally, it has been suggested that the prevailing assessment driven culture in England might encourage a greater focus on the teaching of substantive rather than syntactic content as well as the use of more teacher-centred approaches to teaching in A level biology classrooms. An attempt to change this situation, therefore, might benefit from reducing the burden of examinations on teachers (and pupils) and therefore encourage a change in teachers' perceptions of the main aim of science education as synonymous with examination achievement. Steps in this direction might begin to encourage a broader view of the aims of science education, and in turn, possibly a greater emphasis on other dimensions of subject matter knowledge and understanding as well as a wider range of teaching and learning approaches.

Implications for future research

There are a number of areas of research that might build upon the findings of this study. The finding that the teachers' successful teaching of biology did not

include developing students' knowledge and understanding of its syntactic dimension coupled with the belief that an understanding of the nature of science is an important aspect of science learning in schools suggests important avenues for research. To begin with, it would be useful to investigate why teaching about the nature of biology/science is not an intentional aim of A level biology teachers' teaching despite the emphasis that it is given in curriculum documents. Whilst this thesis has attempted to suggest explanations for the relative absence of this dimension in the classroom, there is a need for rigorous research to explore this in more detail. Further to this, it would also be beneficial to explore what sorts of factors, from the perspectives of teachers themselves, might encourage them to make the nature of biology/science an intentional aim of their subject matter teaching.

Moreover, given that there is no broadly established body of professional knowledge and expertise within the teaching community related to teaching the nature of science (Ryder *et al* 2003) there is also a real need for research to investigate the nature of the practical knowledge and understanding required to successfully teach the syntactic dimension of subject matter knowledge in real biology/science classrooms. Research of this nature, for example, might involve working with teachers highly committed to teaching the nature of science in their classrooms and exploring with them the sort of things they do and why they do these things when they are encouraging their students to develop knowledge and understanding of the syntactic dimension of biology/science.

An additional and potentially highly significant area of research would involve investigating the most appropriate ways to effectively provide pre-service and in-

service support to encourage novice and experienced teachers alike to consider developing students' understanding of the nature of science to be an important aim of their subject matter teaching. Further, it would be useful to explore how such support could be effectively given to encourage novice and experienced practitioners to develop the sort of practical knowledge required to successfully achieve this aim in their own classrooms.

As identified earlier, the findings of this thesis highlight a discrepancy between much academic writing on practice in science education and practice itself. This suggests that how biology/science teachers really work in their classrooms is being ignored in the literature and therefore there is a real need to know more about their actual everyday practice. Consequently, further research exploring biology/science teachers' perspectives of their practice and revealing their well thought out and clear rationales for acting as they do in their classrooms would seem to be important. It is only through developing our knowledge and understanding of teachers' practice that we will be able to institute policies for professional development that will have a chance of being successful in that they will build on an understanding of where teachers are.

In addition, there is also a need for research that *does not ignore what teachers know, believe and do*. The fact that many interventions in science education have had limited success in the classroom are testament to the need to value and encourage this sort of research. More collaborative research in which teachers have the opportunity to bring their practical knowledge to bear on the formulation of research questions would be particularly useful as well as

engaging teachers in research projects that are interested specifically in them and *their* concerns about *their* teaching.

Bibliography

- Abd-El-Khalick, F. and N. G. Lederman (2000). "Improving science teachers' conceptions of the nature of science: a critical review of the literature." International Journal of Science Education **22**(7): 665-701.
- Abd-El-Khalick, K., R. L. Bell, et al. (1998). "The nature of science and instructional practice: making the unnatural natural." Science Education **82**: 417-436.
- Adenyi, E. O. (1985). "Misconceptions of selected ecological concepts held by some Nigerian students." Journal of Biological Education **19**(4): 311--316.
- Akeroyd, F. M. (1983). "Teaching the Krebs Cycle." Journal of Biological Education **17**(3): 245-246.
- Anderson, C. and E. Smith (1985). Teaching Science. The Educators Handbook: A Research Perspective. New York, Longman.
- Anderson, K. E. (1950). "The teachers of science in a representative sampling of Minnesota schools." Science Education **34**(1): 57-66.
- Anderson, L., C. Evertson, et al. (1979). "An experimental study of effective teaching in first-grade reading groups." Elementary School Journal **79**(4): 193-223.
- Anderson, L., C. Evertson, et al. (1980). "Dimensions of classroom management derived from recent research." Journal of Curriculum Studies **12**: 193-223.
- Andersson, B. (1990). "Pupils' Conceptions of Matter and its Transformations (age 12-16)." Studies in Science Education **18**: 53-85.
- Annan, L. (2000). "Biology exercises for assessment and revision (BEAR) - version A." Journal of Biological Education **34**(4): 219.
- Argyris, C. and D. Schön (1974). Theory in practice: increasing professional effectiveness. San Francisco, Josey-Bass.
- Arnaudin, M. W. and J. J. Mintzes (1985). "Students' alternative conceptions of the circulatory system: A cross-age study." Science Education **69**: 721-733.
- Ash, V. (2001). "The report card comment generator: a model to help explain the relationship between genes and alleles." Journal of Biological Education **35**(2): 100-101.
- Associated Examining Board (1997). 1999 Syllabuses: Biology and Human Biology including Modular. Surrey, The Associated Examining Board.

Ausubel, D. P., J. D. Novak, et al. (1978). Educational Psychology: A Cognitive View. New York, Holt, Rinehart and Winston.

Ayala, F. J. (1974). The autonomy of biology as a natural science. Biology, History and Natural Philosophy. A. D. Breck and W. Yourgrau. New York, Plenum/Rosetta.

Baddeley, A. (1990). Human Memory: Theory and Practice. London, Allyn and Bacon.

Baggott la Velle, L. and D. Maddon (2003). "Educational Media Webwatch 50 glorious years - The Golden Jubilee of The Double Helix." Journal of Biological Education **37**(3): 146-7.

Baggott, L. and B. Wright (1996). "The use of interactive video in teaching about cell division." Journal of Biological Education **30**(1): 57-66.

Baggott la Velle, L. (2001). "Educational Media Web watch Biological Images." Journal of Biological Education **36**(1): 45.

Baggott la Velle, L. (2002a). "Educational Media Web watch Digestion." Journal of Biological Education **37**(1): 44.

Baggott la Velle, L. (2002b). "Educational Media Web watch Osmosis." Journal of Biological Education **36**(3): 145.

Baggott la Velle, L. (2002c). "Educational Media Web watch Microbiology." Journal of Biological Education **36**(2): 99.

Baggott la Velle, L. (2003). "Educational Media Web watch A Potpourri." Journal of Biological Education **37**(2): 100.

Bailey, A. (2001). "Web watch: Stem cells." Journal of Biological Education **35**(4): 207.

Ball, D. L. and G. W. McDiarmid (1990). The Subject-Matter Preparation of Teachers. Handbook of Research on Teaching. W. R. Houston. London, Macmillan.

Banet, E. and F. Nunez (1997). "Teaching and learning about human nutrition: a constructivist approach." International Journal of Science Education **19**(10): 1169-1194.

Barker, S. and R. Beare (1999). "Teaching population strategies: an evaluation of approaches." Journal of Biological Education **33**(3): 149-154.

Barritt, L. (1985). Researching Education Practice. Grand Forks, University of North Dakota, Center for Teaching and Learning.

Batten, M. (1989). "Teacher and Pupil Perspectives on the Positive Aspects of Classroom Experience." Scottish Educational Review **21**: 48-57.

Batten, M., P. Marland, et al. (1993). Knowing How To Teach Well: Teachers Reflect on their Classroom Practice. Victoria, ACER.

Batts, G. R. (2000). "Cell and school activities - a useful analogy." School Science Review **81**(296): 111-112.

Beattie, M. (1995). "New prospects for teacher education: narrative ways of knowing teaching and teacher learning." Educational Research **37**(1): 53-70.

Beatty, J. W. and B. E. Woolnough (1982). "Practical work in 11-13 science: the context, type and aims of current practice." British Education Research Journal **8**: 23-30.

Beatty, J. W. and B. E. Woolnough (1982). "Why do practical work in 11-13 science?" School Science Review **63**: 758-770.

Becker, H. S. (1963). Outsiders. New York, The Free Press.

Beckner, M. (1971). Organismic Biology. Man and Nature: Philosophical Issues in Biology. R. Munson. New York, Dell publishing.

Bell, B. and M. Barker (1982). "Towards a scientific concept of 'animal'." Journal of Biological Education **16**(3): 197-200.

Benjafeld, J. G. (1992). Cognition. New Jersey, Prentice-Hall.

Ben-Peretz, M. (1995). "Making Sense of Teaching." Teaching & Teacher Education **11**(1): 103-106.

Bentley, D. I. and M. Watts (1987). "Constructivism in the Classroom: enabling conceptual change by words and deeds." British Educational Research Journal **13**(2): 121-135.

BERA (1992) Ethical Guidelines for Educational Research. Edinburgh, BERA.

Berg, T. and W. Brouwer (1991). "Teacher awareness of student alternate conceptions about rotational motion and gravity." Journal of Research in Science Teaching **28**: 3-18.

Berliner, D. C. (1986). "In Pursuit of the Expert Pedagogue." Educational Researcher **August/September**: 5-13.

Berliner, D. C. (1987). Ways of Thinking About Students and Classrooms by More and Less Experienced Teachers. Exploring Teachers' Thinking. J. Calderhead. London, Cassell Educational.

Berliner, D. C. (1988). The development of expertise in pedagogy. Paper presented at the meeting of the American Association of Colleges for Teacher Education, New Orleans, LA.

Bernard, H. R. (1994). Research Methods in Anthropology: Qualitative and Quantitative approaches. London, Sage Publications.

Beynon, J. (1983). Ways-in and staying-in: fieldwork as problem solving. The Ethnography of Schooling: Methodological Issues. M. Hammersley. Driffield, Nafferton.

Bishop, B. A. and C. W. Anderson (1990). "Student conceptions of natural selection and its role in evolution." Journal of Research in Science Teaching **27**(5): 415-427.

Bloor, M. (1978). "On the analysis of observational data: a discussion of the worth and uses of inductive techniques and respondent validation." Sociology **12**(3): 545-552.

Bogdan, R. and S. J. Taylor (1984). Introduction to Qualitative Research Methods: The Search for Meanings. New York, J. Wiley & Sons.

Borko, H. and R. T. Putnam (1996). Learning to teach. Handbook of Educational Psychology. D. C. Berliner and R. C. Calfee. New York, Macmillan.

Brickhouse, N. W. (1990). "Teachers' Beliefs About the Nature of Science and Their Relationship to Classroom Practice." Journal of Teacher Education **41**(3): 53-62.

Bromley, G. (2002). "Environmental games to teach concepts and issues." School Science Review **82**(298): 39-46.

Brophy, J. and T. L. Good (1986). Teacher Behaviour and Student Achievement. Handbook of Research on Teaching. M. C. Wittrock. New York, Macmillan.

Brophy, J. E. (1983). "Classroom Organization and Management." Elementary School Journal **83**(4): 265-286.

Brown, C. R. (1990). "Some misconceptions in meiosis shown by students responding to an Advanced level practical examination question in biology." Journal of Biological Education **24**(3): 182-185.

Brown, C. R. (1995). The effective teaching of Biology. Essex, Longman.

Brown, K. R. (1991). "Blowfly succession - a simple trap." Journal of Biological Education **25**(2): 89-90.

Brown, S. and D. McIntyre (1985). Research Methodology and New Policies for Professional Development and Innovation. Scottish Educational Research Association, University of Stirling.

- Brown, S. and D. McIntyre (1986). How do teachers think about their craft? Advances of Research on Teacher Thinking. M. Ben-Peretz, R. Bromme and R. Halkes. Lisse., Swets & Zeitlinger.
- Brown, S. and D. McIntyre (1993). Making Sense of Teaching. Buckingham, Open University Press.
- Bryman, A. and R. G. Burgess, Eds. (1994). Analyzing Qualitative Data. London, Routledge.
- Buchmann, M. (1986). Role over person: Legitimacy and authenticity in teaching. Advances of Research on Teacher Thinking. M. Ben-Peretz, R. Bromme and R. Halkes. Lisse, Swets and Zeitlinger.
- Buchmann, M. (1987). "Teaching Knowledge: the lights that teachers live by." Oxford Review of Education **13**(2): 151-164.
- Buck, M. (1986). "A novel approach to Hardy-Weinberg problems." Journal of Biological Education **20**(3): 185-188.
- Bullington, J. and G. I. Karlson (1984). "Introduction to phenomenological psychological research." Scandinavian Journal of Psychology **25**: 51-63.
- Bullough, R. V., J. G. Knowles, et al. (1991). Emerging as a teacher. London, Routledge.
- Burgess, R. G. (1984). In the Field: An Introduction to Field Research. London, Routledge.
- Busby, S. (1995). "A practical way of learning about DNA using rubber tubing as a model." Journal of Biological Education **29**(2): 95-96.
- Bushell, J. (2001). "A model of the ultrastructure of a cell." Journal of Biological Education **35**(3): 152-153.
- Butefish, W. L. (1990). "Science Teachers' Perceptions of Their Interactive Decisions." Journal of Educational Research **84**(2): 107-114.
- Butt, R. L. (1984). Arguments for using biography in understanding teacher thinking. A New Perspective on Persisting Problems in Education. R. Halkes and J. K. Olson. Lisse, Swets and Zeitlinger.
- Calderhead, J. (1981). "Stimulated recall: a method for research on teaching." British Journal of Educational Psychology **51**: 211-217.
- Calderhead, J. (1987). "Developing a framework for the elicitation and analysis of teachers' verbal reports." Oxford Review of Education **13**(2): 183-189.

Calderhead, J., Ed. (1988). Teachers' Professional Learning. Lewes, Falmer Press.

Calderhead, J. (1996). Teachers' Knowledge and Beliefs. Handbook of Educational Psychology. D. C. Berliner and R. C. Calfee. London, Prentice Hall International: 709-725.

Carlsen, W. (1999). Domains of teacher knowledge. Examining Pedagogical Knowledge. The Construct and its Implications for Science Education. J. Gess-Newsome and N. G. Lederman. London, Kluwer Academic Publishers: 133-144.

Carlsen, W. S. (1993). "Teacher Knowledge and Discourse Control: Quantitative Evidence From Novice Biology Teachers' Classrooms." Journal of Research in Science Teaching **30**(5): 471-481.

Carnahan, R. S. (1980). The effects of teacher planning on classroom processes. Madison, Wisconsin R & D Center for Individualized Schooling.

Carrick, T. (1983). "Some biology teachers' goals for Advanced Level teaching." Journal of Biological Education **17**(3): 205-214.

Carrick, T. (1983). "The teaching of options in JMB A-level Biology: some teachers' views." Journal of Biological Education **17**(4): 319-322.

Carter, K. (1990). Teachers' Knowledge and Learning to Teach. Handbook of Research on Teacher Education. W. R. Houston. London, Macmillan: 291-310.

Castells-Brookes, N., R. Mullins, et al. (1999). "The Molecular Biology Notebook on CD-Rom - A step toward the virtual laboratory." Journal of Biological Education **33**(4): 223-225.

Cattell, R. B. (1931). "The Assessment of Teaching Ability." British Journal of Educational Psychology **1**: 48-72.

Caulton, E. (1988). "Rabbit faeces as a source of pollen for dietary and habitat studies - a suggestion for project work suitable for sixth form and higher students of ecology." Journal of Biological Education **22**(1): 37-40.

Champagne, A., R. Gunstone, et al. (1983). "Naive knowledge and science learning." Research in Science and Technological Education **1**: 173-183.

Champagne, A. B., L. E. Klopfer, et al. (1982). "Cognitive research and the design of science instruction." Educational Psychologist **17**(1): 31-53.

Cheverton, J. and F. Ebling (1997). "Datalogging hamster activity rhythms." Journal of Biological Education **31**(1): 11-16.

Cho, H., J. B. Kahle, et al. (1985). "An Investigation of High School Biology Textbooks as Sources of Misconceptions and Difficulties in Genetics and Some Suggestions for Teaching Genetics." Science Education **69**(5): 707-719.

Chubb, D. J. (1998). "Bozo the clown's contribution to teaching A level genetics." School Science Review **80**(290): 105-106.

Cicourel, A. V. (1964). Method and Measurement in Sociology. New York, The Free Press.

Clandinin, D. J. (1985). "Personal Practical Knowledge: A Study of Teachers' Classroom Images." Curriculum Inquiry **15**(4): 361-383.

Clandinin, D. J. (1986). Classroom Practice: Teacher Images in Action. London, Falmer Press.

Clandinin, D. J. (1989). "Developing Rhythm in Teaching: The Narrative Study of a Beginning Teacher's Personal Practical Knowledge of Classrooms." Curriculum Inquiry **19**(2): 121-141.

Clandinin, D. J. and F. M. Connelly (1985). Personal practical knowledge and the modes of knowing: Relevance for teaching and learning. Learning and teaching the ways of knowing. E. Eisner. Chicago., University of Chicago Press.

Clandinin, D. J. and F. M. Connelly (1986). "Rhythms in Teaching: The Narrative Study of Teachers' Personal Practical Knowledge of Classrooms." Teaching and Teacher Education **2**(4): 377-387.

Clandinin, D. J. and F. M. Connelly (1994). Personal Experience Methods. Handbook of Qualitative Research. N. Denzin and Y. Lincoln. Thousand Oaks: California, Sage.

Clandinin, D. J. and F. M. Connelly (1997). "Teachers' personal practical knowledge on the professional knowledge landscape." Teaching and Teacher Education **13**(7): 665-674.

Clark, C. M. and P. L. Peterson (1986). Teachers' thought processes. Handbook of Research on Teaching. M. C. Wittrock. New York, Macmillan.

Claxton, G. (1986). "The Alternative Conceivers' Conceptions." Studies in Science Education **13**: 123-130.

Clement, J., D. E. Brown, et al. (1989). "Not all preconceptions are misconceptions: finding 'anchoring conceptions' for grounding instruction on students' intuitions." International Journal of Science Education **11**(Special Issue): 554-565.

Clermont, C., H. Borko, et al. (1994). "Comparative study of the pedagogical content knowledge of experienced and novice chemical demonstrators." Journal of Research in Science Teaching **31**(4): 419-441.

Cobb, P. and J. W. Whitenack (1996). "A Method For Conducting Longitudinal Analyses Of Classroom Videorecordings And Transcripts." Educational Studies in Mathematics **30**: 213-228.

Coffey, A. and P. Atkinson (1996). Making Sense of Qualitative Data: Complementary Research Strategies. London, Sage.

Cohen, D. (1977). Ideas and Action: Social Science and Craft in Educational Practice. Chicago, Center for New Schools.

Connelly, F. M. and D. J. Clandinin (1984). Personal Practical Knowledge At Bay Street School: Ritual, Personal Philosophy And Image. Teacher Thinking : A New Perspective on Persisting Problems in Education. R. Halkes and J. K. Olson. Lisse, Swets & Zeitlinger.

Connelly, F. M. and D. J. Clandinin (1986). "On Narrative Method, Personal Philosophy, And Narrative Unities In The Story Of Teaching." Journal of Research in Science Teaching **23**(4): 293-310.

Cooper, P. (1993). "Field relations and the problem of authenticity in researching participants' perceptions of teaching and learning in classrooms." British Educational Research Journal Vol. **19**(4): 323-338.

Cooper, P. and D. McIntyre (1993). "Commonality in teachers' and pupils' perceptions of effective classroom learning." British Journal of Educational Psychology **63**: 381-399.

Cooper, P. and D. McIntyre (1994). "Patterns Of Interaction Between Teachers' And Students' Classroom Thinking, And Their Implications For The Provision Of Learning Opportunities." Teaching & Teacher Education **10**(6): 633-646.

Cooper, P. and D. McIntyre (1996). Effective Teaching And Learning: Teachers' and Students' Perspectives. Buckingham, Open University Press.

Cortazzi, M. (1993). Narrative Analysis. London, Falmer Press.

Cosgrove, M. and R. Osborne (1981). Physical Change, a working paper of the Learning in Science Project.

Crist, J., R. W. Marx, et al. (1974). Teacher behaviour in the organizational domain. California, National Institute of Education, Stanford Center for R & D in Teaching, Stanford.

Dagher, Z. and G. Cossman (1992). "Verbal explanations given by science teachers: Their nature and implications." Journal of Research in Science Teaching **29**: 361-374.

Dahllof, U. and U. P. Lundgren (1970). Macro and micro approaches combined for curriculum process analysis: A Swedish educational field project. Goteborg, University of Goteborg, Institute of Education.

Dallas, D. (1980). Teaching Biology Today. London, Hutchinson.

Day, C., J. Calderhead, et al., Eds. (1993). Research on Teacher Thinking: Understanding Professional Development. London, Falmer Press.

Day, C., M. Pope, et al., Eds. (1990). Insight into Teachers' Thinking and Practice. London, Falmer Press.

de Brabander, C. J. (1993). Subject concepts of teachers and school culture. School culture, school improvement, and teacher development. F. K. Kievet and R. Vanderberghe, DSWO Press: 77-105.

Department of Education and Science/Welsh Office (1988). Advancing A levels: Report of a Committee appointed by the Secretary of State for Education and Science and the Secretary of State for Wales (The Higginson Report). London, HMSO.

Delamont, S. and P. Atkinson (1980). "The two traditions in educational ethnography: Sociology and Anthropology compared." British Journal of Sociology of Education 1: 139-152.

Delpech, R. (1999). "The history of life - multimedia CD rom re evolution, genes, language etc." Journal of Biological Education 33(4): 226-227.

Delpech, R. (2000). "Investigating the effects of temperature on the membrane integrity of yeast." School Science Review 82(299): 91-95.

Delpech, R. (2002). "Why are school students bored with science?" Journal of Biological Education 36(4): 156-157.

Denzin, N. K. (1970). Sociological Methods: A Sourcebook. London, Butterworths.

Desforjes, C. and D. McNamara (1977). "One man's heuristic is another man's blindfold: some comments on applying social science to educational practice." British Journal of Teacher Education 3(1): 27-39.

Desforjes, C. and D. McNamara (1979). "Theory and practice: methodological procedures for the objectification of craft knowledge." British Journal of Teacher Education 5(2): 145-152.

Dey, I. (1993). Qualitative Data Analysis A User-Friendly Guide for Social Scientists. London, Routledge.

Diamond, C. T. P. (1993). "Writing To Reclaim Self: The Use Of Narrative In Teacher Education." Teaching & Teacher Education 9(5/6): 511-517.

Dixon, B. (1994). Jobs and careers after A-levels: Your employment opportunities at 18+. Cambridge, Hobsons.

- Dolan, A. (1996). "The making of Mandy - introducing alleles." Journal of Biological Education **30**(2): 94-96.
- Dowdeswell, W. H. (1981). Teaching and Learning Biology. London, Heinemann.
- Downes, S. P. (1992). "The practical investigation of selection: an A-level experiment using *Drosophila melanogaster*." Journal of Biological Education **26**(1): 37-40.
- Doyle, W. (1977). "Learning the classroom environment: An ecological analysis." Journal of Teacher Education **28**: 51-55.
- Driver, R. (1989). Changing Conceptions. Adolescent Development and School Science. P. Adey. Lewes, Falmer Press.
- Duet, C. and J. Newfield (1979). "Curriculum leaders' valuing of the consequences of magnet and comprehensive schools." Journal of Curriculum Studies **11**: 149-158.
- Dunkin, M. J. and B. J. Biddle (1974). The Study of Teaching. New York, Holt, Rinehart and Winston.
- Duschl, R. A. and E. Wright (1989). "A case study of high school teachers' decision making models for planning and teaching science." Journal of Research in Science Teaching **26**: 467-501.
- Duvigneaud, P. (1964). Biology to-day: Its role in education
Report of an OECD working session on the teaching of school biology. OECD.
- Ebel, K. E. (1976). The Craft of Teaching: A Guide to Mastering the Professor's Art. San Francisco, Jossey-Bass.
- Elbaz, F. (1981). "The Teacher's 'Practical Knowledge': Report of a Case Study." Curriculum Inquiry **11**(1): 43-71.
- Elbaz, F. (1983). Teacher Thinking: A Study of Practical Knowledge. New York, Nichols Publishing Company.
- Elliott, J., Ed. (1997). Oxford English Dictionary. Oxford, Oxford University Press.
- Eltringham, J. and R. Lock (1998). "Amazing aprons - an attractive, alternative anatomical aid." Journal of Biological Education **32**(1): 7-10.
- Ely, M. (1991). Doing qualitative research: circles within circles. London, Falmer Press.
- Eraut, M. (1995). "Schön Shock: a case for reframing reflection-in-action?" Teachers and Teaching: theory and practice **1**(1): 9-22.
- Erickson, F. "What makes school ethnography ethnographic?" Council of Anthropology and Education Newsletter **2**: 10-19.

Ernest, P. (1989). "The knowledge, beliefs and attitudes of the mathematics teacher: A model." Journal of Education for Teaching **15**(1): 13-33.

Evans, S. W. (2003). "The Dolly Mixture model of the DNA double helix." School Science Review **84**(308): 23.

Evertson, C. (1983). "Improving class management: An experiment in an elementary classroom." Elementary School Journal **84**(2): 173-188.

Evertson, C., E. Emmer, et al. (1980). "Predictors of effective teaching in junior high mathematics classrooms." Journal for Research in Mathematics Education **11**: 167-178.

Eysenck, M. W. (1993). Principles of Cognitive Psychology. East Sussex, Lawrence Erlbaum.

Eysenck, M. W. and M. T. Keane (2000). Cognitive Psychology: A Student's Handbook. East Sussex, Psychology Press.

Feher, E. and K. Rice (1987). A comparison of teacher-student conceptions in optics. Second International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Department of Education, Cornell University.

Fenstermacher, G. (1986). Philosophy of research in teaching: three aspects. Handbook of Research on Teaching. M. C. Wittrock. New York, Macmillan.

Fishbein, E., R. Stavy, et al. (1989). "The psychological structure of naive impetus conceptions." International Journal of Science Education **11**: 71-81.

Fisher, K. M. (1985). "A Misconception in Biology: Amino Acids and Translation." Journal of Research in Science Teaching **22**(1): 53-62.

Flanders, N. A. (1970). Analyzing teacher behaviour. Reading, Addison-Wesley.

Ford, G. W. and L. Pugno, Eds. (1964). The Structure of Knowledge and the Curriculum. Rand McNally Curriculum Series. Chicago, Rand McNally & Company.

Franfort-Nachmias, C. and D. Nachmias (1996). Research Methods in the Social Sciences. London, Arnold.

Franklin, S., M. Peat, et al. (2003). "Non-traditional interventions to stimulate discussion: the use of games and puzzles." Journal of Biological Education **37**(2): 72-84.

Fuller, F. F. and B. A. Manning (1973). "Self-confrontation reviewed: A conceptualisation for video playback in teacher education." Review of Educational Research **43**(4): 469-528.

- Gage, N. L. (1978). The scientific basis of the art of teaching. New York, Teachers College Press, Columbia University.
- Gaier, E. L. (1954). "A study of memory under conditions of stimulated recall." Journal of General Psychology **50**: 147-153.
- Garfinkel, H. (1967). Studies in Ethnomethodology. Englewood Cliffs, Prentice-Hall.
- Gayford, C. G. (1984). "Water relations and the vacuolated plant cell: a brief study of the topic at Advanced Level in school biology." Journal of Biological Education **18**(2): 151-155.
- Geddis, A. N. (1993). "Transforming subject-matter knowledge: the role of pedagogical content knowledge in learning to reflect on teaching." International Journal of Science Education **15**(6): 673-683.
- Genburg, V. (1992). "Patterns and Organizing Perspectives: A View of Expertise." Teaching & Teacher Education **8**(5/6): 485-495.
- Gess-Newsome, J. (2002). "The Use and Impact of Explicit Instruction about the Nature of Science and Science Inquiry in an Elementary Science Methods Course." Science and Education **11**: 55-67.
- Gess-Newsome, J. and N. G. Lederman (1993). "Preservice biology teachers' knowledge structures as a function of professional teacher education: A year-long assessment." Science Education **77**: 25-45.
- Gess-Newsome, J. and N. G. Lederman (1995). "Biology teachers' perceptions of subject matter structure and its relationship to classroom practice." Journal of Research in Science Teaching **32**(3): 301-325.
- Gilbert, J. K., R. J. Osborne, et al. (1982). "Children's Science and Its Consequences for Teaching." Science Education **66**(4): 623-633.
- Gilbert, J. K., D. M. Watts, et al. (1982). "Students' conceptions of ideas in mechanics." Physics Education **17**: 62-66.
- Godson, I., Ed. (1992). Studying teachers' lives. London, Routledge.
- Goetz, J. P. and M. D. LeCompte (1984). Ethnography and Qualitative Design in Educational Research. Orlando, Academic Press.
- Gold, R. L. (1970). Roles in Sociological Field Observations. Sociological Methods: A Sourcebook. N. K. Denzin. London, Butterworths.
- Good, T. L. (1979). "Teacher effectiveness in the elementary school: What we know about it now." Journal of Teacher Education **30**: 52-64.

- Goode, W. J. and P. K. Hatt (1952). Methods in Social Research. London, McGraw-Hill Book Company.
- Gorden, R. L. (1975). Interviewing: strategy, techniques, and tactics. Sussex, The Dorsey Press.
- Gott, R. and S. Duggan. (1995). Investigative Work in the Science Curriculum. Buckingham, Open University Press.
- Gould, C. (1983). "Biology teaching - is there another way?" The School Science Review **65**(231): 373-377.
- Greenwood, J. J. D. and J. G. Greenwood (1988). "Data analysis in A-level Biology." Journal of Biological Education **22**(2): 107-109.
- Grimmett, P. P. and A. M. Mackinnon (1992). "Craft Knowledge and the Education of Teachers." Review of Research in Education **18**: 385-456.
- Grossman, P. (2002). Teacher Knowledge & Professional Education: The Case of Pedagogical Content Knowledge. Inaugural UPSI International Teacher Education Conference, Stanford.
- Grossman, P., A. Reynolds, et al. (1985). English major to English teacher. New approaches to an old problem. Annual Meeting of the American Educational Research Association, Chicago.
- Grossman, P. L. (1990). The Making of a Teacher. New York, Teachers College Press.
- Grossman, P. L. (1991). What are we talking about anyway? Advances in Research on Teaching. J. Brophy. Greenwich, CT., JAI Press. **2**: 245-264.
- Grossman, P. L. and A. E. Richert (1988). "Unacknowledged Knowledge Growth: A Re-examination of the Effects of Teacher Education." Teaching and Teacher Education **4**(1): 53-62.
- Grossman, P. L. and S. S. Stodolsky (1994). "Considerations of content and the circumstances of secondary school teaching." Review of Research In Education **20**: 179-221.
- Grossman, P. L. and S. S. Stodolsky (1995). "Content as Context: The Role of School Subjects in Secondary School Teaching." Educational Researcher **November**: 5-11.
- Grossman, P. L., S. M. Wilson, et al. (1989). Teachers of Substance: Subject Matter Knowledge for Teaching. The American Association of Colleges for Teacher Education. M. C. Reynolds. Oxford, Pergamon Press.

Gudmundsdottir, S. and L. Shulman (1987). "Pedagogical content knowledge in social studies." Scandinavian Journal of Educational Research **31**(2): 59-70.

Gudmundsdottir, S. (1988). Managing the ideas: Four case studies of high school teaching. Annual Meeting of the American Educational Research Association, New Orleans.

Gundmundsdottir, S. (1990). "Values in Pedagogical Content Knowledge." Journal of Teacher Education **41**(3): 44-52.

Gundmundsdottir, S. (1990). Curriculum Stories: Four Case Studies of Social Studies Teaching. Insight into Teachers' Thinking and Practice. C. Day, M. Pope and P. Denicolo. London, Falmer Press: 197-118.

Gudmundsdottir, S. (1991). Pedagogical models of subject matter. Advances in Research on Teaching. J. Brophy. Greenwich, Connecticut, JAI Press. **2**: 265-304.

Hagger, H. (1995). The problems and possibilities for interns of gaining access to experienced teachers' craft knowledge. Unpublished Doctoral Dissertation. University of Oxford.

Hale, W. G., J. P. Margham, et al. (1995). Collins Dictionary of Biology. Glasgow, Harper Collins.

Halkes, R. and J. K. Olson, Eds. (1984). Teacher Thinking : A New Perspective on Persisting Problems in Education. Lisse, Swets & Zeitlinger.

Hall, A., M. J. Reiss, et al. (2003). "Designing and implementing a new advanced level biology course." Journal of Biological Education **37**(4): 162-165.

Halliday, M. A. K. and J. R. Martin (1993). Writing Science: Literacy and Discursive Power. London, The Falmer Press.

Hammersley, M., R. Gomm, et al. (1998). Case Study and Theory. Paper presented at the Case Study Research in Education (CEDAR) conference, University of Warwick.

Hammersley, M. and P. Atkinson (1995). Ethnography: Principles in Practice. London, Routledge.

Hammersley, M., R. Gomm, et al. (1998). Case Study and Theory. Case Study Research in Education, University of Warwick.

Harlen, W., Ed. (1999). Effective Teaching of Science. Edinburgh, SCRE.

Harris, D. and M. Taylor (1983). "Discovery Learning in School Science: the Myth and the Reality." Journal of Curriculum Studies **15**(3): 277-289.

Harris, T. L. (1950). "Thought Processes." The American Psychologist **5**: 342-343.

- Hartmann, D. P. and D. D. Wood (1990). Observational Methods. International Handbook of Behaviour Modification Therapy. A. S. Bellack, M. Hersen and A. E. Kazdin. New York, Plenum Press.
- Hashweh, M. Z. (1986). Effects of subject matter in the teaching of biology and physics. American Educational Research Association, San Francisco.
- Hashweh, M. Z. (1987). "Effects Of Subject-Matter Knowledge In The Teaching Of Biology And Physics." Teaching & Teacher Education 3(2): 109-120.
- Hauslein, P. L., R. G. Good, et al. (1992). "Biology content cognitive structure: From science student to science teacher." Journal of Research in Science Teaching 29(9): 939-964.
- Heath, S. B. (1983). Ways with Words. Cambridge, Cambridge University Press.
- Henslin, J. M. (1990). It's not a lovely place to visit, and I wouldn't want to live there. Studies in Qualitative Methodology: Reflections on Field Experience. R. G. Burgess. JAI, Greenwich., Conn. 2.
- Hewson, M. and D. Hamlyn (1984). "The influence of intellectual environment on conceptions of heat." European Journal of Science Education 6: 245-262.
- Hewson, P. W., M. E. Beeth, et al. (1998). Teaching for conceptual change. International Handbook of Science Education. K. G. Tobin and B. J. Fraser. Dordrecht, Kluwer.
- Hewson, P. W. and M. G. A. B. Hewson (1987). "Science teachers' conceptions of teaching: Implications for teacher education." International Journal of Science Education 9(4): 425-440.
- Hodson, D. (1993). "Re-thinking old ways: towards a more critical approach to practical work in school science." Studies in Science Education 22: 85-142.
- Holzman, P. S. (1969). "On Hearing And Seeing Oneself." The Journal of Nervous and Mental Disease 148(2): 198-209.
- Housner, L. D. and D. C. Griffey (1985). "Teacher cognition: Differences in planning and interactive decision-making between experienced and inexperienced teachers." Research Quarterly for Exercises and Sport 56(1): 45-53.
- Howarth, S. (2003). "Software." Journal of Biological Education 37(3): 151.
- Hoz, R., Y. Tomer, et al. (1990). "The relations between disciplinary and pedagogical knowledge and the length of teaching experience of biology and geography teacher." Journal of Research in Science Teaching 27(10): 973-985.

Hycner, R. H. (1985). "Some guidelines for the phenomenological analysis of interview data." Human Studies 8: 279-303.

Jackson, P. W. (1968). Life in classrooms. New York, Holt, Rinehart and Winston.

Jenkins, E. W. (2000). "Constructivism in School Science Education: Powerful Model or the Most Dangerous Intellectual Tendency?" Science & Education 9: 599-610.

Johnson, J. (1975). Doing Field Research. New York, Free Press.

Junker, B. (1960). Field Work. Chicago, University of Chicago Press.

Kagan, D. M. and D. J. Tippins (1992). "How US Preservice Teachers 'Read' Classroom Performances." Journal of Education for Teaching 18(2): 149-158.

Killermann, W. (1996). "Biology education in Germany: research into the effectiveness of different teaching methods." International Journal of Science Education 18(3): 333-346.

King, L. H. (1980). Student Thought Processes and the Expectancy Effect. University of Alberta, Research Monograph, Centre for Research in Teaching.

Kingdon, M. (1991). The Reform of Advanced Level. London, Hodder & Stoughton.

Kohl, H. R. (1976). On Teaching. New York, Schocken Books.

Kounin, J. (1970). Discipline and group management in classrooms. New York, Holt, Rinehart & Winston.

Kramer, L. M. J. (1975). Teaching the Life Sciences. London, Macmillan.

Krause, F. (1986). Subjective Theories Of Teachers: Reconstruction Through Stimulated Recall, Interview and Graphic Representation of Teacher Thinking in Advances of Research on Teacher Thinking. M. Ben-Peretz, R. Bromme and R. Halkes. Lisse, Swets and Zeitlinger.

Kremer-Hayon, L. (1990). Reflection and professional knowledge. Insight into teachers' thinking and practice. C. Day, M. Pope and P. Denicolo. London, Falmer Press: 57-70.

Kvale, S. (1996). Interviews: An Introduction to Qualitative Interviewing. London, Sage.

Kyriacou, C. (1986). Effective Teaching in Schools. Oxford, Blackwells.

Lacey, C. (1977). The socialization of teachers. London, Metheun.

Lampert, M. (1985). "How Do Teachers Manage to Teach? Perspectives on Problems in Practice." Harvard Educational Review 55(5): 178-194.

- Lampert, M. (1986). Teachers' Strategies for Understanding and Managing Classroom Dilemmas. Advances of Research on Teacher Thinking. M. Ben-Peretz, R. Bromme and R. Halkes. Lisse, Swets and Zeitlinger.
- Lantz, O. and H. Kass (1987). "Chemistry teachers' functional paradigms." Science Education **71**: 117-134.
- Larochelle, M. and N. Bednarz (1998). Constructivism and Education: Beyond Epistemological Correctness. Constructivism and Education. M. Larochelle, N. Bednarz and J. Garrison. Cambridge, Cambridge University Press.
- Law, R. (1995). "An A-level food test investigation." Journal of Biological Education **29**(4): 251-252.
- Law, R. (1996). "An A-level practical exercise to compare digestive enzyme activity." Journal of Biological Education **30**(1): 19-21.
- Lawton, D. (1994). The Tory Mind on Education: 1979-94. London, Falmer Press.
- Leach, J. and P. Scott (2000). Children's thinking, learning , teaching and constructivism. Good practice in science teaching. M. Monk and J. Osborne. Buckingham, Open University Press.
- Learner, O. (1997). "The 'A' level review." Open Learner(2): 8-9.
- LeCompte, M. D. and J. P. Goetz (1982). "Problems of Reliability and Validity in Ethnographic Research." Review of Educational Research **52**(1): 31-60.
- Lederman, N. G. (1992). "Students' and Teachers' Conceptions of the Nature of Science: A Review of the Research." Journal of Research in Science Teaching **29**(4): 331-359.
- Lederman, N. G. (1999). "Teachers' Understanding of the Nature of Science and Classroom Practice: Factors That Facilitate or Impede the Relationship." Journal of Research in Science Teaching **36**(8): 916-929.
- Lederman, N. G., J. G. Gess-Newsome, et al. (1994). "The nature and development of preservice science teachers' conceptions of subject matter and pedagogy." Journal of Research in Science Teaching **31**: 129-146.
- Lederman, N. G. and D. L. Zeidler (1987). "Science teachers' conceptions of the nature of science: Do they really influence teacher behaviour?" Science Education **71**(5): 721-734.
- Lee, Y. C. (2001). "Construction of heart models using simple air pumps." Journal of Biological Education **36**(1): 42-44.

Leinhardt, G. (1990). "Capturing Craft Knowledge in Teaching." Educational Researcher **19**(2): 18-25.

Leinhardt, G. and J. G. Greeno (1986). "The cognitive skill of teaching." Journal of Educational Psychology **78**(2): 75-95.

Leinhardt, G. and D. A. Smith (1985). "Expertise in mathematics instruction: subject matter knowledge." Journal of Educational Psychology **77**(3): 247-271.

Lester, A. and R. Lock (1998). "Sponges as visual aids - bath time fun for biologists?" Journal of Biological Education **32**(2): 87-89.

Lincoln, Y. S. and E. Guba (1985). Naturalistic Inquiry. California, Sage.

Lincoln, Y. S. and E. Guba (1989). "Ethics: the failure of positivist science'." Review of Higher Education **12**(3): 221-40.

Lock, R. (1997). "Is there Life in Science 2000?" Journal of Biological Education **31**(2): 83-85.

Lock, R. (1998). "Advanced-level biology - is there a problem?" School Science Review **80**: 25-28.

Logan, T. (1984). Learning through interviewing. Pupil Experience. J. Schostak and T. Logan. London, Croom Helm.

Lortie, D. C. (1975). Schoolteacher: A Sociological Study. Chicago, University of Chicago Press.

Lowyck, J. (1986). Post-Interactive Reflections Of Teachers: A Critical Appraisal. Advances of Research on Teacher Thinking. M. Ben-Peretz, R. Bromme and R. Halkes. Lisse, Swets and Zeitlinger.

Lucas, A. M. (1997). "Teaching X^2 intuitively." Journal of Biological Education **31**(1): 20-22.

Lunetta, V., A. Hofstien, et al. (1981). "Evaluating science laboratory skills." The Science Teacher **48**(1): 22-25.

Magnusson, S., J. Krajcik, et al. (1999). Nature, Sources, and Development of Pedagogical Content Knowledge for Science Teaching. Pedagogical Content Knowledge and Science Education. J. Gess-Newsome and N. G. Lederman. London, Kluwer: 95-132.

Maloney, D. (1988). "Novice rules for projective motion." Science Education **72**: 501-513.

Mann, P. H. (1971). Methods of Sociological Series. Oxford, Blackwell.

- Marks, R. (1990). "Pedagogical content knowledge from a mathematical case to a modified conception." Journal of Teacher Education **41**(3): 3-11.
- Marland, M. (1975). The Craft of the Classroom. Exeter, NH., Heinemann Educational Books.
- Marland, P. (1993). Knowing How To Teach Well Teachers Reflect on their Classroom Practice. Victoria, ACER.
- Marques, L. M., J. D. Arrabaca, et al. (2001). "Science notes: An alternative way to study the role and activity of the catalase enzyme." School Science Review **83**(303): 100-3.
- Marsh, C. (1982). The Survey Method. The contribution of Surveys to Sociological Explanation. London, George Allen and Unwin.
- Maskill, R., M. Veiga, et al. (1989). "Teachers' language and pupils' ideas in science lessons: can teachers avoid reinforcing wrong ideas?" International Journal of Science Education **11**(4): 465-479.
- Maykut, P. and R. Morehouse (1994). Beginning Qualitative Research: A Philosophic And Practical Guide. London, Falmer Press.
- McClelland, J. (1984). "Alternative frameworks: Interpretation of evidence." European Journal of Science Education **6**: 1-6.
- McDonald, F. J. (1965). Educational Psychology. Belmont California, Wadsworth.
- McIntyre, D. and S. Brown (1985). Research Methodology and New Policies for Professional Development and Innovation. Scottish Educational Research Association.
- McIntyre, D. and G. MacLeod (1978). The characteristics and uses of systematic classroom observation. Understanding Classroom Life. R. McAleese and D. Hamilton. Slough, NFER.
- McKay, D. A. and P. W. Marland (1978). Thought processes of teachers. AERA Conference, Toronto, Canada.
- McNair, K. and B. Joyce (1979). Teachers' Thoughts While Teaching: The South Bay Study, Part II, Research Monograph 58, Institute for Research on Teaching, Michigan State University.
- McNamara, D. (1991). "Subject Knowledge and its Application: problems and possibilities for teacher educators." Journal of Education for Teaching **17**(2): 113-128.

- McNamara, D. and C. Desforges (1978). "The social sciences, teacher education and the objectification of craft knowledge." British Journal of Teacher Education 4(1): 17-36.
- McNamara, D. R. (1980). "The outsider's arrogance: the failure of participant observers to understand classroom events." British Educational Research Journal 6: 113-125.
- McNeill, P., Ed. (1990). Research Methods: Society Now. London, Routledge.
- McRobbie, C. J., W.M. Roth, et al. (1997). "Multiple learning environments in a physics classroom." International Journal of Educational Research 27: 333-342.
- McTiffin, L. (1996). "Draw-a-Chain Game - a fun way to revise food chains." Journal of Biological Education 30(3): 171-174.
- Meatyrd, B. (1999). "Phosphatase enzymes from plants: a versatile resource for post-16 courses." Journal of Biological Education 33(2): 109-112.
- Miles, M. B. and A. M. Huberman (1994). An Expanded Sourcebook: Qualitative Data Analysis. London, Sage.
- Millar, R. (1989). "Constructive criticisms." International Journal of Science Education 11(Special issue): 587-596.
- Millar, R. and R. Driver (1987). "'Beyond Processes'." Studies in Science Education 14: 33-62.
- Miller, M. B. and G. A. Russell (1996). "Practical DNA technology in school - 2 Computer analysis of bacteriophage lambda base sequence." Journal of Biological Education 30(3): 176-183.
- Mohapatra, J. K. and S. Bhattacharyya (1989). "Pupils, teachers, induced incorrect generalisation and the concept of 'force'." International Journal of Science Education 11(4): 429-236.
- Morine-Dershimer, G. (1990). To Think Like a Teacher. American Educational Research Association, Boston.
- Morland, P. W. (1977). A study of teachers' interactive thoughts. Edmonton, Canada., University of Alberta, Edmonton.
- Morris, M. C. (1999). "Using woodlice (Isopoda Oniscoidea) to demonstrate orientation behaviour." Journal of Biological Education 33(4): 215-216.
- Moser, C. A. and G. Kalton (1971). Survey Methods in Social Investigation. Hants, Dartmouth Publishing.

Munro, M. and A. Jamieson (1993). Your choice of A-levels: The essential guide to A-level and AS subjects and examinations. Cambridge, Hobsons.

Munson, R., Ed. (1971). Man and Nature: Philosophical Issues in Biology. New York, Dell Publishing.

National Institute of Education (1975). Teaching as clinical information processing. Report of Panel 6, National Conference in Studies in Teaching. Washington, DC, National Institute of Education.

Northern Examinations and Assessment Board (1999). Syllabuses for 1999 Biological Sciences. Manchester, The Northern Examinations and Assessment Board.

Nisbett, R. E. and T. Decamp-Wilson (1977). "Telling More Than We Can Know: Verbal Reports on Mental Processes." Psychological Review **84**(3): 231-259.

Novak, J. D. and J. H. Wandersee (1990). "Special Issue: Perspectives on Concept Mapping." Journal of Research in Science Teaching **27**(10): 921-1079.

Ogborn, J., G. Kress, et al. (1996). Explaining Science in the Classroom. Buckingham, Open University Press.

Ogunniyi, M. B. (1987). "Conceptions of traditional cosmological ideas among literate and nonliterate Nigerians." Journal of Research in Science Teaching **24**(2): 107-117.

Olsen, T. P., P. W. Hewson, et al. (1996). "Preordained science and student autonomy: the nature of laboratory tasks in physics classrooms." International Journal of Science Education **18**(7): 775-790.

Oppenheim, A. N. (1992). Questionnaire Design, Interviewing and Attitude Measurement. London, Pinter.

Osborne, R. J., B. F. Bell, et al. (1983). "Science teaching and children's views of the world." European Journal of Science Education **5**(1): 1-14.

Parliamentary Office of Science and Technology (1996). Teaching science and maths: POST technical report 88. London, Parliamentary Office of Science and Technology.

Patton, M. J. (1991). "Qualitative research on college students: Philosophical and methodological comparisons with the quantitative approach." Journal of College Student Development **13**: 389-96.

Pearson, J. T. and W. J. Hughes (1986). "Designing an A-level Genetics course II: Sequencing the material and developing a strategy for teaching and assessment." Journal of Biological Education **20**(2): 133-137.

- Pendry, A. (1994). The pre-lesson pedagogical decision making of history student teachers during the internship year. Unpublished Doctoral Dissertation. University of Oxford.
- Peterson, P. L. and C. M. Clark (1978). "Teachers' reports of their cognitive processes during teaching." American Educational Research Journal **15**: 555-565.
- Phoenix, D. (2003). "Government policy and higher education." Journal of Biological Education **37**(3): 108-109.
- Pickering, W. R. (1999a). "Revise through diagrams: B vitamins are important cofactors for respiratory enzymes." Journal of Biological Education **33**(3): 155-157.
- Pickering, W. R. (1999b). "Revise through diagrams: the TCA (Kreb's) Cycle." Journal of Biological Education **33**(2): 100-102.
- Pigge, F. L., T. C. Gibney, et al. (1980). "An updated comparison of the number of mathematics courses taken by elementary teachers and their mathematical understandings." School Science and Mathematics **80**: 643-650.
- Placek, W. (1987). Preconceived knowledge of certain Newtonian concepts among gifted and non-gifted eleventh grade physics students. Second International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Department of Education, Cornell University.
- Poland, R. H. C., G. B. Hall, et al. (1996). "Turtles and tourists: a hands-on experience of conservation for sixth formers from King's College, Taunton, on the Ionian Island of Zakynthos." Journal of Biological Education **30**(2): 120-128.
- Powell, R. P. (1996). "Special Series on Personal Practical Knowledge." Curriculum Inquiry **26**(2): 147-173.
- Powney, J. and M. Watts (1987). Interviewing In Educational Research. London, Routledge.
- Prosser, M. and K. Trigwell (1999). Understanding learning and teaching: the experience in higher education. Buckingham, Society for Research into Higher Education and Open University Press.
- Purchon, V. (1998). Why biology's lifeblood is draining away. Times Educational Supplement Magazine: 25.
- Purdon, A. (1991). Jobs and Careers After A-Levels: A guide for people looking for a job after A-Levels. Cambridge, Hobsons.
- Quentin-Baxter, M. and D. Dewhurst (1995). "An interactive laser video disc to teach the functional anatomy of the rat." Journal of Biological Education **29**(1): 34-39.

Reiss, M., Ed. (1999). teaching secondary BIOLOGY, ASE John Murray Science Practice.

Reynolds, M. C. (1989). Knowledge base for the beginning teacher. Oxford, Pergamon.

Richardson, J. and R. Lock (1993). "The readability of selected A-level biology examination papers." Journal of Biological Education **27**(3): 205-212.

Rickinson, M. (1999). The teaching and learning of environmental issues through geography: a classroom-based investigation. Unpublished Doctoral Dissertation. University of Oxford.

Roberts, M., M. Reiss, et al. (1993). Biology: Principles and Processes. Surrey, Nelson.

Roberts, R. (2001). "Procedural understanding in biology: the 'thinking behind the doing'." Journal of Biological Education **35**(3): 113-116.

Roberts, R. and R. Gott (2000). "Procedural Understanding in Biology: how is it characterised in texts?" School Science Review **82**: 83-91.

Robinson, P. M. and R. E. Parker (1981). "Sixth-form projects in biology: a case history." Journal of Biological Education **15**(4): 275-278.

Roth, W. M., C. J. McRobbie, et al. (1997). "The local production of order in traditional science laboratories: a phenomenological analysis." Learning and Instruction **7**: 107-136.

Rowland, M. (1992). Biology. Surrey, Nelson.

Roy, D. (1991). "Improving recall by eyewitnesses through the cognitive interview." The Psychologist **14**(9): 398-400.

Ruse, M. (1973). The Philosophy of Biology. London, Hutchinson.

Ryder, J., A. Hind, et al. (2003). Teaching about the epistemology of science in school science classrooms: case studies of teachers' experiences. Paper presented at the European Science Education Research Association, Noordwijkerhout.

Sanders, L. R., H. Borko, et al. (1993). "Secondary Science Teachers' Knowledge Base When Teaching Science Courses in and out of Their Area of Certification." Journal of Research in Science Teaching **30**(7): 723-736.

Sanders, L. R. S. (1990). Secondary science teachers' planning, teaching and reflecting when teaching science courses in and out of their area of certification. Unpublished Doctoral Dissertation. University of Maryland.

Sanderson, P. (1987). "The natural revegetation of a pitheap: an extended sixth form research project." Journal of Biological Education **21**(4): 259-266.

Schatzman, A. and A. L. Strauss (1973). Prentice-Hall Methods of Social Science Series. London, Prentice-Hall.

Schollar, J. (2003). "Building a 3-D Lego model of DNA." School Science Review **84**(308): 26-30.

Schön, D. A. (1983). The Reflective Practitioner: How Professionals Think in Action. London, Temple Smith.

Schön, D. A. (1987). Educating the Reflective Practitioner. San Francisco, Jossey-Bass.

Schutz, A. (1973). Collected Papers: The Problem of Social Reality. The Hague, Martinus Nijhoff.

Schwab, J. J. (1963). Biology Teachers' Handbook. New York, Wiley.

Schwab, J. J. (1964a). Structure of the disciplines: Meanings and significances. The Structure of Knowledge and the Curriculum. G. W. Ford and L. Pugno. Chicago, Rand McNally & Company.

Schwab, J. J. (1964b). The Structure of the Natural Sciences. The Structure of Knowledge and the Curriculum. G. W. Ford and L. Pugno. Chicago, Rand McNally & Company.

Schwab, J. J. (1971). "The practical: Arts of the eclectic." School Review **79**(4): 493-542.

Schwab, J. J. (1978). Education and the Structure of the Disciplines. Science, Curriculum and Liberal Education. I. Westbury and N. J. Wilkof. Chicago, University of Chicago Press.

Schwandt, T. A. (1997). Qualitative Inquiry: A Dictionary of Terms. London, Sage.

Scott, P. and J. Leach (1998). Learning science concepts in the secondary science classroom. ASE Guide to Secondary Science Education. M. Ratcliffe. Cheltenham, Stanley Thornes.

Screen, P. (1986). "The Warwick Process Science Project." School Science Review **68**(242): 12-16.

Seddon, K. and L. Baggott (1999). "The Butterfly 'Sight' - using the Internet in education." School Science Review **81**(294): 61-68.

Sewell, R. D. E., R. G. Stevens, et al. (1995). "Multimedia computer technology as a tool for teaching and assessment of biological science." Journal of Biological Education **29**(1).

Shavelson, R. J. (1973). "What is the basic teaching skill?" Journal of Teacher Education **24**: 144-151.

Shavelson, R. J. and P. Stern (1981). "Research on teachers' pedagogical thoughts, judgements, decisions, and behaviour." Review of Educational Research **51**: 455-498.

Shulman, L. S. (1986). Paradigms and Research Programs in the Study of Teaching: A Contemporary Perspective. Handbook of Research on Teaching. M. C. Wittrock. New York, Macmillan.

Shulman, L. S. (1986). "'Those Who Understand: Knowledge Growth in Teaching'." Educational Researcher **15**(2): 4-14.

Shulman, L. S. (1987). "Knowledge and Teaching: Foundations of the New Reform." Harvard Educational Review **57**(1): 1-22.

Shulman, L. S. and A. S. Elstein (1975). Studies of problem solving, judgement, and decision-making: Implications for educational research. Review of Research in Education. F. W. Kerlinger. Itasca, Illinois., F.E. Peacock. **3**: Kerlinger, F.W. (Ed.) , Vol. 3, , F.E. Peacock, Itasca, Illinois.

Silverman, D. (1993). Interpreting Qualitative Data Methods for Analysing Talk, Text and Interaction. London, Sage.

Sindall, M. (2003). "Some modelling ideas for teaching about DNA." School Science Review **84**(308): 24-5.

Singleton, R. A., J. S. B.C., et al. (1993). Approaches to Social Research. Oxford, Oxford University Press.

Sizmur, S. and J. Ashby (1997). Introducing Scientific Concepts to Children. Slough, NFER.

Slingsby, D. R. (2003). "Biological education: where next?" Journal of Biological Education **37**(4): 160-161.

Smith, D. C. and C. W. Anderson (1999). "Appropriating Scientific practices and discourses with future elementary teachers." Journal of Research in Science Teaching **36**(7): 755-776.

Smith, D. C. and D. C. Neale (1989). "The construction of subject matter knowledge in primary science teaching." Teaching and Teacher Education **5**(1): 1-20.

Smith, J. A., R. Harre, et al., Eds. (1995). Rethinking Methods In Psychology. London, Sage.

Smith, J. K. (1989). The Nature of Social and Educational Inquiry: Empiricism versus Interpretation. Norwood, Ablex.

Soar, R. S. and R. M. Soar (1979). Emotional climate and management. Research on teaching. P. L. Peterson and H. J. Walberg. Berkeley, CA., McCutchan.

Sockett, H. T. (1987). "Has Shulman Got the Strategy Right?" Harvard Educational Review **57**(2): 208-219.

Solomon, J. (1980). Teaching Children in the Laboratory. London, Croom Helm.

Solomon, J. (1992). "Of science teaching." Education in Science **148**: 12-13.

Solomon, J. (1994). "The Rise and Fall of Constructivism." Studies in Science Education **23**: 1-19.

Spradley, J. P. (1979). The Ethnographic Interview. New York, Holt, Rinehart and Winston.

Srinivasan (1998). "Exploring the limitations of the 'DNA as a videotape' analogy." Journal of Biological Education **33**(1): 42-44.

Stake, R. E. (1995). The Art of Case Study Research. London, Sage.

Stallings, J. A. and D. Kaskowitz (1974). Follow through classroom observation evaluation. California, Stanford Research Institute.

Stodolsky, S. S. and P. L. Grossman (1992). Subject matter as context. Annual Meeting of the American Educational Research Association, San Francisco.

Strange, H. (2002). "Software." Journal of Biological Education **36**(4): 199.

Strauss, A. L. (1987). Qualitative Analysis For Social Scientists. Cambridge, Cambridge University Press.

Stubbs, M. and S. Delamont, Eds. (1976). Explorations in Classroom Observation. London, Wiley.

Tamir, P. (1983). "Inquiry and the Science Teacher." Science Education **67**(7): 657-672.

Tamir, P. (1988). "Subject matter and related pedagogical knowledge in teacher education." Teaching and Teacher Education **4**(2): 99-110.

- Tao, P. K. and R. F. Gunstone (1999). "The Process of Conceptual Change in Force and Motion during Computer-Supported Physics Instruction." Journal of Research in Science Teaching **36**(7): 859-882.
- Tesch, R. (1990). Qualitative Research: Analysis Types and Software Tools. London, Falmer Press.
- Tobin, K., D. J. Tippins, et al. (1994). Research On Instructional Strategies For Teaching Science. Handbook of Research on Science Teaching and Learning. D. L. Gabel. New York, Macmillan.
- Tom, A. (1980). "Teaching as a moral craft: a metaphor for teaching and teacher education." Curriculum Inquiry **10**(3): 317-23.
- Tom, A. (1984). Teaching as a Moral Craft. New York, Longman.
- Tom, A. R. and L. Valli (1990). Professional Knowledge for Teachers. Handbook of Research on Teacher Education. W. R. Houston. New York, Macmillan.
- Tomkins, S. P. (2000). "Ornamental gourds help thinking about genetics." School Science Review **81**(296): 69-77.
- Tomlinson, H., Ed. (1993). Education and Training 14-19: Continuity and diversity in the curriculum. London, Longman.
- Toulmin, S. (1972). Human Understanding. Oxford, Oxford University Press.
- Tsui, C. Y. and D. Treagust (2003). "Learning genetics with computer dragons." Journal of Biological Education **37**(2): 96-98.
- vanMaanen, J. (1988). Tales of the Field. Chicago, University of Chicago Press.
- Viennot, L. (1979). "Spontaneous reasoning in elementary dynamics." European Journal of Science Education **1**: 205-221.
- Viennot, L. and S. Rainson (1999). "Design and evaluation of a research – based teaching sequence: the superposition of electric field." International Journal of Science Education **21**(1): 1-16.
- Wandersee, J. H. (1986). "Can the history of science help science educators anticipate students' misconceptions?" Journal of Research in Science Teaching **23**: 581-597.
- Wandersee, J. H., J. J. Mintzes, et al. (1994). Research on Alternative Conceptions in Science. Handbook of Research on Science Teaching and Learning. D. L. Gabel. New York, Macmillan: 177-210.
- Watson, J. R. and T. Prieto (1994). "Secondary Science in England and Spain." Education in Chemistry **31**(2): 40-1.

Watson, J. R., T. Prieto, et al. (1995). "The effect of practical work on students' understanding of combustion." Journal of Research in Science Teaching **32**(5): 487-502.

Watson, J. R. and V. Wood-Robinson (1998). Learning to investigate. ASE Guide to Secondary Science Education. M. Ratcliffe. Cheltenham, Stanley Thornes.

Watson, R. (2000). The role of practical work. Good practice in science teaching: What research has to say. M. Monk and J. Osborne. Buckingham, Open University Press.

Wax, R. (1971). Doing Fieldwork: Warnings and Advice. Chicago, Chicago University Press.

Weade, R. (1987). "Curriculum 'n' Instruction: The Construction of Meaning." Theory into Practice **26**(1): 15-25.

Wells, J. (1991). "Observing cells in plucked hair follicles." Journal of Biological Education **25**(1): 3-4.

Westbury, I. and N. J. Wilkof, Eds. (1978). Science, Curriculum and Liberal Education: Selected Essays. Chicago, The University of Chicago Press.

White, R. T. and R. P. Tisher (1986). Research on Natural Sciences. Handbook of Research on Teaching. M. C. Wittrock. London, Macmillan.

Whyte, W. F. (1984). Learning from the field. London, Sage.

Wilson, J. and M. Thomas (2000). "Mark-recapture using a population of pupils." School Science Review **81**(297): 101-102.

Wilson, S. (1977). "The use of ethnographic techniques in educational research." Review of Educational Research **47**(1): 245-65.

Wilson, S. M. (1989). Understanding Historical Understanding: An analysis of the subject matter knowledge of teachers. Paper presented at the annual conference of the American Educational Research Association, San. Francisco.

Wilson, S. M., L. Shulman, et al. (1987). 150 Different Ways of Knowing: Representations of Knowledge in Teaching. Exploring Teachers' Thinking. J. Calderhead. London, Cassell.

Windale, M., T. Hudson, et al. (1995). "Teaching and learning approaches in science education - what has been the effect of the National Curriculum?" Journal of Biological Education **29**(4): 235-7.

Wolcott, H. F. (1994). Transforming Qualitative Data: Description, Analysis, and Interpretation. London, Sage.

- Wood-Robinson, C. (2001). "Osmosis in the balance." Journal of Biological Education **35**(2): 98-99.
- Woolnough, B. and T. Allsop (1985). Practical work in science. Cambridge, Cambridge University Press.
- Woolnough, B. E. (1991). Practical Science: the role and reality of practical work in school science. Buckingham, Open University Press.
- Woolnough, B. E. (1994). Effective Science Teaching. Buckingham, Open University Press.
- Wubbels, T. (1992). "Taking Account of Student Teachers' Preconceptions." Teaching and Teacher Education **8**(2): 137-149.
- Yan Yip, D. (2004). "Questioning skills for conceptual change in science instruction." Journal of Biological Education **38**(2): 76-83.
- Yin, R. K. (1994). Case Study Research: Design and Methods. London, Sage Publications.
- Yinger, R. and M. Hendricks-Lee (1993). Working Knowledge in Teaching. Research on Teacher Thinking: Understanding Professional Development. C. Day, J. Calderhead and P. Denicolo. London, Falmer Press.
- Yinger, R. J. (1986). "Examining thought in action: a theoretical and methodological critique of research on interactive teaching." Teaching and Teacher Education **2**(3): 263-282.
- Zeitsman, A. and P. Hewson (1986). "Effect of instruction using microcomputer simulations and conceptual change strategies on science learning." Journal of Research in Science Teaching **23**: 27-39.

Appendix A

A copy of the three teachers’ syllabuses outlining the content comprising the different topic areas they taught during their respective units-of-work

John AEB Biology (Advanced) Modular 0601 1998

Module 3

Supply and Demand in Living Organisms

(d) Transport

Content	Notes
3.9 The blood system of a mammal transports metabolites between exchange surfaces. (4.9B)	
The advantages of a double circulation over a single circulation. The general pattern of mammalian circulation.	Names only required of the carotid artery and of blood vessels entering and leaving the heart, liver and kidneys.
The structure of arteries, veins and capillaries in relation to their function. The histology of blood.	Confined to recognition of red blood cells, lymphocytes, monocytes and granulocytes in stained smears. Candidates should be aware that different organisms possess different types of haemoglobin with different oxygen transporting properties.
The roles of haemoglobin and hydrogencarbonate ions in the carriage of respiratory gases and the control of blood pH. Oxyhaemoglobin dissociation curve and the Bohr effect. The importance of capillaries in metabolic exchange. The formation of tissue fluid and lymph and their return to the circulatory system.	Details of the lymphatic system are not required.

3.10 The heart and circulation continually adapt to meet the varying demands of the body. (4.10B)

The gross structure of the mammalian heart in relation to function.

Pressure and volume changes and associated valve movements during the cardiac cycle.

Myogenic stimulation of the heart and transmission of the wave of excitation.

Nervous and hormonal control of heart rate in relation to changing demands.

Roles of sino-atrial node and atrio-ventricular node and bundle of His.

3.11 Humoral and cell-mediated immunity play critical parts in the body's response to antigens. (4.11B)

Definition of antigen and antibody.
The concept of self and non-self.

Principles should only be stressed in this section. The function of cell types other than those specified and the classes of immunoglobulins are not required.

Phagocytosis and the subsequent destruction of ingested pathogens.

The essential differences between humoral and cellular responses as shown by B-lymphocytes and T-lymphocytes. The role of plasma cells and memory cells in producing primary and secondary responses. The immunological aspects of transfusing blood and transplanting organs.

The production of monoclonal antibodies and their use in enabling the targeting of specific cells and chemicals.

Section 1 The Organisation of Living Organisms

Content

Notes

1.6 Aerobic and anaerobic respiration produce ATP which is the immediate source of energy for all cell activities.

The utilisation of different respiratory substrates and the determination, calculation and interpretation of RQ.

RQ should be considered with reference to lipid, protein and carbohydrate.

The release of energy from carbohydrate by aerobic respiration. Glycolysis, the Krebs cycle and the electron transport system.

The role of the cytoplasm and mitochondria in these processes.

This process should be considered only in such detail as to show that:

- glycolysis involves the oxidation of glucose to pyruvate with the net gain of ATP and reduced NAD;
- acetyl coenzyme A is produced from the combination of pyruvate and coenzyme A;
- acetyl coenzyme A combines with a 4-carbon molecule to produce a 6-carbon molecule in the Krebs cycle;
- in a series of oxidation-reduction reactions, Krebs cycle generates reduced coenzymes and ATP by substrate phosphorylation and carbon dioxide is lost;
- oxidative phosphorylation leads to the aerobic generation of ATP via a chain of electron carriers;
- aerobic respiration is more efficient than anaerobic respiration in terms of ATP production.

Content	Notes
The production of ethanol or lactate and the regeneration of NAD in anaerobic respiration.	
The role of ATP as an immediate source of energy in active transport, glycolysis, photosynthesis and other metabolic processes.	

BY03: Physiology

Topic	Knowledge, skills and understanding	Possible learning experiences
3.5 Digestion in mammals	Mammals have a gut to digest, then absorb food. The generalised structure of the mammalian gut wall. The movement of food through the gut by peristalsis. The sites of production and action of the following: Amylases, endopeptidases, exopeptidases, lipase, maltase and bile. Mechanism for the absorption of food by the ileum. Candidates should: • Be able to relate modifications of the generalised structure of the gut wall in the oesophagus, stomach, ileum and colon to the functions of these organs • Understand the role of the nervous reflexes and the hormones gastrin, cholecystokinin and secretin in the control of digestive secretions.	Investigating the effect of bile salts on the rate of fat digestion by lipase. Using colorimetry to investigate starch digestion. Investigating protein digestion using photographic film or egg albumen. Investigating digestion and absorption using visking tubing as a model gut. Microscopic investigations of gut sections. Using secondary sources to investigate the development of understanding of the control of digestive secretions.

Appendix B

A copy of the introductory letter sent to all three teachers inviting them to participate in the project

University of Oxford Department of Educational Studies
15 Norham Gardens
Oxford
OX2 6PY

Date

Name

Address of school

Dear,

'A' Level Biology Teaching Research

I am a first year D.Phil. student in the Department of Educational Studies at Oxford University. At the present time I am planning a project that will investigate the teaching of 'A' level biology. Your name has been recommended to me by the LEA Science Advisor,, and the Tutor for Biology at the Department of Educational Studies,, as an expert 'A' level biology practitioner.

I am writing to ask you if you would be interested in being involved in such a project and if so if it would be possible to meet up with you.

If you are interested please could you contact me either at the Department on 01865 274001 or at home on 01865 559877. Please leave a message on the answer phone if I am not there.

Thank you very much for you time. Looking forward to hearing from you soon,

Yours faithfully,

Alison Black
D.Phil. Research Student
OUDES
15 Norham Gardens
Oxford OX2 6PY

Tel: 01865 274001

Email: alison.black@green.ox.ac.uk

The written summary (resume A) of the research project presented to John during the introductory meeting

Research project

Area of interest

- My project is all about trying to understand, from your perspective, how you teach biology successfully at 'A' level
- In particular I am interested in getting you to talk about what it is you are doing when you are teaching biology successfully at 'A' level and why you teach biology in the particular ways you do

Data collection

1. **Exploratory interview** – the purpose of this interview is to find out something about you – your educational background, your employment background, how you came into teaching and so on
2. **Unit-of-work interview** – the purpose of this interview is to talk a bit more about the unit-of-work you will be teaching (How many lessons will there be? Will any of the lessons be practicals? And so on)
3. **Period of familiarisation** – a chance for me to get to know you and your class a bit better and to practice with the radio-mikes and tape recorders (1 or 2 lessons)
4. **Post-lesson interview** – after each lesson I will interview you as soon as possible. This will involve asking you what you thought was good biology teaching at 'A' level in the observed lesson – we shall explore what you say in as much detail as we can for as long as you like (this may take anything from 10mins to 30mins)

Alison Black
D.Phil. Research Student
OUDES
15 Norham Gardens
Oxford
OX2 6PY

Tel: 01865 274001
Email: alison.black@green.ox.ac.uk

The written summary of the research project presented to Catherine and Sally (resume B) during the introductory meeting

Research project

Area of interest

- My project is all about trying to understand, from your perspective, how you teach biology successfully at 'A' level
- In particular I am interested in getting you to talk about what it is you are doing when you are teaching biology successfully at 'A' level and why you teach biology in the particular ways you do

Data collection

1. **Exploratory interview** – the purpose of this interview is to find out something about you – your educational background, your employment background, how you came into teaching and so on
2. **Unit-of-work interview** – the purpose of this interview is to talk a bit more about the unit-of-work you will be teaching (How many lessons will there be? Will any of the lessons be practicals? And so on)
3. **Period of familiarisation** – a chance for me to get to know you and your class a bit better and to practice with the radio-mikes and tape recorders (1 or 2 lessons)
4. **Long post-lesson interview** – here I will ask you what you thought was good biology teaching at 'A' level in the observed lesson – we shall explore what you say in as much detail as we can for as long as you like (this may take anything from 10mins to 30mins)
5. **Short post-lesson interview** – here I will ask you to identify episodes/isolate instances of your good/successful teaching of biology in the observed lesson so that we can discuss them further, a day or so later, in the vignette interview (this will take about 5 mins max)
6. **Vignette interview** – this will involve me playing back sequences from the observed lesson, identified by you in the short post-lesson interview, that you regard as instances of good/successful teaching of biology at 'A' level in your classroom. I will ask you to listen to the sequences and stop the tape when you feel you are engaging in good/successful teaching of biology. When you stop the tape I will ask you some questions about the passage of lesson tape you heard (this will take anything up to an hour).

Alison Black
D.Phil. Research Student
OUDES
15 Norham Gardens
Oxford OX2 6PY

Tel: 01865 274001
Email: alison.black@green.ox.ac.uk

A copy of the letters sent to key gatekeepers in two of the teachers’ schools to seek their support for the project

University of Oxford Department of Educational Studies
15 Norham Gardens
Oxford
OX2 6PY

Date

Name
Headteacher
Address of school

Dear,

‘A’ Level Biology Teaching Research

I write to seek your approval to work with one of your colleagues,, in the Science Department at

I am currently a post graduate student at the Oxford Department of Educational Studies researching into the teaching of ‘A’ level biology. The project involves a number of teachers in Oxfordshire schools and has been recommended by both the County and Department as an expert practitioner.

I have been in touch with who is willing to work with the project. It involves several interviews with her and observations of her teaching this half term.

I very much hope that you will be happy to let me work in your school.

Yours sincerely,

Alison Black
D.Phil. Research Student
OUDES
15 Norham Gardens
Oxford OX2 6PY

Tel: 01865 274001
Email: alison.black@green.ox.ac.uk

University of Oxford Department of Educational Studies
 15 Norham Gardens
 Oxford
 OX2 6PY

Date

Name
 Head of Science
 Address of school

Dear,

‘A’ Level Biology Teaching Research

I write to seek your approval to work with one of your colleagues,, in the Science Department at

I am currently a post graduate student at the Oxford Department of Educational Studies researching into the teaching of ‘A’ level biology. The project involves a number of teachers in Oxfordshire schools and has been recommended by both the County and Department as an expert practitioner.

I have been in touch with who is willing to work with the project. It involves several interviews with her and observations of her teaching this half term.

I very much hope that you will be happy to let me work with in your Department.

Yours sincerely,

Alison Black
 D.Phil. Research Student
 OUDES
 15 Norham Gardens
 Oxford OX2 6PY

Tel: 01865 274001
 Email: alison.black@green.ox.ac.uk

A copy of the confirmation letter sent to the three teachers upon their agreement to participate in the research project

University of Oxford Department of Educational Studies
15 Norham Gardens
Oxford
OX2 6PY

Date

Name

Address of school

Dear,

Just a quick note as promised about the research this half term. I shall be coming in on the following dates:

- Exploratory interview – basically an opportunity for me to find out a bit more about you, your educational/employment background, what brought you into teaching and so on (date and time)
- Period of familiarisation – an opportunity for the class to meet me and learn to ignore me (!) and also for you and I to get used to the workings of the recording equipment and radio mikes (dates and times)
- Unit-of-work interview – basically an opportunity for you and I to talk a bit more about what you are going to teach and arrange some practical things e.g. how to get the equipment to you before the lesson starts etc. (dates and times)
- Lessons (unit-of-work): (dates and times)

I hope that this suits you. If you are unsure about anything or want to talk to me a bit more about something then please phone 01865 274001.

Thanks so much for all your help. See you soon.

Best wishes,

Alison Black
D.Phil. Research Student
OUDES
15 Norham Gardens
Oxford OX2 6PY

Tel: 01865 274001

Email: alison.black@green.ox.ac.uk

Appendix C

A copy of the exploratory interview guide complete with prompts/supportive questions

Exploratory interview

Introduction

Brief resume of the purpose of the interview and a quick run through of the areas of interest.

Section 1: Educational background/life history

Can you tell me something about your educational and employment history from the age of 16 onwards?

Prompts/supportive questions:

What subjects did you take at 'A' level/equivalent?

Why did you choose to take those subjects?

What did you do when you finished school?

Why?

What subject did you take at degree level?

Why did you choose to take that subject?

What did you do when you finished university?

Where did you do your training?

What was it like?

Did you go straight from training into your first teaching job?

How long /many years have you been in your current job?

What did you do in-between?

Can you tell me what you did before becoming a teacher?

Section 2: Why teaching?

Can you tell me something about why you became a biology teacher?

What made you go into teaching?

Possible supports/prompts:

- possible influences?
- possible rewards?
- job satisfaction?

Section 3: Life history as an 'A' level biology teacher/course/school students and current group

How many years experience have you had teaching 'A' level biology?

What course(s) have you taught in the past?

Have you been teaching 'A' level biology all the time that you have been at this school? (make sure that you clarify this - how many years?)

Have you been teaching the same course all the time you have been here?

What course before?

What course now?

Linear/modular

How do you feel about the course you do now in comparison with the previous one?

Can you give me an outline of the course? What are the main components of the course?

Prompt with:

Fieldwork, coursework, experiments e.g. can you tell me something about the fieldwork element to the course? etc.

What do you think of the course?

Are there things that you would include or get rid of from the course?

What are students like that take biology for 'A' level at this school?/In general how would you characterise the students that come and do 'A' level biology here?

What are they like in terms of ability?

Prompt:

Boys/girls, scientists/artists, intelligent/not intelligent

Can you tell me a bit more about your current group of students?

Section 4: Perception of teaching 'A' level biology:

What do you enjoy about 'A' level biology teaching?

Are there any areas of your teaching of 'A' level biology e.g. the students, the syllabus etc. that you find frustrating?

What are your overall aims/goals as an 'A' level biology teacher?

Key thing that you feel is important about your teaching e.g. getting your students through their 'A' levels, encouraging them to develop into independent learners etc.

Why do you think biology is an important subject to study at 'A' level? If you had to make a case for the inclusion of the subject what would your case be? Why is it valuable?

Is there anything else you'd like to say that I haven't given you the chance to?

A copy of the unit-of-work interview guide complete with prompts/supportive questions

Unit-of-work interview

Introduction

Purpose of the interview is for the researcher to gain more understanding of/familiarisation with the content of the unit of work. Also to make some organisational and practical arrangements.

Section 1: Overall unit

How many lessons/periods for the unit overall?

Can you tell me about your overall plan for the unit of work?

Section 2: Breaking it down - lessons

At this stage have you got plans to break this down into individual lessons?

Can you tell me about these?

At this stage what kinds of teaching and learning strategies have you got in mind?
What sorts of things are you hoping to do?

Section 3: Assessment

In your plans do you have any ideas about assessment?

Section 4: Reasons for this 'unit of work'

Can you tell me why you chose this 'unit of work'?

Have you taught this unit before?

How often have you taught this?

Is there anything else you would like to say?

Are there any questions you would like to ask?

Appendix D

Interview transcripts from each type of interview used in this study: 'short' and 'long post-lesson interviews' and vignette interviews

Lesson 2

Case 2

'Short post-lesson interview'

Key:

A = me in the interview

C = Catherine in the interview

- 1 C: Trial and, trial and error, and you never know how they will react, and they got
- 2 really-, oh isn't it silly, are you listening to me here? You are aren't you!
- 3
- 4 A: Is that all right?
- 5
- 6 C: Yeh (**) Did you think oh my goodness! []
- 7
- 8 A: Um, now this is a short one isn't it?
- 9
- 10 C: Yep, no, this is only a shortie, shortie one.
- 11
- 12 A: Thursday's the longer one isn't it?
- 13
- 14 C: So is there anything you want to find out?
- 15
- 16 A: Yeh, yeh basically all I want you to do is try and isolate for me episodes of that
- 17 lesson that you felt were good teaching of biology.
- 18
- 19 C: No (**)
- 20
- 21 A: So over to you! (**)
- 22
- 23 C: Right, I kept saying you can do it, you can do it, you can do it, cause this is
- 24 really, technically it's very difficult and really pr-, I mean I really felt I had to praise
- 25 a lot and I did when they got it. You saw how they would respond to that, there's
- 26 a lot of excitable-, and you just have to allow for that I think, I think, you know. I
- 27 tried to get them back because I knew I wanted to get them to that stage today
- 28 [*Catherine points to the blackboard behind her which has a big diagram of*
- 29 *glycolysis on it*], um, but (**) [] but I think they enjoyed what they were doing. I
- 30 don't know if they, did you get that impression? I think they were enjoying, you
- 31 know, just because it's, it's something that they had to challenge themselves to
- 32 get it done, um, there were little things that I should have done before like tell

33 them about the dye and so on, but which obviously I, you know, I'll remember
 34 next time, but you forget that when you try and-, at least I forgot, no I think, um,
 35 right now getting them to predict and to work out-, um, I felt we had to take-, we
 36 had to-, I had to make sure that I-, within the teaching, that there was an element
 37 where they could take this experiment to its logical conclusion because I'm not
 38 sure they're going to work, um, and so I felt it was important to do that and I think
 39 they certainly got that. They are on the ball a lot of these, they're really very good,
 40 um, and demonstrating, helping the, helping when things went wrong to try and
 41 make myself available as much as I could, um, and it is fortunately, you know,
 42 you've only, I only have four groups here but I think I was able to spread round
 43 them and to make sure that they were seeing, excuse me, that they could do
 44 something and responding to things like 'oh help it's going to die', you know,
 45 (**) []. You know, you could have taken the view with Amanda that the others
 46 take that it's only a maggot kill it, you know, (**) but, um, no then. And rounding it
 47 off with, you know, them-, getting them to-, getting them to talk through
 48 something I thought which was, I hope is good biology teaching and what I try to
 49 do with this every time is to get them to improve the method which was the
 50 business of, um, how the control was better, so improving the very thing that they
 51 were doing within that []. And there was nothing else that was good, it was all
 52 rubbish (**).

53
 54 A: Can you isolate then, um, the actual episodes that were good teaching of
 55 biology, I mean I think I can find the one on the control cause you were standing
 56 back there

57
 58 C: Yeh, yep, yep, yep.

59
 60 A: And the predicting, what was that one? Can you just remind me of that?

61
 62 C: That's when I said to them we don't have to write a long method. I want you to
 63 make notes on the bits of the method that are not identified in the pictures,
 64 cause they were sticking the picture on, um, because there's no, you know,
 65 there's no need for them to do that so they had to mention how they got the dye
 66 in and things like that, and how they set it up, and then I said and at that stage I
 67 want you then to predict well what's going to happen and work out why, and
 68 that's when we, and then we talked about it, well they, I talked about that with
 69 individuals, so I went round to try and make sure that everybody was able to tell
 70 me why the dye would move in that direction, so I would think that was, why, a
 71 good piece of biology. Oh, and another good bit was the getting used to the
 72 apparatus, practical skills, learning how to use different bits and things.

73
 74 A: Right, so I can get that one.

75
 76 A: Um, any other good episodes, good instances of biology teaching that you
 77 were particularly happy with?

78
 79 C: The awareness of the animals I think is good. I mean I made them handle
 80 them first, and that is, er, that's a genuine ploy to make them aware of the fact
 81 that it is a living organism. We-, I related it to us. I said 'this organism is doing
 82 exactly the same as you' and although you had-, because Emma and Nerissa
 83 weren't here to start with, 'I'm not handling maggots', everybody handled a
 84 maggot in the end and doing it myself, quite, because it's a living organism is

85 showing that. So the respect for living organisms I would think is a useful, but
 86 you can't get that off the tape, that was an action (**). You saw me do that []. But
 87 I expected this lesson to be very, um, it will have no structure to it, well no
 88 prescribed structure. You're not sure how it will go. I would never, I would never
 89 be able to predict, but it was all right, because once you, I always think that if you,
 90 you're timing, ah, that's the other thing I didn't, we didn't talk about at all in the
 91 last lesson was timing. I think I usually can manage timing quite all right.

92

93 A: So any other episodes of good biology teaching?

94

95 C: Well you've got the control, you've got the predicting, you've got the respect for
 96 animals, and handling, and responding to the animal, and again at the
 97 beginning, um, the recap, and I used what I had done on Friday. I have to say,
 98 Friday was brilliant. I had 16 non-chemists in here Friday. I wish you'd been
 99 here, not a single chemist, and I was able to take them to that. [*Catherine points*
 100 *to what is written on the board about glycolysis*] And I had to really enthuse (**).
 101 You should have seen me, I thought you should have been here for that
 102 because of course you have to, you know, with something like this they could
 103 just so, um, completely switch off []. Emma is an able girl, but she is, she's very
 104 unsure sometimes of herself, and she will want to be [] but it's nice to, er-. The
 105 other thing is to make sure that, to use each other, and to use the strengths of
 106 some students to use, you know, both Tanya and Paul do a lot of chemistry and
 107 they use their strengths to explain the oxidation and reduction. Oh it is a terrible
 108 topic isn't it! (**). Anyhow, that's it.

109 A: Yeh and, any other things?

110

111 C: No (**) rubbish.

112

113 A: (**)

114

115 A: Anything else you want to say?

116

117 C: No thank you!

118

119 A: That's ok (**)

Interview ends

Lesson 5

Case 3

‘Long post-lesson interview’

Key:

A = me in the interview
 S = Sally in the interview

- 1 A: Can you tell me what you thought was successful A level biology teaching
- 2 in that lesson?
- 3
- 4 S: Right. I debated whether to go through the question or not and I decided
- 5 yes I would because I knew they wouldn't have done all of them, or that
- 6 they would have had problems with some and I also thought it would be a
- 7 good opportunity to bring in some exam papers. I think that was sort of
- 8 successful A level biology teaching, that I could actually show them some A
- 9 level papers. I didn't photo copy the questions, because we haven't got
- 10 much money, and therefore I needed to make it-, if, it would have been
- 11 better if I could have given them a question sheet and they could write on it,
- 12 but they will actually see those questions again, because before the exam
- 13 we do revision, we do revision of all past papers, so at least I referred to it,
- 14 shown it, waved it around, so that was a good point, going through the
- 15 questions enabled me to do that, but I suppose I could have stood at the
- 16 front of them and talked it through and that would have allowed me to do it,
- 17 but going through the questions also allowed me to find out the bits that
- 18 they found difficult and therefore to pick up on, so they are my two little bits.
- 19 Oh the other thing what, that going back to because some of the modules
- 20 are core modules, so I went back to those a number of times, you have to
- 21 keep doing that because otherwise they forget that they ever had to know
- 22 that, and then it's a shock when they're sitting the exam and think, 'this is
- 23 processes of life and I haven't learnt it', and also I was able to go on to
- 24 excretion which I'll be talking about later. I think the more you can drop little
- 25 bits in like that, the more the biology becomes easy to understand. You
- 26 can see where things link in rather than just seems two separate little
- 27 boxes like today is digestion, today is excretion, whereas you should relate
- 28 the things together, so I was able to do that.
- 29
- 30 A: Anything else?
- 31
- 32 S: That's it I think.
- 33
- 34 A: Ok. Can I pick up on the, on what you just said about excretion, um, drop
- 35 little bits in. Can you tell me a bit more about that? Can you expand a bit
- 36 for me about what you mean?
- 37
- 38 S: There are some concepts like excretion, and defecation that actually get
- 39 confused, and they get confused as to what really is excretion, so it's nice if
- 40 you can, it's useful to be able to do those, talk about those sort of things as

41 many times as possible and that's what I was trying to sort of do, you
42 know, use an opportunity to mention excretion, 'lets do it, what is an
43 excretory product, waste produced by metabolism', and then later we'll be
44 able to mention it again. When we do excretion then at least we will have
45 said that, and I can then relate back to when we were talking about bile
46 pigments, and 'do you remember?' It's just reinforcing things, which they
47 need a lot of that.

48
49 A: Um, then you said this lesson gave you an opportunity to go back to pro

50
51 S: cess. Yes.

52
53 A: The core modules. Why is that successful? What were you doing and why
54 was that successful A level biology teaching?

55
56 S: If you don't link back to the core modules, they will just assume that they've
57 done-. One of the dangers of doing a module course is when they've done
58 that particular module they say 'that's it, I've finished that, I can put it away
59 now', although in actual fact you can't because biology doesn't work like
60 that, you can't really put down, you can't put down the concepts, and in
61 particular the ones that the exam board have decided as a core module.
62 You have to keep referring back to, so again it's, you know, the more times
63 you can reintroduce them, like the enzymes, specificity of enzymes, pH of
64 enzymes, it's all in the processes of life and they are expected to know it.
65 But again it's a concept which goes all the way through biology, and I don't
66 think you can stop talking about such things if you want to understand
67 biology as a whole subject and not as little separate compartments. So
68 it's to stop them thinking, 'this is a module, done that module, forget it',
69 which is a danger.

70
71 A: You said something about, um, you debated whether to do the, whether to
72 go through the questions, can you tell me a bit more about what you were
73 doing throughout that bit of the lesson and why you were doing it that way?

74
75 S: Well I could have stood at the front and gone through the process of
76 digestion from mouth to sort of end again. Um, they'd produced
77 information for little groups, so I didn't really want to do that. I wanted them
78 to have an input, a bit more of an input into it, and I suppose I decided that
79 answering the questions was the best way to do that. And that, it just lent
80 itself to breaking it down, handed out sheets on the gut, going through
81 questions. It gave me something to focus on and them something to focus
82 on.

83
84 A: What about the exam papers bit, the exam questions that you read out?

85
86 S: They need lots of practice into, um, the style of exam questions, um, how
87 examiners think I suppose, because I mean part of it is exam technique,
88 and of course the more times you can introduce that the better. I don't think
89 it does them any harm in seeing something twice, once where you just
90 discuss it and then the next time they have to do it. But I mean that is really
91 just for exam purposes, getting them through.

92

- 93 A: Can you tell me what you were doing when you had the questions,
94 because I sort of missed this bit because my microphone business, could
95 you tell me what you were actually doing?
96
- 97 S: Right, I'd come to the relevant bit in the questions, and I knew there was a
98 question on the gut wall, on the stomach, which they'd actually looked at
99 the sections of last Friday, so I sort of said, 'Here is the question, this is
100 structure March 1998, this is what the picture is of, this is what the question
101 was asked'. Part of it I think is also so that they are not frightened of the
102 question, because seeing a face, a picture sometimes you do get a bit
103 thrown, but if you can answer, but if you have, can stand in front of them
104 and say, 'look this, you've seen slides of this, you've drawn this sort of
105 thing and all it's asking you is what are the muscles for in the stomach?' I
106 mean they, that particular group have actually said that it would be a good
107 idea if I stood in the front of an exam room and interpreted the question.
108 They need a lot of help on that. Confidence mainly, which is why they
109 mumble and talk quietly, [], so I was trying to just get them to think, 'Ooh
110 that's not a difficult question', and breaking them down into little bits rather
111 than 'there's a question do it'.
112
- 113 A: Right. Um, I think that's it. Is there anything else you would like to say that
114 you felt was successful, that you want to sort of talk about?
115
- 116 S: No I don't think so. I think they were the main points I felt about the lesson.

Interview ends

Vignette interview 1

Case 1

Key:

A = me in the interview

J = John in the interview

J=John in the lesson

S(s) = More than one student answering a question or talking at once.

Ethan, Harvey, Joe, Helen, Sarah, Sam, Euan, Clare, Jess, Finn and Chloe = students in the class

- 1 J: [*J reads off the handout*] Monoclonal antibodies. It has long been the
- 2 dream of scientists and doctors to produce a drug that could kill microbes
- 3 without affecting any other cells of the body. So far no drug can quite do that
- 4 even the best drugs occasionally produce harmful side effects. In 1975
- 5 scientists working in Cambridge took a step nearer the dream when they
- 6 discovered how to produce substances called monoclonal antibodies.
- 7
- 8 [*J addresses the class*] Now you might know someone, or even yourself,
- 9 who has to have injections of antibodies
- 10
- 11 [*J stops the tape*]
- 12
- 13 A: Ooh yep, definitely can, can you?
- 14
- 15 J: Open the parcel! Right (**)
- 16
- 17 A: Can you, sorry?
- 18
- 19 J: Unpack that?
- 20
- 21 A: Can you tell me why you stopped that?
- 22
- 23 J: I can tell you why. I stopped that because I asked them whether they knew
- 24 anyone who had antibody injections, and, and some of them might have done,
- 25 and I think it was just bringing some real life stuff. We'd gone through-, I was
- 26 reading there from Robert's, often, um, kids often see textbooks as being I think
- 27 in some way disjointed from everyday biology and they don't really understand
- 28 that Mr Robert's is a person who, er, you know, has written good textbooks and
- 29 he is actually someone who knows a bit about biology. He is a human being
- 30 and they seem to think that these textbooks come from professors stuck up in
- 31 ivory towers and so we'd been through all that and then to actually bring things
- 32 down to earth, 'does anyone know anyone who has antibody injections?'. Now
- 33 it, there's a very slim chance that anyone did but it might just get them thinking
- 34 about 'why would someone want antibody injections? I've never heard of that,
- 35 well fancy that', you know, 'what do these antibodies look like? How do they get
- 36 them in you? Where would they get them from?' Those sort of questions.
- 37
- 38 A: Uh um, anything else you want?

39
 40 J: No, I think we'll go on and listen.
 41
 42 A: Um [] sorry I'm a bit of a novice at this.
 43
 44 J: It's all right, you go, yeh so am I!
 45
 46 A: So, ok?
 47
 48 J: Yep.
 49
 50 A: Continue, yep, continue.
 51
 52 *[J starts the tape again]*
 53
 54 **J: because they are lacking certain antibodies. I know someone who I used**
 55 **to work with actually on the farm, and he used to-, he was forever getting**
 56 **cold, er, chest infections verging on, well, pneumonia a couple of times and**
 57 **pleurisy and all sorts of things, and they couldn't work out why he was getting**
 58 **this so he went in for tests and they realised that he was lacking the**
 59 **antibodies that fight bac-, certain bacteria that cause chest infections. Now,**
 60 **what are the options, imagine if you were a, if you had anything at your**
 61 **fingertips, what could you do for someone who did not have the right**
 62 **antibodies?**
 63
 64 **Helen: Cure them.**
 65
 66 *[J stops the tape]*
 67
 68 J: Right, 'what could you do?', gets them to think. That's why I've done that
 69 rather than saying 'the first thing you could do is give them such and such, the
 70 second thing is this' because they don't want to be, um, well they probably do
 71 want to sit there and have, be spoon fed but they're not going to be spoon fed
 72 because it won't get them very far when they come to actually sit the exams and
 73 go on to develop further study, so, I mean posing the question, you know, can
 74 anyone come up with any suggesting, you've heard enough from me get
 75 yourself thinking now.
 76
 77 A: Uh um, can you tell me what it is about that, what you've just heard that makes
 78 it a 'good' piece of A level biology teaching?
 79
 80 J: I think it's get, it's posing a question, um, asking them to think about a
 81 solution, a problem solving exercise if you like. I've told them that the situation
 82 exists, the problem exists, so how, 'how did they sort this poor chap out if he
 83 didn't have enough antibodies? How would you do it?' Put yourself in his
 84 shoes. Problem solving.
 85
 86 A: Um
 87
 88 *[J starts the tape again]*
 89
 90 **J: Cure them, right how are we going to cure them?**

91
92 **S(s): Get them to [^]**
93
94 **J: Right, you obviously realise, the first thing you could do is you find the right**
95 **antibody and inject them with antibodies to do the work. What is the**
96 **drawback of that?**
97
98 **Ethan: [^]**
99
100 **J: Got to keep doing it. Good! Why? Why is that not a drawback for us, people**
101 **who make our own antibodies?**
102
103 **Harvey: Cause you don't realise you're doing it.**
104
105 **J: It's going on all the time isn't it? We're topping up, we're forever**
106 **synthesising or making more antibodies or we're ready to make them. When**
107 **we were born we had B lymphocytes that were ready to produce antibodies**
108 **when that antigen arrived. Now this chap, I don't know what happened, either**
109 **he didn't get that B lymphocyte from his mother when he was born or it just**
110 **doesn't work anymore, for some reason it doesn't produce those antibodies**
111 **so he has to have an injection, I think it's every two months or something,**
112 **actually rigs up a drip and just sits there, watches tele and happy as anything,**
113 **and this drip just feeds him antibodies so he can fight that infection if he gets**
114 **it. The question is, how do you, where do these antibodies come from? Yeh,**
115 **in our own case they are our own but how do you start giving someone,**
116 **someone?**
117
118 **Joe: You have to make them.**
119
120 **J: Yeh.**
121
122 **Chloe: From a dead person?**
123
124 **J: From a dead person, oh God, (**). The thought of it! Well I suppose you**
125 **could.**
126
127 **Harvey: Borrow them?**
128
129 **J: Borrow them, yeh, um, [*students chattering*], yep, the question was where**
130 **are we going to get these antibodies to give to people who haven't got them?**
131
132 **Helen: Clone them.**
133
134 **J: Clone them. Fancy that Helen, you're gonna clone them (**). And we clone**
135 **them by a process called monocloning or monoclonal antibodies. Now,**
136 **looking at our sheets, let's see what happens. [*J reads from the sheet*]**
137 **Monoclonal antibodies are made by special cells and are proteins with the**
138 **amazing property of recognising foreign substances or antigens either in the**
139 **bloodstream or in tissues. This means that they are useful for helping**
140 **doctors to detect and treat many types of disease and will eventually help to**
141 **treat cancers in man. The special cells which make monoclonal antibodies**
142 **are called hybridomas and are made in test tubes by joining a special rapidly**

143 dividing cancer cell with an educated normal cell which knows which
144 antibody to make. So what type of cell will that be?

145

146 Ethan: A clever one.

147

148 Chloe: A B lymphocyte.

149

150 J: A B lymphocyte, yeh, a clever B lymphocyte. These hybridomas can
151 therefore divide and multiply vigorously producing large amounts of identical
152 monoclonal antibody molecules. Monoclonal antibodies can be used in the
153 development and manufacture of new vaccines. They are made to recognise
154 the virus protein which the body's own defence mechanism detects and can
155 be used to purify. [*J has finished reading the sheet and addresses the class*]
156 Right, so we're using them to produce antibodies basically. See the process
157 they get? They put an antigen into, in this case a mouse, notice that the, I
158 think it must be a bacteria, has antigens around it one, two, three, four. Why
159 have they drawn different shapes on those antigen things do you think?

160

161 [*J stops the tape*]

162

163 J: Is that about right? (**) That's what you hoped wasn't it? Right, that question
164 'why have they drawn different antigens?' was because I wanted them to link
165 back to what antigens were. I think when they're given a handout you are never
166 really sure whether they're with you or not, looking at it, what are they thinking of,
167 they might not be as, um, as inspired as I am (**) about monoclonal antibodies,
168 if that would be possible. So we-, I want to get them thinking again about these
169 antigens, what, because that was a very clever little diagram, the way they'd
170 drawn four or five different shapes. I guess when the person created that he or
171 she was thinking the very same thing, 'I could draw them all just circles' but the
172 fact that they were different shapes reminded them that antigens come in all
173 different types, yep?

174

175 [*J starts the tape again*]

176

177 J: They're specific, yeh, each antigen has a special shape, so a bit like the old
178 enzyme lock and key remember?

179

180 [*J stops the tape*]

181

182 J: There's a lot in there isn't there? A lot of biology, lock and key, there you are a
183 concept they've had rammed into them since Year 9 (**), and it's gradually being
184 proved further away from what actually happens but anyway we refer back to lock
185 and key systems, and it's again sort of reiteration, and I've talked about this
186 before but, um, what's the word called, repetition, where you keep reminding
187 them of concepts, that's what I'm always so keen to do rather than just facts,
188 because I've said to you, as you know, in the past I learnt a lot of my science by
189 having, by remembering facts which was the wrong way for me, um, probably
190 the wrong way for most people, but certainly for the way I think now I have to
191 unpick concepts and get to grips with them in my own mind, then apply them to
192 situations which is really what A level is all about, because when they go in for
193 an exam it's very unlikely that they will be faced with a picture of bacteria, for
194 example, with four or five different antigens shapes and be asked 'why are they

195 different shapes?', but what they might be asked is, 'why would, you know, only
 196 one type of antibody suit a certain type of antigen?' Getting them to think about
 197 different shapes and so on, so linking back to the lock and key concept is getting
 198 them to again visualise the concept, that lock and key is, when you get to it, is so
 199 visually effective cause they can see-, visualise in their mind shapes fitting
 200 together which they have actually been doing for years since they've been tiny
 201 kids, putting round things through round holes and they'll get, hopefully, you
 202 know, that concept is reinforcing the idea of these antibodies. It is difficult,
 203 you're on about a bacteria, you know, a minuscule organism with these
 204 chemicals and we're drawing them as circles and squares on the side of the
 205 bacteria and they don't look like that, you know, if you get an electron microscope
 206 you don't see triangles, but you've got to understand, or they've got to
 207 understand that these chemicals are important, the fact that they are different
 208 shapes means that they lead to different things happening.

209
 210 A: Um

211
 212 J: Ok? (**)

213
 214 *[J starts the tape again]*

215
 216 **J: so it's a bit like that, in that goes to the mouse, the mouse produces lots of**
 217 **antibody producing cells, like B lymphocytes get reproducing, if you fuse**
 218 **them with tumour cells-, what's a tumour cell?**

219
 220 **Sarah: One that rapidly divides.**

221
 222 **J: One that rapidly divides, and if you fuse them a bit like what you saw Joe in**
 223 **that cloning**

224
 225 *[J stops the tape]*

226
 227 J: Going back to that 'what is a tumour cell?', they won't have come across
 228 anything about cancer cells throughout the syllabus or GCSE or A level yet, and
 229 that again that's, um, picking up content that they've learnt from everyday life,
 230 cancer and tumours, rapidly dividing cells they would have heard from
 231 somewhere, Tomorrow's World type of thing, er cause no-one, it's not taught at
 232 GCSE, so, and I knew that, but, you know, I'm always interested to bring in stuff
 233 that they've, they've got from other areas.

234
 235 A: So what is it about what you said that makes it a 'good' piece of A level biology
 236 teaching?

237
 238 J: Again linking in everyday things, things that they've heard, concepts and ideas
 239 that they've picked up outside of the class, because, it is, it's very easy to get, I
 240 think, to get in some way isolated when you are doing A levels, you know, it's so
 241 theoretical lots of it, they are walking around with big textbooks, big lever arched
 242 files and they're thinking 'oh, you know, got all my A level stuff', but there's more
 243 to it than that, because not all of them are going to be doctors or surgeons or
 244 work in a med, you know, a medical field or plant biology field, and yet they're
 245 going to be, um, having kids possibly or certainly working with other people and
 246 if someone says to them, um, you know, 'such and such had cancer or had a

247 tumour', you know, someone might quite likely say to them 'what is a tumour?'
 248 or a, you know, a child saying 'why did so and so die because of cancer', you
 249 know, 'what happened to them?' and I just think to be able to prepare yourself
 250 for those type of things make is a lot about why we are here.

251
 252 A: Um, (**).

253
 254 J: Yep?

255
 256 A: Absolutely!

257
 258 *[J starts the tape again]*

259
 260 **J: programme, if you fuse the two, then you fuse and confuse, there you are,**
 261 **you fuse and confuse, because you've confused the tumour cell, it doesn't**
 262 **know what, it's just there being a tumour cell, and it, but it's given**
 263 **instructions in the form of what? What would the instructions be?**

264
 265 **Harvey: Divide.**

266
 267 **J: It would be to divide, but it's in the, locked in the DNA, good,**

268
 269 *[J stops the tape]*

270
 271 J: Am I stopping too often?

272
 273 A: Go ahead, stop away! (**).

274
 275 J: Um, there we go again, back to DNA for instructions, what is it that the, um,
 276 what is it virus? No, what was I talking about?

277
 278 A: Tumour.

279
 280 J: Tumour, that's right, the tumour's going bonkers that's right and it's because
 281 the DNA has somehow got mixed up and it's saying reproduce [^] so get them
 282 back to mitosis, although I didn't mention that, but they, some of them will have
 283 linked to cell division, mitosis, ok?

284
 285 A: Uh um.

286
 287 J: Am I linking back enough to, am I talking about good biology as opposed to-,
 288 yeh, are you happy?

289
 290 A: Yeh!

291
 292 *[J starts the tape again]*

293
 294 **J: go round producing loads of antibodies, which is what it's been taught to**
 295 **do, if you like, and it says there, description at the bottom, antigens are**
 296 **injected into a mouse, the mouse produces antibodies, the antibody**
 297 **producing cells are fused with tumour cells to produce hybridoma cells each**

298 of which produce the unique type of antibody and you can separate those,
 299 and then, how would you go on and get more and more from each type?

300
 301 S(s): [^]

302
 303 J: Ethan?

304
 305 Ethan: Clone the cells.

306
 307 J: Yep, you could go on and clone the separate antibody producing cells,
 308 Bob's your uncle, you've got billions of antibodies coming, all right? Now this
 309 is the process they actually specify that, you know, about in the syllabus, it
 310 came up didn't it Sarah?

311
 312 Sarah: Um?

313
 314 J: Didn't it come up in module three one of them?

315
 316 Sarah: What was that? Sorry!

317
 318 J: (**) What we're talking about, monoclonal antibodies!

319
 320 Sarah: I think it did.

321
 322 J: I thought it did, monoclonal antibodies. Ok, so I would keep hold of that
 323 carefully, there is a similar description in Roberts on 4

324
 325 [*J stops the tape*]

326
 327 J: It came up in the syllabus, sorry, it's in the syllabus, and they do specify it.
 328 Quite a nice, it's a tidy little bit. Monoclonal antibodies is something that, well,
 329 we covered just there and then, and if you understand what is going on, you can
 330 answer a question on it basically, so, and I think it's-, although I've talked about,
 331 you know, teaching biology and learning biology for everyday life, at the end of
 332 the day they've got to get through an exam, which I personally don't feel is the
 333 best way of assessing their biological knowledge, but there's another can of
 334 worms (**), um, they've got to get through it and just from time to time, you know,
 335 I do link back to the syllabus, because to have a syllabus like we've got is such
 336 an asset, because, um, I'm sure in the past, you know, teachers have taught
 337 biology and they enjoy doing lah de da, and all, you know, everything that's under
 338 the sun you could talk about, but you never know what-, which part of that's
 339 gonna come up in the exam. At least with this syllabus content you can say
 340 what, specify, this could be on so you jolly well need to know it, it's not
 341 something to be stuffed in the back of your file.

342
 343 A: So what is it about what you've just heard that makes it a 'good' piece of A
 344 level biology teaching?

345
 346 J: Well, I'm helping them. I'm giving them a tip. A jungle tip.

347
 348 A: A jungle tip!

349

J: And the jungle tip of the day then was, 'this bit of paper I'm giving you and what we've just talked about has every chance of coming up, so understand it', and, in a way, a sort of negative way, 'don't come to me in June and say 'Monoclonal antibodies, there was a question on it', you know, which for their benefit they need to know, they need to be reminded, they don't see the value of a syllabus like we do, so every possible point, you know, of help and advice I can give them hopefully is the best way to do it.

A: Um.

[J starts the tape again]

J: which you are going to be looking at in a minute, um, but I thought this was a bit more clear actually than his. Right, we've got one major section left and that is the problems involved with transplanting organs and blood as it happens, er, we won't write anything in addition to that apart from what you'll write yourself.

Joe: Sir [^].

J: Would they think it was?

Joe: Yeh.

J: [] That is a good, Joe has just asked a good question which is very valid. Let's see if anyone's got the answer cause I'm having to think as well, um, would the mouse not start rejecting the foreign antibody producing cells? Would it not think that that was an antigen in itself?

Chloe: Well, had it been, if it, what if the antibodies had been taken from [^].

J: Yeh, that, that's the key.

Joe: No, I mean when you inject it into humans.

J: Oh, into humans. So, if you go around injecting antibodies, don't forget yeh, so the antibodies are the chemical that is going to attack antigens, so what you are saying is won't the body try and attack the antibodies?

[J stops the tape]

J: Gonna stop there, cause I confessed to not knowing the answer, and I've said this to you before, didn't I, cause I said when I said 'Joe's got a good question and I want you to think about it cause I don't know the answer either and I'm having to think about it', um, and I, this, this happened before, and I can't remember where, some other topic some other part do you remember? And I said to you then that it is importa-, it is I think, it's important for them to realise that there are things that we don't know, and to be quite honest with them, and a similar thing happened this morning with Year 12's and I was doing biochemistry and someone said to me 'did you do a chemistry degree?', and I laughed, and I said 'no I certainly didn't', and they said 'oh we thought, you know, we thought, you know, you were like a chemist as well' and they seem to think

that because you talk about little snippets, you know, carbohydrates, and what have you, and start drawing some structural formulae that they think you are the walking expert on chemistry, and that happens a bit in biology, you know, they think that you will know everything, it's a bit like going to a doctor and saying, you know, there's a specialist that he will refer you too, um, so that was why I came clean then cause I, cause I didn't, I didn't know, I'm still not sure myself now why the antig-, antibodies produced by the mouse could be used, the only the two options, well it's not relevant here, or is it? But there are two possibilities, one they can get rid of the antigens on the surface of the antibodies so that we don't recognise them, or two, they somehow get antibodies cloned in human cells.

[J starts the tape again]

J: no, yeh, but they do, they've got a whole bank, you go to the JR and they'll say 'oh yeh you want antibody XY233, here you are, have some of that'. Now, it won't have come from you, well from, come from the same person, so why, I wonder if they can in some way

Ethan: wouldn't they, at the same time as injecting antibodies like they have to do with, um, when they do a transplant, just give them something to stop

J: suppress it?

Ethan: Yeh.

J: Well, yeh, but the danger then, if you're, once you start suppressing or, um, reducing the immune system, which you do when you have transplants, you run the risk of having infections from other things, so every time you do your antibody injection, you might get, start walking around getting flu and colds and warts and all sorts (**). Helen?

Helen: What?

J: I thought you were going to say, did you not say something?

Helen: Yeh, if you do it every two months, and you suppress it, then you're gonna get [^] aren't you?

J: Yeh exactly, so I don't think you suppr-, that's what, but that was one option. I wonder whether they can't in someway change the antigens on the coat, on the, that are coating the antibodies. When you have a vaccine for example, say you have the polio or measles, rubella, your antibodies don't go around trying to attack that do they?

Harvey: It's in the deadened form isn't it?

J: It's in the deadened form but it's

Chloe: don't they, they do, that's the whole point to try and remember [^].

J: This is where the memory cells come in you see. They are able to remember what happened the first time so they'll go and do it again. I'm not-,

454 the only way I can think is that somehow the antigens on the new antibodies
455 are neutralised or somehow changed and I don't know the answer but it's an
456 interesting point.
457
458 Joe: Sir, would the body reject the tumour cells?
459
460 J: Um, well don't, yeh, but the tumour cells aren't going back into the body,
461 don't forget all you're putting back in the body are antibodies, yeh, so the
462 tumour cells are out of the immune system. Right, transplanting,
463 transplanting
464
465 *[A stops the tape. End of vignette 1]*
466
467 A: Anything else you'd like to say?
468
469 J: No, I think I'm done on that one.
470
471 A: Right. Now, the second thing comes from the same lesson where there are a
472 group of students discussing brain transplants?
473
474 J: Uh
475
476 A: Um, so can you have a look at this one?
477
478 J: Yeh, yeh.
479
480 *[J starts the tape again]*
481
482 J: Talking of brain transplants, Harvey, why do they say a brain transplant
483 would be better off being called a body transplanting onto the brain? Have
484 you seen that? There's a question
485
486 Harvey: yeh yeh [^]
487
488 J: Is that what you're talking about?
489
490 Harvey: [^]
491
492 J: Yeh, why
493
494 Helen: [^]
495
496 J: Why do they say that?
497
498 Helen: Rather than [^]
499
500 J: Why?
501
502 Helen: You can't transplant a brain to a body.
503
504 J: Why? Why not?
505

506 Sarah: Cause it has it's own personality.

507

508 J: Has it's what?

509

510 Sarah: It's own personality, doesn't it?

511

512 Chloe: Um, the brain's connected to the body through the receptors and
513 everything, the brain's in control of the body isn't it?

514

515 Sarah: It would be different the way it would link up as another body would,
516 like a heart, it's not all the same the heart [^].

517

518 J: In what way?

519

520 Sarah: The way the body accepts it [] or more like, the brain is in control of
521 the body rather than the body in control of the brain. The brain is the control
522 centre so you can't really stick a control centre in someone else, you have to,
523 er

524

525 J: but you could do that with a car or a computer you could take out the, the,
526 what is it, pentium, whatever it is you have in these computers, you could, you
527 could take one from your computer which you could call the brain of it and
528 put it in mine and it would still work wouldn't it?

529

530 Sarah: No, you'd start again wouldn't you? You'd have to start all over again
531 wouldn't

532

533 Joe: cars don't have souls.

534

535 J: Sorry?

536

537 Joe: Cars don't have souls.

538

539 J: Ooh yeh, very interesting, cars don't have, cars don't have souls

540

541 [*J stops the tape*]

542

543 J: Um, I don't know whether this is, is this a good aspect of biology teaching?

544

545 A: You tell me.

546

547 J: Oh (**), um

548

549 A: I mean do you think you are teaching biology at the moment?

550

551 J: Oh definitely yeh, yeh, it's not something, um, this type of teach-. What's going
552 on at the moment is not something that happens very often because they are
553 actually having really to think about a very unusual situation, but as unusual as it
554 would have been to have thought of putting a heart in someone fifty years ago,
555 so it may not, I mean, I, well I think it would be very diff-, the thought of putting a
556 brain or, you know, a brain transplant is, well who knows, but it does seem
557 highly unlikely and I would have said impossible, but then you don't know what's

gonna happen in the future, er, so that, they've got really something to think about. It's a very good piece in that book I think, written by the transplant man and they seem-, people are fascinated by transplants, well they are certainly. I think it is-, there's something weird about it that you are, as Joe was getting on to saying about the soul, um, you know, and there is something slightly, um, uncon-, well it's unconventional, sort of something that's not quite right about putting someone else's organ into another person, it's just not natural, but it can, you know, be a tremendous benefit for people and many thousands of people have gained, got their life back from it, so it's just that, it's a really good part of biology for them to think about the ethics, what it will be like I think to actually be given someone else's organ or to give someone else part of you and they, this group particularly were getting their head round it and really thinking hard about what it would be like and was it possible.

A: Can you, sorry, can you tell me why you think that's an example of a 'good' piece of biology teaching?

J: Well, again, it's very relevant to everyday life, they see things on tele they hear about transplants, they'll hear more and more about rearing organs, animal, er, human organs inside animals, going on in the future. When they're sort of middle aged it will be, there'll be nothing unusual I'm sure about having a-, an organ that had been grown in a pig or I don't know, some other, some way of creating, you know, human tissue and organs outside of living organisms, who knows? And it's just getting them to delve into the possibilities in the future and try and bring in their, their understanding of, you know, what are the problems with transplanting things, why is it so difficult? So it's, it's bringing in previous knowledge, getting them to apply it to a sort of, a futuristic situation, problem solving again in a way is underlying it all and almost open ended thinking. It's not like, um, how do you make up a protein, well, you know, you do that from a load of amino acids, that's the answer end of story, this is very much, um, unknown, the thought of, er, putting a new brain into someone, it's this sense of there not being a correct answer, it's a discussion point, people have been discussing this for years, they still will as to whether it is right or wrong, so it's an open ended problem, all right?

A: Uh um

[J starts the tape again]

Ethan: What's that to do with transplants?

Joe: Don't worry about that Ethan

J: but no don't

Joe: you'd have to start all over again though wouldn't it?

J: What do you mean don't worry about that! It's not

**Ethan: it's an entire different way of thinking, it wouldn't be the same person
[^]**

610 Helen: No but it's irrelevant

611

612 Harvey: of course it wouldn't

613

614 S(s): [^]

615

616 J: Ok what about the memory? What happens if you take someone else's
617 memory?

618

619 Harvey: They wouldn't even know if they were being operated on!

620

621 Joe: They'd be like [^]

622

623 J: Habits?

624

625 Sarah: Wouldn't like, um, the body would have, a certain body have some
626 habits right? And then a new brain there, what, what would happen then,
627 would it like be this sort of battle going on?

628

629 J: It would be like a battle between the old and the new wouldn't it?

630

631 Sarah: Like, um, the body's trying to tell the brain, um, that it's used to doing
632 something

633

634 J: but would the body tell the brain, because surely it's the brain that tells the
635 brain, if you haven't got another brain to tell your new brain that you're wrong!

636

637 S(s): Your body's [^]

638

639 Joe: Your brain's accepting the heart really, your brain's the control centre

640

641 J: ah, is your brain accepting the heart?

642

643 Joe: Yeh, cause doesn't your brain control everything?

644

645 J: What's the brain got to do with whether the heart is new or old?

646

647 Chloe: It doesn't, does it, cause the heart beats independently?

648

649 J: Yeh, what, what's the problem-, the problem with these transplants isn't
650 that the brain says ooh, new liver, new kidney, what's the, what's the problem
651 with transplanting these new organs, it's not the brain that causes these
652 problems, what is it that rejects the organ?

653

654 S(s): Immune system.

655

656 J: Immune system. It's the blood isn't it? It's nothing to do with the brain, you
657 wouldn't know, you wouldn't be able to tell whether you had a new kidney, you
658 wouldn't walk around thinking, 'God there's something strange here, would
659 you?' But you're-, as far as I know anyway, but your blood, you know, you'd
660 know about it, because you'd be in pain, there'd be all sorts of problems with,
661 um, rejection and so on.

662
663 *[A stops the tape. End of vignette 2]*
664
665 A: Ok, can, can I play you a bit of the next one?
666
667 J: Yep no problem yeh.
668
669 A: So same pattern, so if I just play it, and when you think you're engaged in a
670 piece of good biology teaching, just stop that tape.
671
672 *[J starts the tape again]*
673
674 **J: So why, why does the doctor give you antibiotics when you've got a viral**
675 **infection?**
676
677 **S(s): [^]**
678
679 **J: Antibiotics can't kill viruses full stop.**
680
681 **Ss: [^] spreading?**
682
683 **Helen: It stops them spreading!**
684
685 **J: But antibiotics don't have any effect at all on the virus. Chloe?**
686
687 **S(s): [^]**
688
689 **J: Nope.**
690
691 **Helen: Does it stop it spreading?**
692
693 **J: Nope.**
694
695 **S(s): [^]**
696
697 **J: What do you?**
698
699 **Harvey: [^]**
700
701 **J: Nope, it cannot effect viruses. The reason they give you antibiotics is**
702 **because when you have a viral infection, you, you're, um, you feel pretty low,**
703 **your defence is low which opens up, if you like, your immune system to**
704 **attack by a bacteria, so when you're coughing away and you've got a really**
705 **sore throat it's sore because the, you're making it all red and it's open to**
706 **infection, in comes bacteria and thinks heh while you've got a viral infection I**
707 **shall get in there so the antibiotics will prevent or will deal with a bacterial**
708 **infection. Now, quite often when you get a cold it can lead on to a chest**
709 **infection, so the reason the doctor will check your chest and so on is they'll**
710 **want to know if the, if you've got a bacterial infection as a secondary**
711 **infection,**
712
713 *[J stops the tape]*

714
 715 J: Back to every day life again. That's what that is all about, I mean, very similar
 716 to what I, what we talked about before about the chap who's antibodies, so
 717 linking in this business about being given antibiotics when you've got a viral
 718 infection cause that used to puzzle me, I used to think 'well cold's a virus why
 719 am I having antibiotics'. There you are, ok?

720
 721 [J starts the tape again]

722
 723 J: so those bac, those antibiotics will do nothing to help your cold, your
 724 streaming nose, your sore, might help the sore throat if it's a bacterial,
 725 bacteria caused sore throat. Ok?

726
 727 Jess: So there's nothing you can do for it?

728
 729 J: There is nothing at the moment you can do for

730
 731 Finn: isn't there a flu jab

732
 733 J: well, that's prevention. You can immune, immunise people against viral
 734 infections

735
 736 Finn: [^] but if they can't cure it how can they immon, um, that word of the
 737

738 J: immunise.

739
 740 Finn: Immunise, that's it.

741
 742 J: You're, oh

743
 744 Finn: see, got you there didn't !!

745
 746 J: No, you haven't got me, I'm just trying to think how to explain it. The flu jab
 747 Finn

748
 749 Finn: [^]

750
 751 J: Yep, in a flu jab they will try and identify the current flu virus, now you
 752 probably know that viruses change a lot and there are lots of different types
 753 and people working in research will say this winter we accept, we, we expect
 754 flu virus X to be the main cause of flu, so drugs companies will get producing
 755 lots of virus X and doctors will get-, yeh they will kill it, radiate it, stop it being
 756 dangerous and if you go for a flu jab they will inject you with virus X. Now as
 757 we're going to come on and find out in a minute, your body will then produce
 758 antibodies which can attack virus X if you get it, if virus Y comes along that
 759 winter, you've wasted your time at the doctors.

760
 761 Jess: How do they know which virus?

762
 763 J: Well they, they're monitoring things, they're looking at outbreaks of
 764 viruses, doctors will be feeding back into central registers at different parts
 765 of the world. Viruses spread. They might start in China, for example, and

766 spread across the world and you can almost see it coming, it can be that
 767 obvious, if you get a flu epidemic like you do in this country sometimes, um,
 768 that is-, that flu epidemic might have been across America then it comes into
 769 this country, yep in outbreak

770

771 *[A stops the tape. Vignette 3 finished]*

772

773 A: Right, now, just the final one. I am, this is, when, this is at the end of the
 774 lesson when you were, the end of the same lesson when you were going
 775 through what they'd done. You were doing a bit of a recap of what they'd learnt
 776 in the lesson.

777

778 *[J starts the tape again]*

779

780 J: um, let's just recap what we know about defence against invasion of
 781 pathogens. We have methods to stop invasion like, Chloe, what stops
 782 pathogens getting into the body?

783

784 Chloe: Skin.

785

786 J: Skin, thank you, [^]. What else stops pathogens coming in?

787

788 S(s): [^]

789

790 J: Er, we said not really a, ssh ssh ssh folks please. We said not really the
 791 hair. *[J coughs and splutters]*

792

793 Sam: Oh that is really sly!

794

795 J: Is it a cough? Yeh coughing. Ok. Helen, over to you. What else, what's
 796 your other line of defence, no sorry, what's an additional feature of the body
 797 which stops invading micro-organisms?

798

799 Clare: Um, the lysosomes [^]

800

801 J: Lysosomes or lysozymes?

802

803 Euan: Lysozymes.

804

805 J: Lysozyme. Lysozyme is an enzyme, what's a lysosome?

806

807 Students in unison: It's a membrane bound organelle.

808

809 J: You're like parrots aren't you, very good like parrots! Um, it's a membrane
 810 bound organelle which contains the enzyme lysozyme, ok?

811

812 *[J stops the tape]*

813

814 J: Recap, revisiting of bits of module 1, um, which most of them are revisiting in
 815 January, um, yeh, like electron microscopes, lysosomes, they got, they knew
 816 what was going on, they remembered the right information. That was good.

817

818 *[J starts the tape again]*

819

820 **J: Chloe, anything else you want to add to coughing, skin, lysozymes?**

821

822 **Chloe: Blood clotting.**

823

824 **J: Blood clotting, well done**

825

826 **Euan: And sneezing.**

827

828 **J: And sneezing.**

829

830 **Sam: And mucus.**

831

832 **J: And mucus, ok thank you. Once they're in Harvey, once we've got our**
833 **invasion**

834

835 *[A stops the tape. Vignette 4 finished, end of Vignette interview 1]*

836

837 **A: Yeh that's great!**

Interview ends

Appendix E

Examples of lesson summaries for all three teachers

John

Lesson 8

MAJOR LESSON EVENTS	SUBJECT MATTER COVERED	RESOURCES USED
Teacher-led discussion and note taking concerning human mechanisms of preventing the entry of micro-organisms and natural immunity.	Human mechanisms of preventing the entry of micro-organisms	OHT (Appendix H, p. 426-427)
Students work on comprehension exercise and answer the following 3 questions: State the function of neutrophils and macrophages Why do skin infections go red? What are the limitations?	Phagocytosis and the subsequent destruction of ingested pathogens	Textbook OHT (Appendix H, p. 427)
Teacher-led note taking task concerning acquired immunity. Various concepts defined and discussed.	Acquired immunity Antigen, antibody, B and T lymphocytes	OHT (Appendix H, p. 427-428)
Teacher-led run through of comprehension exercise questions.	Phagocytosis and the subsequent destruction of ingested pathogens	
Recap of human mechanisms of preventing the entry of micro-organisms and natural immunity through a teacher-led question and answer session.	Human mechanisms of preventing the entry of micro-organisms Natural immunity	

Catherine

Lesson 2

MAJOR LESSON EVENTS	SUBJECT MATTER COVERED	RESOURCES USED
Question and answer session recapping the previous lessons work on glycolysis.	Glycolysis	
Demonstration of experiment on respiration in maggots	Learning how a respirometer works	Equipment required for making a respirometer
Students do the respirometer experiment and Catherine assists them throughout.	Learning how a respirometer works Experimental method e.g. prediction, controls	Equipment required for making a respirometer
Teacher-led discussion and note taking of glycolysis – continuing the previous lessons discussion.	Glycolysis	Board (Appendix I, p. 441)

Sally

Lesson 5

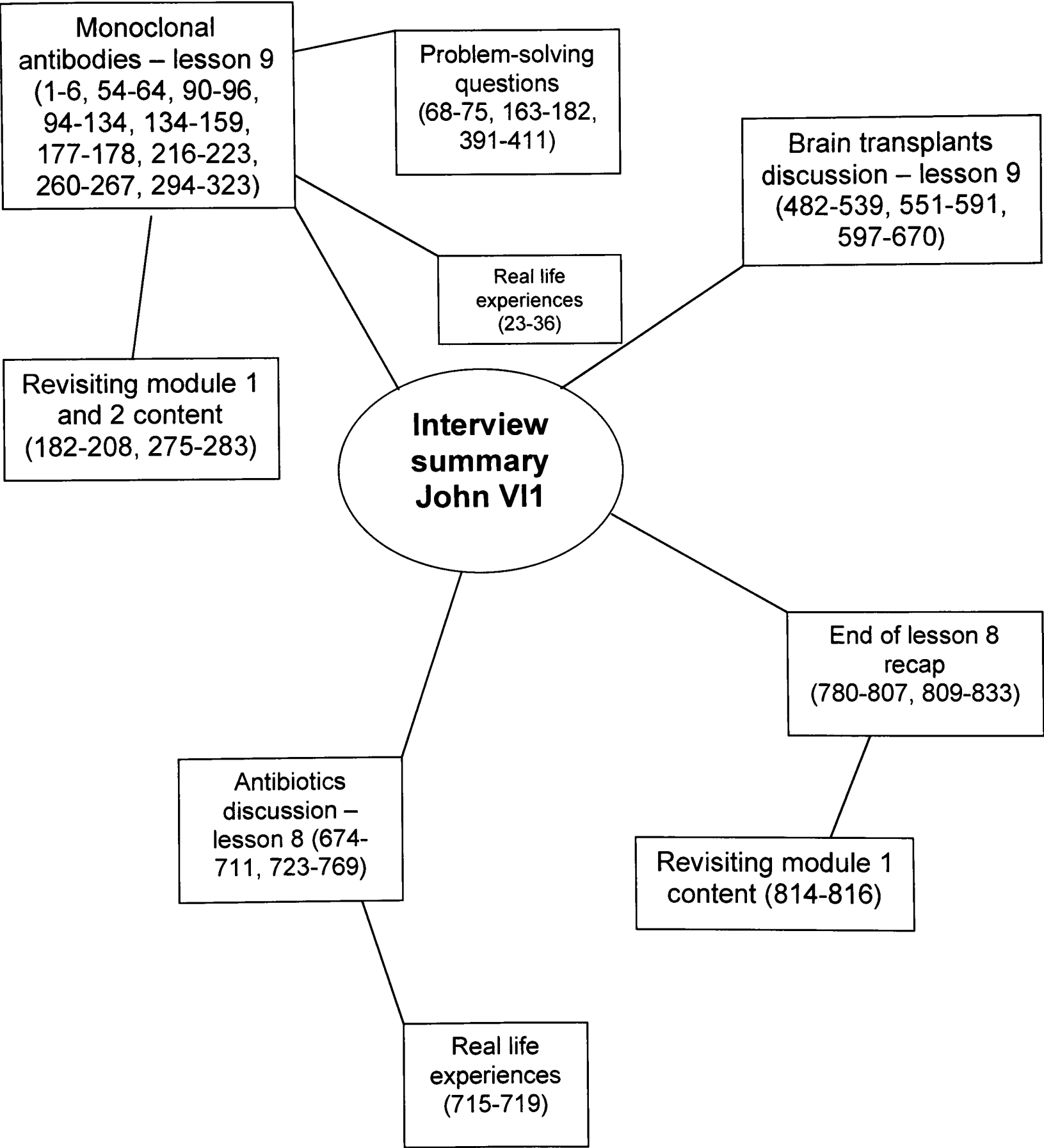
MAJOR LESSON EVENTS	SUBJECT MATTER COVERED	RESOURCES USED
Sally and her students go through the question sheet she set them in the previous lesson for their homework. This involves discussion, question and answer and the drawing of diagrams.	Structure and function of the gut Digestive juices – contents, stimulus, place of production etc.	Board (Appendix J, p. 465) Question sheet from lesson 4 (Appendix J, p. 464)
Two handouts about the structure of the gut are given to the students. Sally goes through them with the students.	Structure and function of the gut	Handouts concerning the structure of the gut (Appendix J, pp. 466-467)

Appendix F

Examples of interview summaries for all three teachers

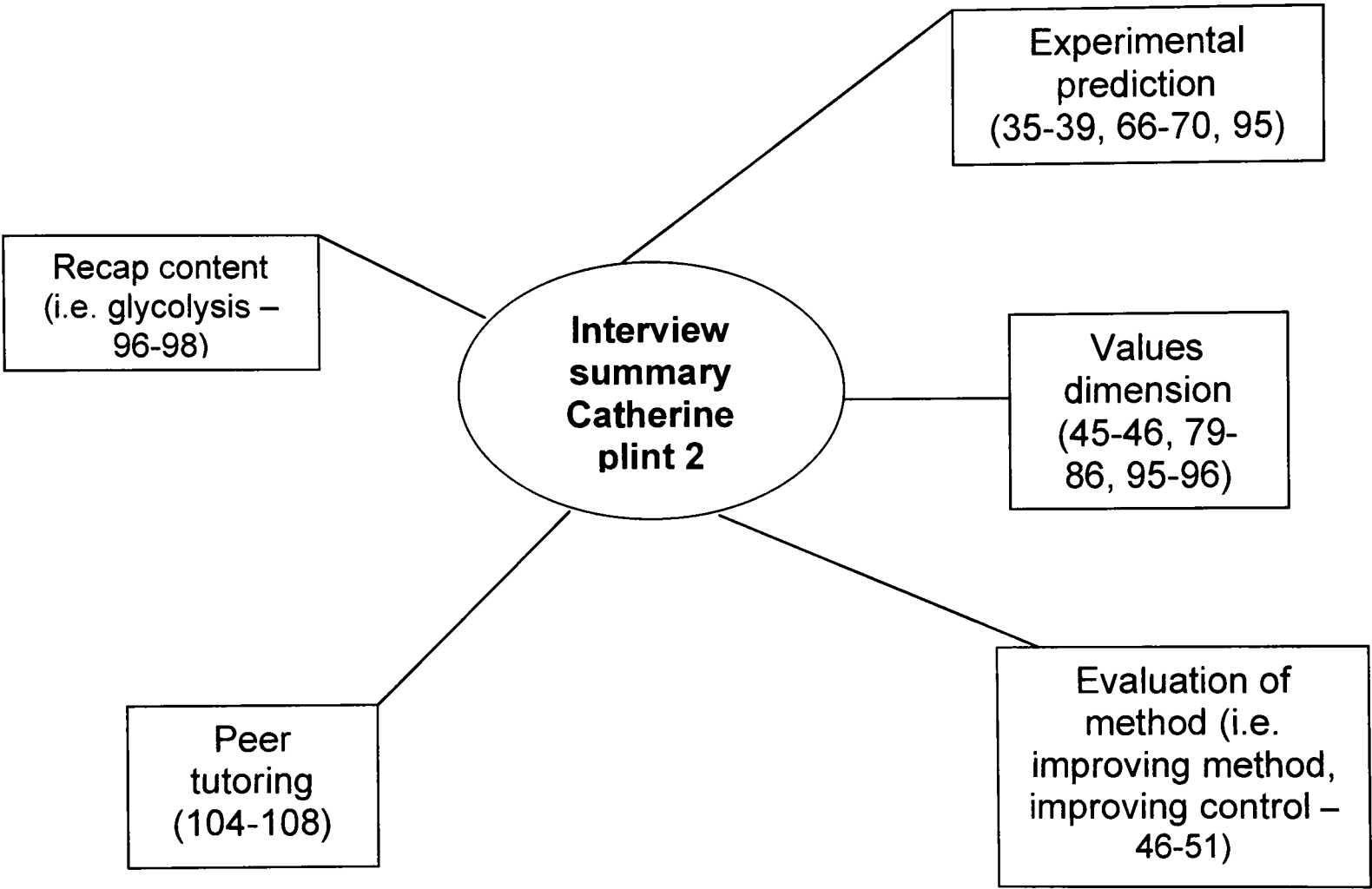
Interview summary – John vignette interview 1

This interview is based on excerpts from lessons 8 and 9 of John’s unit-of-work. The numbers refer to line numbers in the interview transcriptions. See Appendix D, pp. 363-379 for a full transcription of John’s vignette interview 1.



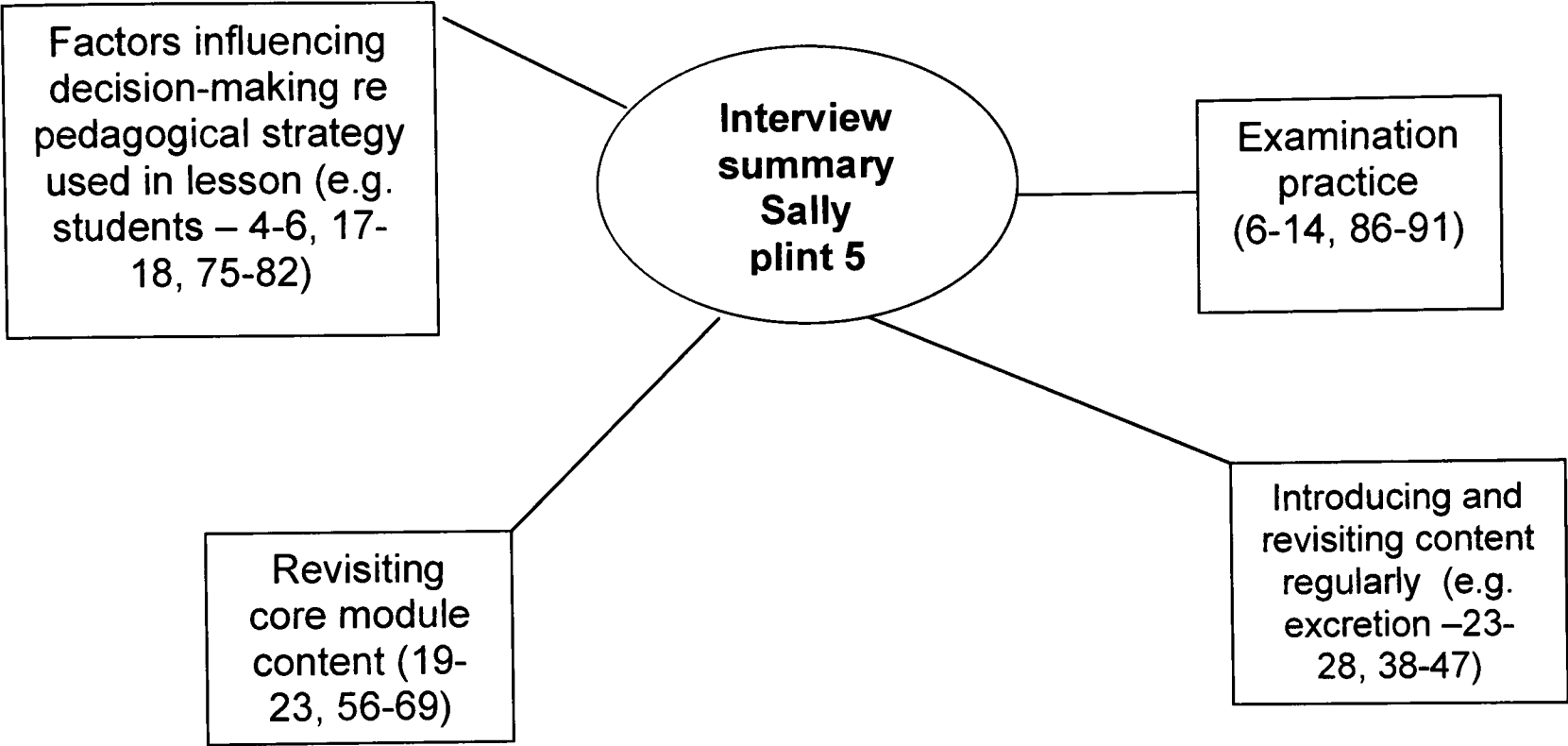
Interview summary – Catherine ‘short post-lesson’ interview 2

This interview follows a lesson in which Catherine’s students engaged in an experiment to investigate respiration in maggots. The numbers refer to line numbers in the interview transcriptions. See Appendix D, pp. 357-359 for a full transcription of Catherine’s ‘s plint 2’.



Interview summary – Sally ‘long post-lesson interview’ 5

This interview follows lesson 5 in which Sally spent the lesson going through the digestion questions she had set her students in lesson 4. The numbers refer to line numbers in the interview transcriptions. See Appendix D, pp. 360-362 for a full transcription of Sally’s ‘long plint 5’.



Appendix G

Examples of teacher comment/teaching episodes for all three teachers

Example 1: John, lesson 3, introduction to arteries, veins and capillaries

The episode comes from the beginning of lesson 3. It concerns periods of discussion between teacher and students as well as long pauses where teacher and students take notes.

Teaching episode		Teacher comments
1	J: [<i>J addressing whole class</i>] We are	J: I think we got to grips with vessels. And I think we now know, or they know the different structures and functions of the blood vessels. (plint 3 J 63-64)
2	going to look today at the structure	
3	and function of blood vessels to start	
4	with. We are going to look at the	
5	structure and function of each type of	
6	vessel, arteries, capillaries and veins.	A: Um, right, you said they got to grips with vessels. Can you tell me a bit more about that?
7	Ok. So let's start off with arteries.	
8	And if we just make some points.	
9	Um. Transports blood away from	
10	heart. What about pressure, can	
11	anybody tell me about the pressure in	J: ... it took me a long time to understand the principles and the concepts behind things. That's one thing that I've always been trying-, I've tried to do. What I've tried to do with these kids is get them to understand what is behind the things that we're teaching and I think if they do that they can go on <i>ad infinitum</i> learning and building on that ... I think in the end I would be confident enough to say that if you stopped anyone walking out the door they would know the difference between an artery and a vein and a capillary and they'd be able to give you some points about them ... I'm happy with the way that went and what they learnt. (plint 3 J 94-122)
12	an artery? Have a guess. Is it going	
13	to be high or low?	
14		
15	Helen: Higher than in a vein.	
16		
17	J: Good. Why?	
18		
19	Helen: Because its taking it round the	
20	body. It's got to get round the body [].	
21		
22	J: Yes, that wouldn't make the	
23	pressure any greater. Don't forget the	
24	oxygen is dissolved in the liquid, it's	
25	not like gas pressure. Any other	
26	reason why the artery is under high	
27	pressure?	
28		
29	Ethan: []	
30		

Teaching episode	Teacher comments
31 J: Ok, so arteries, yes the blood's got 32 to be pushed upwards sometimes if 33 you're standing up, it's got to go up to 34 your head. What creates this 35 pressure?	A: Um, you just said you'd like them to know what is behind the things that you're teaching. Can you explain to me what you mean?
36 37 Ethan: Pumping.	J: ... when we started talking about vessels we need to realise and bring in, you know, what is the aim of these things? Why are they thick? Why are some thick? Why are some thin? Why do they have valves? Rather than just remembering parrot fashion 'veins have valves', you actually work back and think 'why do they need valves?' 'Surely that blood's going fast enough, oh no, hang on, there's nothing pushing it cause it's been through all the capillaries. What's happened in the capillaries to make it lose its pressure?' So as they go on they're developing links which I think is so important in A level ... the more I get them to think about the reasoning behind things the better. ... So, it's trying to tie in all those concepts and there's so many things you can bring in, so many links you can make ... (plint 3 J 124-145)
38 39 J: Pumping of the [?]	
40 41 Ethan: Heart.	
42 43 J: Yes, there is two things. One is the 44 heart pumping and the first place it 45 goes from the heart is into the 46 arteries.	
47 48 Harvey: Is it the size of the arteries as 49 well?	
50 51 J: Yes. I suppose that is-, the heart is 52 quite a big volume isn't it and if you're 53 forcing blood into a small, relatively 54 small artery it's going to be high 55 pressure. But there is another thing 56 to do with the structure of the artery 57 which helps it's pressure?	
58 59 Jess: Walls are thick.	A: Um, so you were saying something about making links. Can you tell me a bit more about that?
60 61 J: Right, what is thickness of the 62 walls caused by? What is the 63 thickness?	
64 65 Chloe: Cholesterol.	J: ... links ... within biology ... the more I can provide them with the more chance they've got of understanding some of those things. (plint 3 J 154-179)
66 67 J: Come on to cholesterol in a 68 minute. What's the actual artery made 69 of? It's got a lot of muscle and it's got 70 some fibres, collagen and elastin that 71 we'll look at. Ok. So when you force 72 blood into this tube it's a bit like a soft 73 hose, garden hose. What happens if 74 you hold the end of the hose?	
75 76	

Teaching episode	Teacher comments
77 Samantha: You get lots of pressure.	
78	
79 J: Pressure builds up doesn't it and 80 you get a sort of-, it will blow up if you 81 like until it burst. Now that's a bit like 82 the walls of the artery because as 83 soon as the blood's forced into the 84 artery it swells up a bit. What 85 happens when you take your finger off 86 the end of the hose?	
87	
88 Sarah: It goes shhhh.	
89	
90 J: It goes down. Well that's, if you 91 like, the blood going through the 92 arteries and that's how the blood 93 moves through. The blood is forced 94 into the arteries from the heart. The 95 walls of the vessel swell out and then 96 retract and a little bit further down the 97 line they swell up and retract, further 98 down. So if you like, the artery in a 99 way is a bit like a heart in itself 100 because it expands and retracts. Ok. 101 So it's under high pressure, blood is 102 under high pressure. How about the 103 speed of flow?	
104	
105 Helen: Fast.	
106	
107 J: Fast. <i>[John has written a summary</i> 108 <i>of the information raised in this</i> 109 <i>discussion as a series of bullet points</i> 110 <i>on an OHT. There is a pause as</i> 111 <i>students write down these points in</i> 112 <i>their notebooks.]</i> Now, is-, I write that 113 blood is oxygenated except in [?] 114 What am I going to finish it with?	
115	
116 Jess: Pulmonary artery.	
117	
118 J: Good. <i>[Pause as students continue</i> 119 <i>to copy bullet points written by John</i> 120 <i>on the OHT]</i>	
121	

Teaching episode	Teacher comments
122 J: Right. What do we know about 123 veins? What could we put down 124 there?	
125 126 Helen: Carry blood to the heart. 127	
128 J: Carry blood to the heart. Ok. What 129 about pressure?	
130 131 Sarah: Low. 132	
133 J: Why? 134	
135 Sarah: Because it felt like it. 136	
137 J: Because it felt like it. Possibly. 138 Why is it lower pressure Finn than the 139 arteries?	
140 141 Finn: Because arteries accept the 142 flow straight from the heart that is at 143 high pressure.	
144 145 J: Right. 146	
147 Finn: And the vein, I don't know. 148	
149 J: Yes you do. 150	
151 Finn: No I don't. 152	
153 J: But you do because you're 154 explaining it, you just need to get the 155 words in the right order. The blood is 156 going, forced into the artery, where 157 are the veins? If you think of, if you 158 stretch arteries, blood vessels all out 159	
160 Finn: further away. 161	

Teaching episode	Teacher comments
162 J: Further away. Yes, that's it, they are 163 further away. So, by the time the 164 blood gets to the veins they have 165 gone quite a long way so they are 166 lowering in pressure. All right. So you 167 did know. So blood is under low 168 pressure, um, what else have we 169 said, flow is going to be slow. Now 170 there is something that veins have if 171 you remember that arteries don't.	
172 173 Sarah: They've got valves.	
174 175 J: Valves, well done. Right. So what 176 is the relevance of-, what is the point 177 of veins having valves? Why do veins 178 have valves?	
179 180 Chloe: Because veins take blood 181 back to the heart and cause they have 182 to go up and the blood is at low 183 pressure, it isn't pumped there, and 184 so some blood might go back the 185 wrong way, so the valves keep the 186 blood going the right way and stop it 187 going backwards.	
188 189 J: Exactly that. What Chloe is saying 190 for those who couldn't hear was that 191 the veins have valves because the 192 blood really needs, it's not under 193 pressure being forced through, it's 194 draining if you like, that's how I 195 always remember veins go back to 196 the heart, they drain, veins are drains 197 and they are draining back. Now if 198 you're not pumping this blood 199 through there's a good chance that 200 it's going to slip back the wrong way, 201 so you've got valves. <i>[Pause as</i> 202 <i>students continue to copy bullet</i> 203 <i>points written by John on the OHT]</i> 204	

Teaching episode	Teacher comments
205 J: Right, that's good. What about-, 206 how does the blood-, you PE people, 207 how does the blood pass through 208 veins? I mean, it's got a bit of 209 pressure from the heart 210	
211 Harvey: contraction of muscles. 212	
213 J: Good. Contraction of the skeletal 214 muscle and that is assisting the 215 blood flow through. All right. So, in 216 between our skeletal muscles we've 217 got little, the veins are flowing, the 218 veins are running through the 219 muscles and as we move about and 220 go like that [<i>John flexes the muscles</i> 221 <i>in his legs</i>] we help the blood flow. 222 So, um, what shall we say? Flow is 223 assisted by skeletal muscles. [<i>Pause</i> 224 <i>as students continue to copy bullet</i> 225 <i>points written by John on the OHT</i>] 226	
227 J: Capillaries, what do we know about 228 capillaries, they are [?] 229	
230 Chloe: Little. 231	
232 J: Little. 233	
234 Samantha: When I chopped my finger 235 off the doctor said that it was bleeding 236 so much because I'd sliced a 237 capillary. 238	
239 J: Well yes, in that case if you slice a 240 capillary there will be quite a bit of 241 blood. Usually when you cut yourself 242 you're just going sort of between the 243 capillaries and the tissue fluid. 244	
245 Sarah: You disgusting cow. You bled 246 all over the flipping fish didn't you, 247 and the meat. 248	

Teaching episode	Teacher comments
249 J: Oh no! Right, now they are the 250 smallest vessels in the system. Yes. 251	
252 Chloe: [] 253	
254 J: To the 255	
256 Chloe: to the lungs [] 257	
258 J: The pulmonary artery will take the 259 blood to the lung and then that will 260 divide up into capillaries which 261 surround the alveoli of the lung which 262 rejoin to go back into the pulmonary 263 vein back to the heart. Right, they link 264 arteries to veins so they are in 265 between arteries and veins, no 266 valves. [<i>Pause as students continue to</i> 267 <i>copy bullet points written by John on</i> 268 <i>the OHT</i>] 269	
270 J: Have you oxygenated or 271 deoxygenated? 272	
273 Euan: Both. 274	
275 J: Good, both. 276	
277 Clare: You should put for the veins 278 that they are deoxygenated except for 279 the pulmonary artery. 280	
281 J: [<i>J talks individually to Clare</i>] So, 282 yes, you can add that if you like to 283 yours, it's a valid point. [<i>Pause as</i> 284 <i>students continue to copy bullet</i> 285 <i>points written by John on the OHT</i>] 286 [<i>John addresses the whole class</i>] In 287 the veins, which vein carries 288 oxygenated blood? 289	
290 Clare: Pulmonary. 291	

Teaching episode		Teacher comments
292	J: Yes, it's the only one. Clare was	
293	just saying that if you wanted to write	
294	on here, veins carry deoxygenated	
295	blood except the pulmonary vein you	
296	could have that. Thank you Clare.	
297		
298	Clare: That's ok, any time.	
299		
300	J: Ok. Drawing time. Well I'm not	
301	going to get the slides out. I would	
302	like you to draw a cross section of an	
303	artery, a vein and a capillary and there	
304	are some good examples in your	
305	textbook.	

John

Notes taken during lesson time
from DKIT.

The structure of arteries, veins and capillaries in relation to their function.

Arteries

- Transports blood away from heart
- Blood is under high pressure
- Blood flows fast
- Blood is oxygenated EXCEPT in pulmonary artery

Veins

- Transport blood to heart
- Blood is under low pressure
- Blood flows slowly
- contain valves
- Flow assisted by skeletal muscles

John

Notes taken during lesson three
from 0117.

Capillaries

- smallest vessels
- link arteries to veins
- no valves
- both oxygenated and deoxygenated

Draw cross-section of each (p. 329/330)

Read "The Capillaries"

What is the relevance of pavement endothelium to a capillary?

What is the relevance of sphincter muscles to a capillary network?

What is the relevance of shunt vessels to a capillary network?

Example 2: Catherine, lesson 3, introduction to the Krebs cycle

Teaching episode		Teacher comments
1	C: And the next stage in this process,	I put the diagram from their book because that's what they're going to see. I wanted, I felt I got across the main points, the important bits of biology. That's what they need to know for this, you know, for A level. The main points for me were getting the carbons, showing them where the carbons decrease and that there are hydrogen's coming off, because that's what we have to deal with next in the electron transport chain. So effectively they could forget all intermediate compounds and that's why I kept saying 'well in different books you'll see different intermediate compounds' and taking away that anxiety about something on a diagram. (plint C 3 33-41)
2	step three, also takes place in the	
3	mitochondrial matrix and is aerobic.	
4	If you remember we haven't used any	
5	oxygen, and it's called Krebs cycle.	
6	Now Hans Krebs is the German	
7	scientist who came over to Oxford	
8	and worked out this Krebs cycle, not	
9	very far away from here, just across	
10	the park, in the Biochemistry	
11	Department. So this is local news,	
12	it's been done locally. He only died-	
13	in the 1980s he died. I used to see	
14	him walking around Oxford. His son	
15	is still working here. So it was done	
16	right here in Oxford. However, you	
17	ought to know it's also called the	
18	Tricarboxylic Acid Cycle. You can call	
19	that the TCA cycle. Now it is a cycle	
20	so things are going to go round and	
21	round and round. So what is entering	
22	this cycle, remember?	
23		
24	George: Acetyl coenzyme A.	
25		
26	C: Acetyl coenzyme A is entering this	good biology teaching? (**) was going-, was showing them, getting the important parts of the Krebs cycle and using the terminology Tricarboxylic Acid Cycle and reducing the carbon, showing that oxygen for the first time was coming in cause we said it was an aerobic process, excuse me, and then the next step when we were breaking these hydrogen's (plint 3 C 44-49)
27	cycle. So the purple there represents	
28	the end of the link reaction [<i>Catherine</i>	
29	<i>is referring to the OHT diagram see</i>	
30	<i>figure 6.3</i>]. Now all I've shown on	
31	there is something is happening.	
32	What is happening?	
33		
34	Amanda: The carbon is being taken	
35	away.	
36		
37	C: So carbon is being lost between	
38	steps one and two there. Stars are	
39	where the carbons are lost.	
40	Hydrogen is being lost there, there	
41	and there [<i>Catherine is pointing to the</i>	

Teaching episode	Teacher comments
42 <i>parts of the diagram where the</i> 43 <i>following is written –</i> 44 <i>NAD⁺ → NADH + H⁺]</i> and is 45 being picked up by the hydrogen 46 acceptor and taken somewhere else. 47 It picks up two H's and goes off 48 again. Now what's happening here? 49 Well, we've got this acetyl coenzyme A 50 joining up with a four-carbon 51 substance. What is this four-carbon 52 substance? Well I'm going to give 53 you the names of these things to put 54 in as a key in your diagram but the 55 reason I left it like that is that I want to 56 show you that the carbon-, where the 57 carbon is being lost and therefore the 58 number of carbon atoms is reducing. 59 It's called oxaloacetate. See if you 60 can find oxaloacetate on that diagram 61 [<i>Catherine is referring to the handout</i> 62 <i>reproduced in figure 6.4</i>]. So here 63 [<i>Catherine is pointing to the middle</i> 64 <i>left hand section of the OHT diagram</i>] 65 somewhere you are to write 66 oxaloacetate. Oxaloacetate 67 combines with acetyl coenzyme A to 68 give you a six carbon substance. 69 Here is your four carbon oxaloacetate 70 which combines with the acetyl 71 coenzyme A. So how many carbons 72 are adding? We are adding four 73 carbons plus two carbons to give us 74 a six carbon substance. So what's 75 the name Lizzie of that six-carbon 76 substance? 77 78 Lizzie: Citrate. 79 80 C: Citrate yes. What is the next? On 81 the board there I have left out a step. 82 It is called oxoglutarate that one. So I 83 have left out the second of the six 84 carbon substances which is 85 oxalosuccinate. You happy with that. 86 And I have gone straight to the five- 87 carbon substance called	the good biology of the Krebs, of the respiration, pointing out the important bits and not letting them confuse themselves with names of intermediary compounds and showing them how that comes in secondary and the important thing is the the decarboxylation of the, and also the hydrogen (plint 3 77-82 C) I think, I think I covered the points about the importance, about the important bits of biology (plint 3 116C) All right. Well, because there are so many intermediate compounds, now I had talked to them about that right at the beginning of respiration when I talked about the multi-step process and lots of things being formed and I remember using the word intermediate compounds with them. There are so, so many. Important features of Krebs Cycle I thought in terms of biology was the reduction of the carbons to form the carbon dioxide. Sorry, removal of carbon to form carbon dioxide and the removal of hydrogen which will be picked up on the electron transport chain as Nerissa reminded us to form the-, ultimately to form the ATP. So that's why in my boxes to start with I just had the carbons being done and the hydrogen's going down, and where the carbons were lost the hydrogen's removed. So, in terms of the names of the substances they do need to know some names, they do, you'll see it in the, in the, um, questions, but in some questions it only gives them the number of carbons so again that's using the knowledge of the biol-, of the questions that they

Teaching episode

Teacher comments

88 oxoglutarate. But on my diagram I
 89 have shown you that carbon has
 90 come off and I've also shown you that
 91 two H's have come off both of which
 92 are written on this diagram here. Do
 93 you want to put a key for the blue star,
 94 the blue star means loss of carbon.
 95 And when you lose carbon what
 96 happens to it? It combines with?

97
 98 Sophie: Oxygen.

99
 100 C: To form?

101
 102 Sophie: Carbon dioxide.

103
 104 C: Can you see that this is the first
 105 time we have used oxygen in this
 106 whole process and therefore this is
 107 the aerobic part of the process. So
 108 the star means a loss of carbon. So
 109 from oxoglutarate can you see that
 110 we've gone to the next four carbon
 111 substance which is called what?
 112 That is called succinate. This is why I
 113 said to you there are so many
 114 intermediary steps in this thing.
 115 Various books will give you various
 116 numbers of steps. I am trying to
 117 reduce them by showing you the
 118 basic principle of all this, is the loss
 119 of carbon and the loss of hydrogen at
 120 different points. The next four C is
 121 fumarate. And then one more which
 122 is not on your sheet, here is the last
 123 one. It's called malate. It is in your
 124 book. There are lots and lots of
 125 intermediate compounds.
 126 Remember the word intermediate
 127 compound. But remember the
 128 principle of the thing is how many
 129 including the link reaction Amanda
 130 how many carbons have we lost?

131
 132 Amanda: Three.

get in a biology exam, um, so I didn't
 want them to, to put in-. If I had put in
 oxaloacetate, fumarate, succinate, I
 think they would be, psychologically
 that would have been what they would
 have latched on to. Does that explain
 what I was trying to do? They would
 have latched on to names of things as
 kids do because it's new, it's, they
 haven't seen that before and not
 latched on to 'first of all let's look
 at what's happening and what's the
 um carbon product'. [^]

A: So, can you tell me why that, for
 you, was good biology teaching?

C: Because I was dealing first with
 the important aspect of the cycle. I
 think comes after all these sentences
 or as people say in my opinion and
 you think 'well who else's opinion?'
 (**) Because, so the important
 aspects first before clouding with
 something that, from experience you
 know they will latch on to, names of
 things which as I said to them you
 know 'there are many more
 substances in this thing'. Does that
 make sense to you?

A: Was this something that you were
 thinking about at the time of doing it?

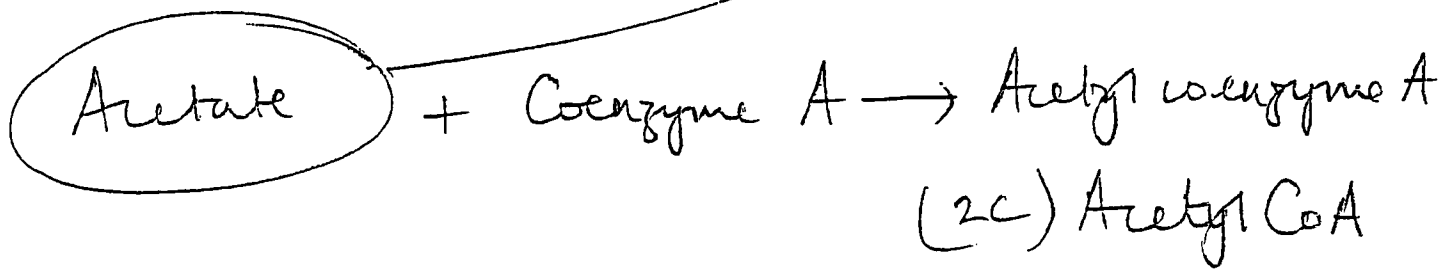
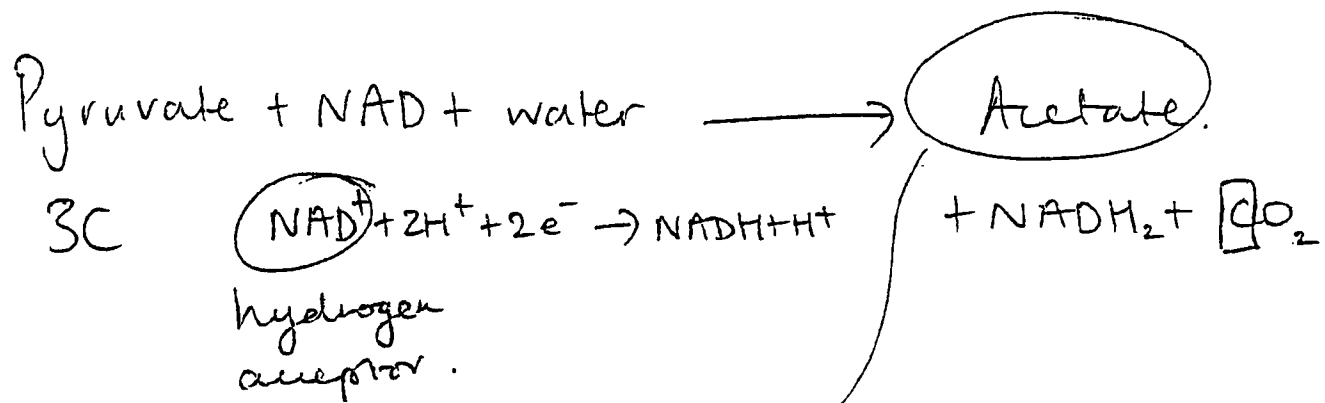
C: Oh no no no no. Pre-determined,
 premeditated. Cause I was, that's
 why I-, cause I'd been looking
 yesterday at their text, what's in there,
 refreshing my mind on what's in
 Rowland about it and I thought they
 are gonna go home and look at that
 cycle and they would think 'oh all
 these names I can't cope' and so
 using the same diagram in their
 books and putting in the simpler

Teaching episode	Teacher comments
133 134 C: That's right. So do you see where I 135 get the term Tricarboxylic Acid Cycle. 136 What happens when we get back to 137 the oxaloacetate?	things first, does that make sense? (plint 3 C 200- 249)
138 139 George: It joins with more acetyl 140 coenzyme A. 141 142 C: More acetyl coenzyme A comes 143 back in and we go round the cycle 144 again each time losing carbon 145 dioxide. And what's going to happen 146 to this carbon dioxide that we lose?	C: Now, I want them to learn this diagram, but I also-, I gave them a handout of Krebs from another book, I want them to see that it might have different names in it and things but what it looks like is really the same. They need to know, you know, what it looks like. They need to recognise it. (plint 3 C 254-259)
147 148 Emma: Breathe it out.	
149 150 C: We breathe it out precisely. This is 151 the very carbon dioxide that when you 152 talk about respiration you are getting 153 rid of. So the only thing we haven't 154 done now is what about all these two 155 H's that are being picked up by the 156 NAD.	
157 158 Amanda: The electron transport 159 chain.	
160 161 C: That goes to the electron transport 162 chain and that would be our final 163 stage, the electron transport stage ... 164 now what I'd like you to do tonight is 165 summarise the Krebs Cycle. There 166 are five little points to summarise on 167 page 127.	

Catherine

Notes taken during lesson three from board

② The Link Reaction (matrix of mitochondria) - location -

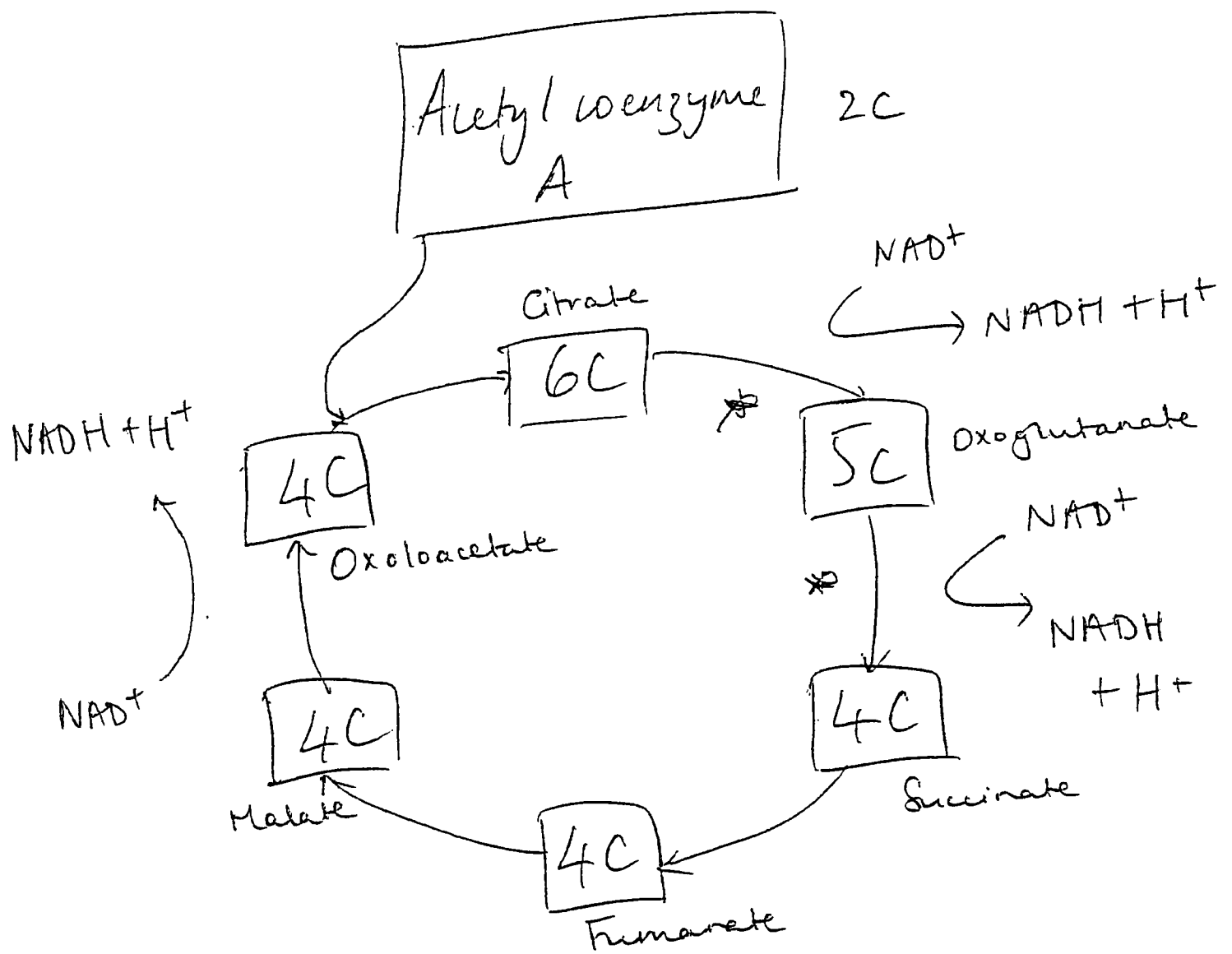


Step 3 — mitochondrial matrix — location
 — aerobic process

KREB'S CYCLE Tricarboxylic acid cycle $\equiv$ TCA cycle

Catherine

Lesson three - Krebs Cycle OHT.



* loss of $\text{C} + \text{O}_2 \longrightarrow \text{CO}_2$

Catherine

Lesson three - Krebs Cycle handout

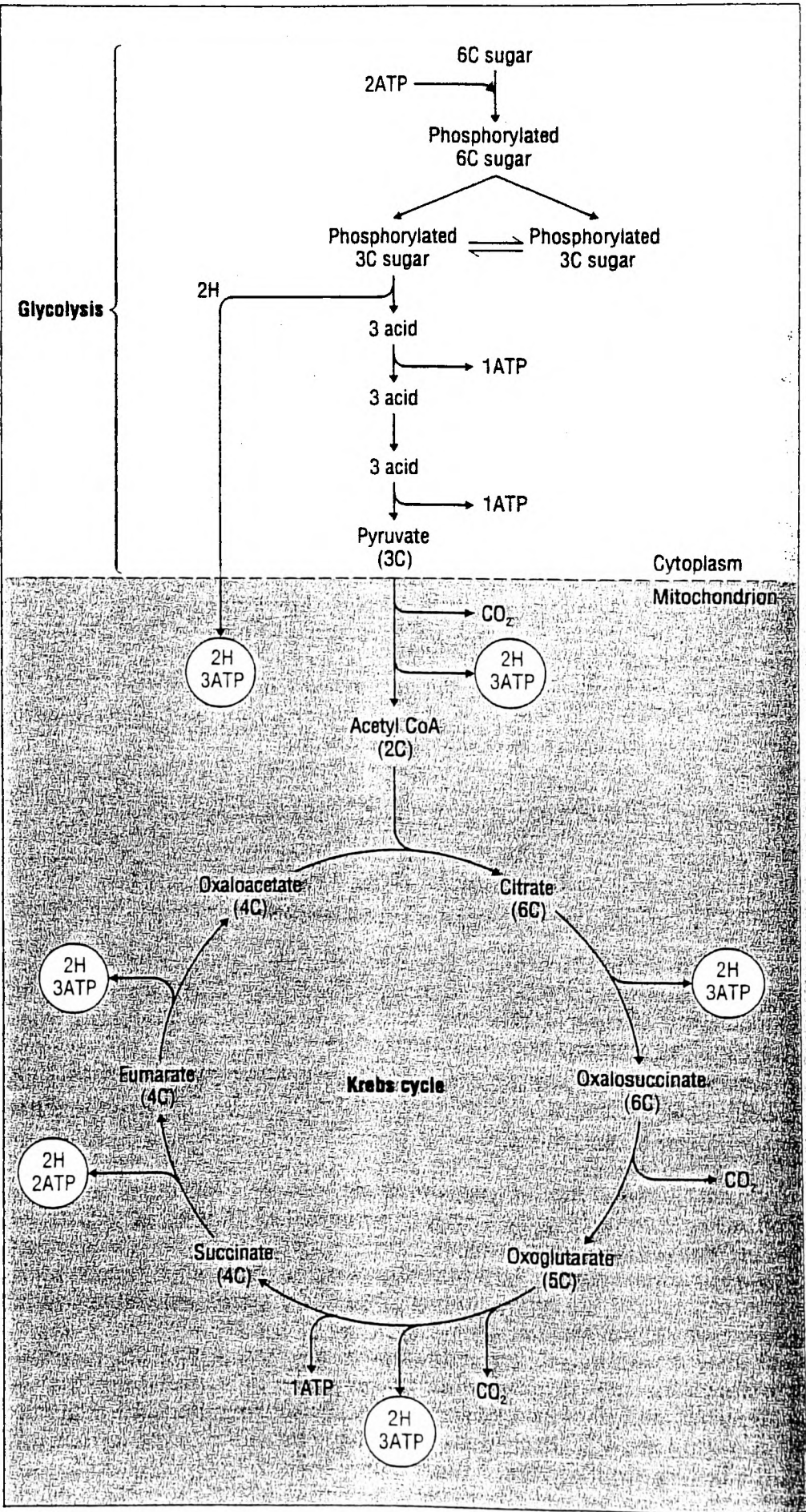
The release of energy

Figure 14.5 The metabolic pathway in which sugar is broken down in respiration. The process starts with phosphorylation of 6-carbon sugar (glucose). In the diagram this is shown happening in one step but in fact it involves several steps. In the first a phosphate group is added to the glucose molecule, resulting in the formation of **glucose 6-phosphate**, so-called because the phosphate group is attached to the glucose molecule at position 6 (see page 126). A second phosphate group is then attached to the sugar which is subsequently split into two molecules of 3-carbon sugar. These are in equilibrium with each other and normally both are converted into pyruvic acid and fed into the Krebs cycle.

The overall function of the pathway is to produce ATP molecules. Energy is transferred to ATP mainly as a result of the removal of pairs of hydrogen atoms from intermediate compounds in the pathway. The diagram shows the stages at which hydrogen atoms are removed, together with the numbers of ATP molecules synthesised. The ATP molecules circled are produced via the hydrogen carrier system which is explained on page 234. Usually three ATP molecules are synthesised every time two hydrogen atoms pass through the carrier system. However, in the conversion of succinate to fumarate only two ATPs are produced because in this case the initial carrier (NAD) is absent.

One of the most important intermediates in the pathway is acetyl CoA because it links glycolysis with the Krebs cycle. Coenzyme A is a complex molecule derived from the vitamin pantothenic acid (see page 149). Its function is to transfer an acetyl group (CH_3CO) from pyruvate to oxaloacetate. In this way two carbon atoms are added to the oxaloacetate with the formation of citrate.

The process outlined here is called **oxidative phosphorylation**. It is oxidative in the sense that hydrogen atoms are removed from certain compounds and combined with oxygen. It is phosphorylation in that phosphate groups are added to ADP to give ATP. The process also involves **decarboxylation**, the removal of carboxyl groups with the formation of carbon dioxide.



Example 3: Sally, lesson 3, digestion research projects

This example covers a substantial part of lesson 3. Unfortunately research equipment failure meant that only the first part of the teaching episode was transcribed. The teaching episode involves Sally allocating research projects to her students which concern investigating aspects of the mammalian digestive system. It also involves discussing what those research projects will entail with individuals.

	Teaching episode	Teacher comments
1	S: Right. I said the other day that we	S: Right. ... I'd asked them to do notes
2	need to do the structure of the	on different parts, so I thought it's
3	digestive system. We need to look at	good to be able to talk to each person
4	what each of the parts of the digestive	about what they have to-, what
5	system does. What the basic layers	information they have to include
6	of each of the parts are like. Why they	because that helps their note taking
7	are different. What the digestive	skills which is something they're not
8	juices produced are. Whether the	very good at. What they're not very
9	juices are produced by nerves or by	good at is picking out the points that
10	hormones or both. What the action of	they need, so as I went round and
11	the digestive juices is and so on. So I	talked to them I was able to highlight
12	am going to ask you to find some	the important points. And also refer
13	information out using the ordinary	to the syllabus because the last
14	textbooks and to do sort of a bullet	lesson I kept saying 'let's look at the
15	point things and diagrams, where	syllabus'. 'What does the syllabus
16	necessary, so that you are providing	ask us to do' because they will just
17	information for everybody to use. We	copy a chunk out of a book and they
18	have got lots of advanced biology	won't actually think 'how much of this
19	books now, so we have got a few	do I need?' And they won't think
20	more books. Now I want it nice and	about whether they know what it's on
21	neat because I would actually like to	about. The other thing I thought
22	put it up. If you do it in rough first of	which was good out of what I'd asked
23	all, I will come round to each of you	them to do was-, because they
24	and talk you through and make sure	couldn't find all the information in one
25	you understand what you are	textbook, or one textbook wasn't good
26	supposed to be doing. It might help if	enough to use because different
27	you have the syllabus, because if you	textbooks do different things better
28	are doing anything which has	than others, so they couldn't
29	enzymes, the syllabus has the	necessarily find a diagram they
30	enzymes on and so we don't want to	understood in one textbook and good
31	be doing more than we actually need	enough notes and sort of vice versa,
32	to do. The syllabus also has the	so I mean I do all my notes from a
33	hormones that you are meant to	variety of textbooks and I think they
34	know. Right who wants to do the	should realise that and they should
35	mouth? We are going to do this as	do the same. So they were able to do

	Teaching episode	Teacher comments
36	individuals because otherwise we	that. And it also meant because we
37	won't get all my things off my list	were in here, if they couldn't find
38	because I've got 8. There's 8 of you.	something I could say 'well let's look
39	Right, who wants to do the mouth?	in the textbook' so we had a variety
40	Right, Eleanor, you do the mouth then	out.
41	I will come and say talk about what to	(plint 3and 4 S 15-45)
42	do so find some paper to start writing	S: Right. I said quite often they will
43	some information about the mouth,	just chunk copy, so they'll see a
44	what goes on in it, obviously we talk	heading in the textbook and they
45	about amylase, saliva with amylase	won't read through what it says but
46	in it. Mechanical digestion. Right,	they'll just start copying the chunk out.
47	that's your task. Who wants to do	So that's one thing they do and then
48	oesophagus which will include	they don't take it in. The other thing
49	obviously peristalsis, description	that they do is see the word and then
50	about, Owen, did I hear you say you	just copy the little bit around the word
51	would do it? Basic layers of the gut	without again realising, reading
52	wall, really the basic ones, the	through it and thinking 'well does this
53	mucosa, submucosa, muscularis	actually answer what I'm supposed to
54	externa, that one and the serosa.	be doing. Is it relevant?' So what I
55	What they are like, not what they are	was trying to get them to do was to
56	like in each of the regions but what	ask themselves these sorts of
57	they consist of. Who wants to do that	questions, you know, get them to look
58	one? Right, we will come back to that	for the relevant bits without doing the
59	one then. Stomach. Who fancies the	whole chunk. And then there were
60	stomach? We have got two there for	better ways of doing it, like some
61	stomach. Right, Charlotte, stomach.	books do tables of enzymes, others
62	So yours will be physical mechanical	don't do that. I find a table of
63	digestion. The juices, what	enzymes useful so I say to them you
64	stimulates the juices. Right. Gall	know 'this is a good way of learning'.
65	bladder, bile and pancreas I've	It might not be for them but if it
66	lumped together. Gall bladder, bile	summarises all the information I
67	and pancreas, Stephen, right.	think that's a useful piece of
68	Intestinal wall. Just the digestive	information. So it's trying to get them
69	juices because in fact the intestinal	to, not to copy everything down, to pick
70	wall produces quite a number of	out the relevant, the pertinent points
71	digestive juices. So there is probably	and to use a bit of thought while they
72	not that much on that one but quite a	are doing it, so it's not just in their
73	number of juices and what actually	eyes and down their fingers but
74	causes secretion of those. Right,	there's a little bit of brain power going
75	Charlie, intestinal. Villi. [S says <i>this</i>	on.
76	<i>as she points to a student</i>] A diagram	(plint 3 and 4 S 143-166)
77	has to be done here. Structure of the	S: Right. I was picking out words
78	villus, purpose of it, role of it. Can you	from the book, looking through the
79	mention the hepatic portal vein	pages in the book and saying 'well
80	because the hepatic portal vein is the	
81	vein that takes the end products of	

	Teaching episode	Teacher comments
82	digestion from the intestines to the	there's information but is there a better way it's written in the book? Is there a table somewhere?' Cause I knew there was cause I knew what was in the books. So I knew that say Toole and Toole had a really good digestive table so although the information was written and it was written in other books in paragraphs just to be able to go through and say 'well it's here'. So I suppose I was trying to do with them what I would do myself and that's sit with the information in front of me in the variety of books and just sort of flick through and say 'right, what's best for me to learn from? What's the explanation I understand?' So I went round to each of them. That's what I was doing with them. (plint 3 and 4 S 172-189)
83	liver. So you need to include a bit on	
84	that. Colon, caecum. [<i>S says this as</i>	
85	<i>she points to a student</i>] Anne we	
86	haven't got anything have we. I've got	
87	8 things down here and there is 8 of	
88	you, where have I gone wrong. Oh	
89	basic layers of the gut, no-one	
90	wanted to do—, you are going to have	
91	to do basic layers of the gut Anne.	
92	Colon, caecum, especially in	
93	herbivores. Do the herbivores that	
94	have a large caecum. We won't do	
95	ruminants with the stomachs. Right,	
96	so its structure if it's a structural thing.	
97	Juices and any contents of juices.	
98	What the juices are produced by,	
99	which particular bits, the action of the	
100	juices, whether they are stimulated,	
101	whether its nervous, whether its	
102	hormonal or whether it's a mixture.	
103	Use the syllabus. It is quite precise	
104	on the hormones. Gather your	
105	information together now. Not loads	
106	of information, well you won't have	
107	loads because I gave you very	
108	precise little bits. Bullet point pieces	
109	of fact which can then be transferred	
110	to one of these sheets. [<i>Sally waves</i>	
111	<i>around the paper for the posters.</i>]	
112	Find yourselves a book and paper,	
113	find your little region and I will come	
114	round and make sure everybody is	
115	sorted. Any other questions?	
116		

Appendix H

Curriculum materials and copies of all notes put on the board/OHT during John’s unit-of-work

John

Notes taken during lesson one from OHT

39 Blood system of a mammal

Transport

Necessary materials

Body systems

Relevant components

Substances

Oxygen

Soluble products of digestion

Fighting disease

Purpose of a circulatory system is to provide rapid mass flow of materials from one part of the body to another over distances where diffusion would be too slow.

A circulatory system needs

- ① Pump
- ② Fluid
- ③ Vessels.

John

Notes taken during lesson one from OHT

2 types of circulatory systems

① Single Circulation System

- found in fish
- blood flows through the heart only once during each circuit of the body
- the result is LOW BLOOD PRESSURE
- therefore return of blood is slow

Draw single circulatory system.

② Double Circulation System

- found in mammals
- the blood pumped in the lungs is at a pressure $\frac{1}{6}$ of the body blood pressure.

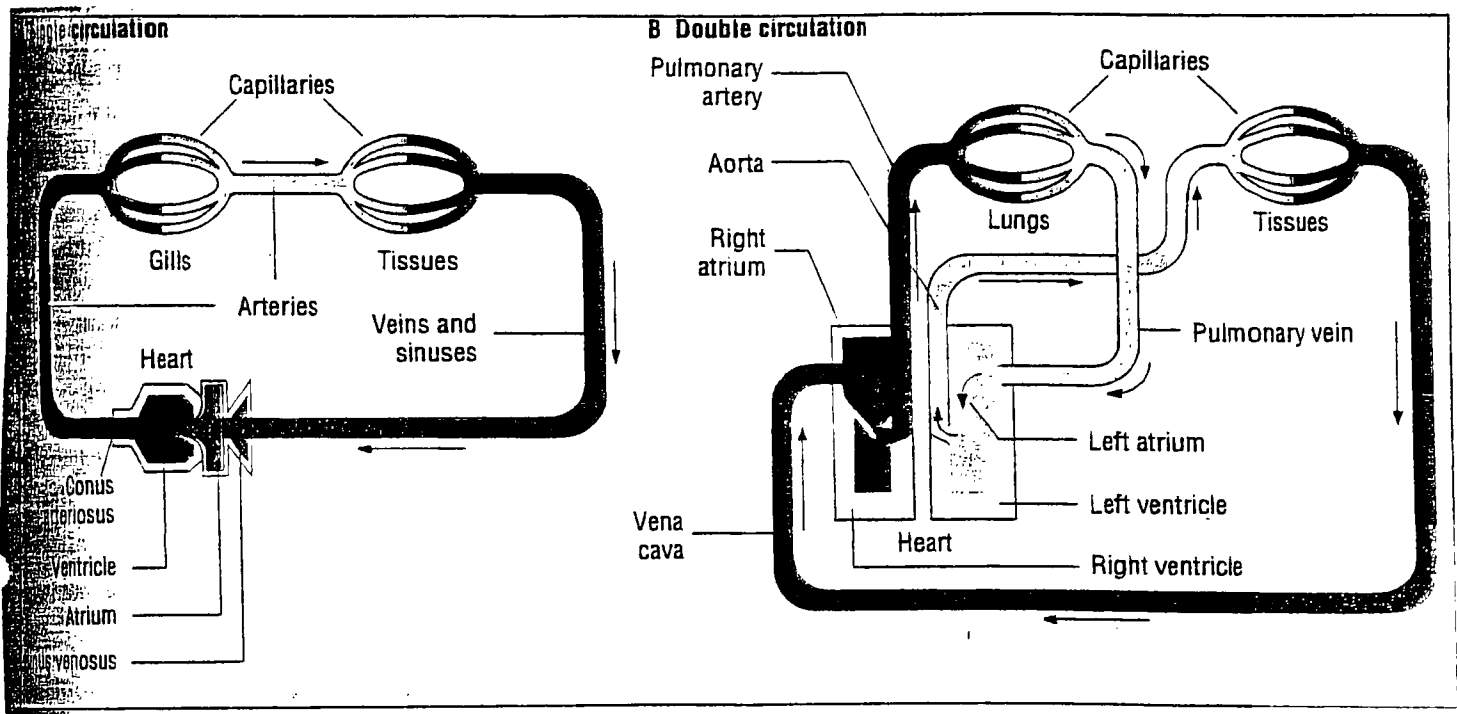
Why do higher mammals need a D.C.S?

- Because of a higher metabolic rate demanding more oxygen which is only possible with a double circulatory system

John

Lesson one - diagram of single circulatory system copied from textbook.

Figure 18.6 The arrangement of the heart and blood vessels
A in the single circulation of a fish,
B in the double circulation of a mammal.
The arrows indicate the direction of the blood flow. Oxygenated blood, light grey; deoxygenated blood, dark grey.



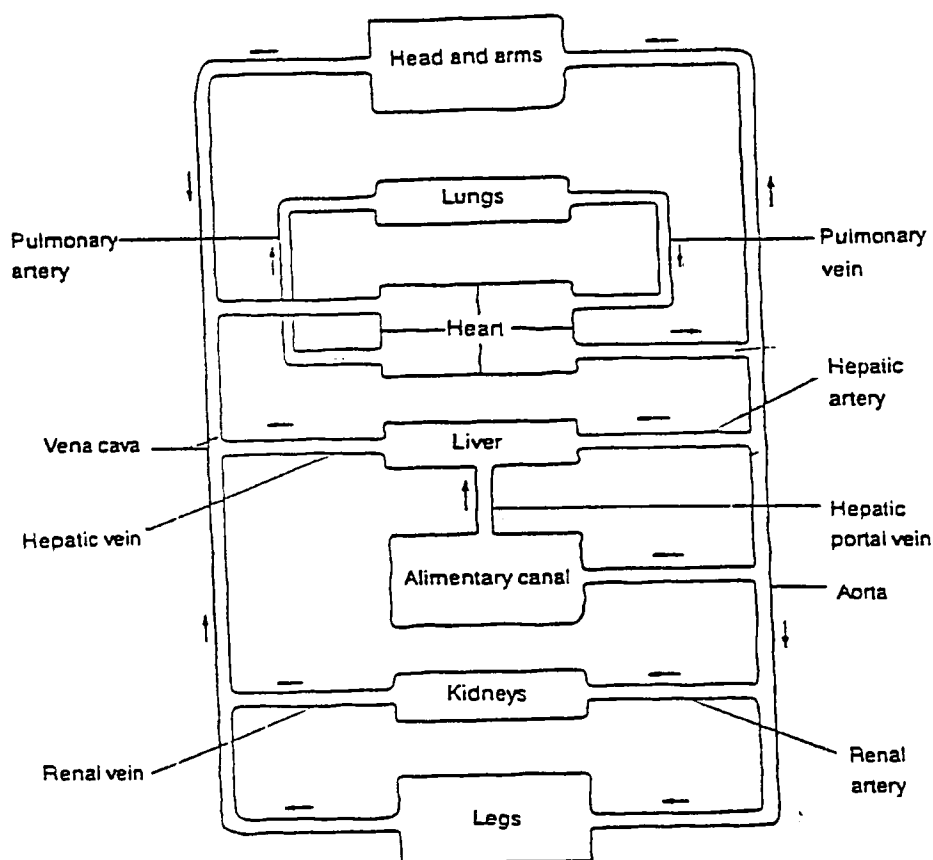
John

Lesson one - worksheet on mammalian circulatory system including diagram of double circulatory system.

CIRCULATION OF BLOOD

BLOOD 2.

1. Copy the plan of human circulation. Colour the arteries and the pulmonary veins red and the veins and the pulmonary artery blue.



2. What side of the heart (right or left) pumps blood to the lungs ?
3. Where does the oxygenated blood go after leaving the lungs ?
4. What side of the heart does the deoxygenated blood return to ?
5. Mark on your diagram the blood vessel which has
 - a) Highest pressure
 - b) Most oxygen.
 - c) Most carbon dioxide.
 - d) Most glucose after a meal.
 - e) Least poisonous waste (urea).
6. The blood system has been compared to London Underground. Write the following in the correct pairs.

Circulation

Heart

Bloodcells

Vessels

Oxygen

London Underground.

Tunnels

Electrified third line

Brains

Stations

John

Lesson one - generalised diagram of a mammalian heart (from textbook) used in question and answer session.

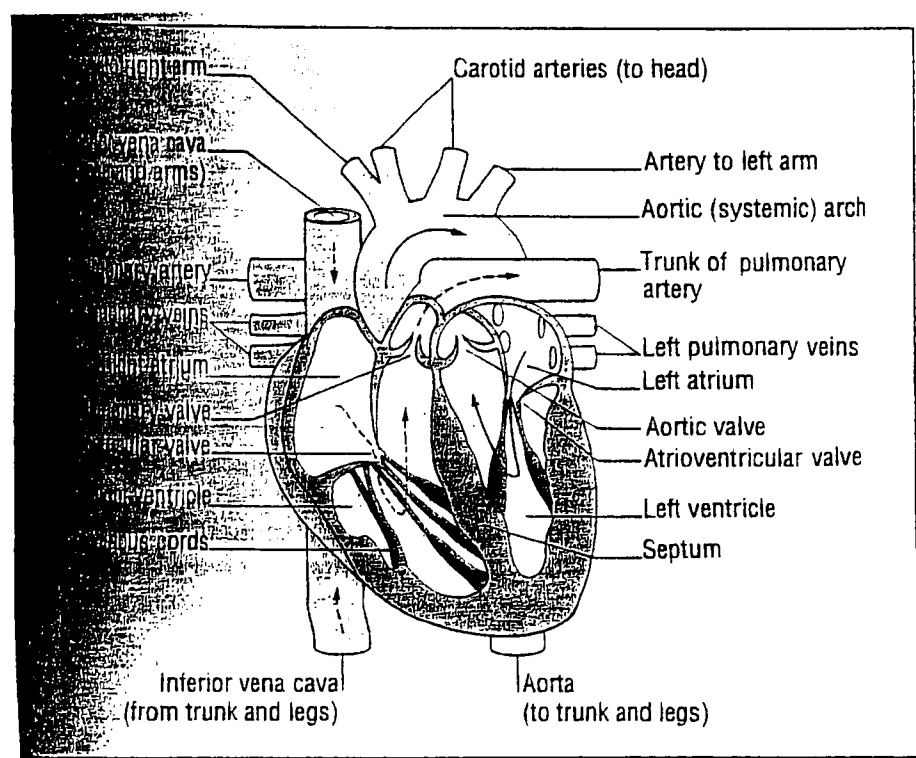


Figure 19.9 Ventral view of the mammalian heart and the blood vessels connected to it. Oxygenated blood, solid arrows; deoxygenated blood, broken arrows. The atrioventricular valve on the right side of the heart consists of three flaps or cusps (tricuspid valve); the atrioventricular valve on the left side of the heart consists of two flaps (bicuspid valve or mitral valve). The pulmonary valve guarding the entrance to the pulmonary artery, and the aortic valve at the entrance to the aortic arch, both consist of pocket-like flaps which catch the blood if it tries to flow back into the heart.

John.

Notes taken during lesson three from OHT.

The structure of arteries, veins and capillaries in relation to their function.

Arteries

- Transports blood away from heart
- Blood is under high pressure
- Blood flows fast
- Blood is oxygenated EXCEPT in pulmonary artery

Veins

- Transport blood to heart
- Blood is under low pressure
- Blood flows slowly
- Contain valves
- Flow assisted by skeletal muscles

John

Notes taken during lesson three from OHT.

Capillaries

- smallest vessels
- link arteries to veins
- no valves
- both oxygenated and deoxygenated

Draw cross-section of each (p. 329/330)

John

Lesson three - cross sectional diagrams of each blood vessel type (from textbook) used by students for personal drawings.

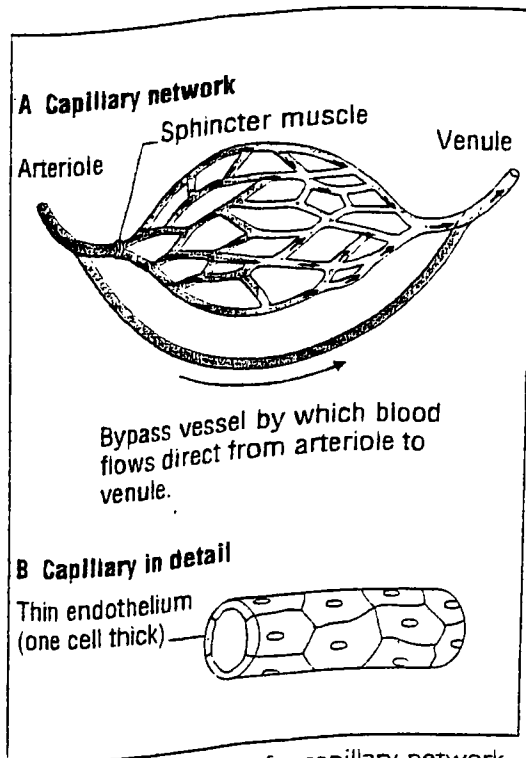
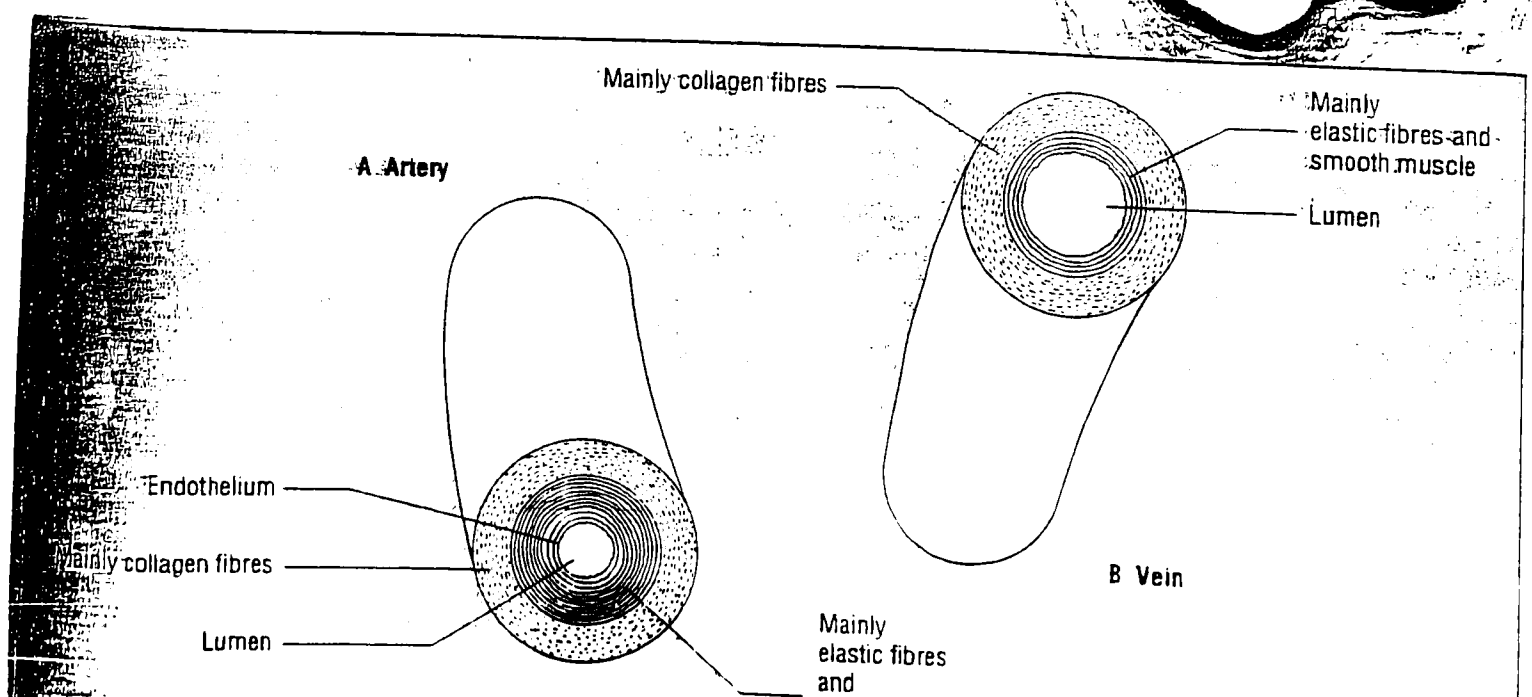


Figure 19.20 Diagram of a capillary network. The capillaries provide a vast irrigation system which supplies the cells with their needs. It is said that if all the body's capillaries were placed end to end they would extend for over 80 000 km! The bore of the capillaries averages about $10\text{ }\mu\text{m}$, just wide enough to permit the passage of red blood cells in single file. The single layer of lining epithelial cells is, at its thinnest, less than $0.1\text{ }\mu\text{m}$ thick, thus facilitating rapid exchange of materials between the blood and tissue cells. No cell is more than $25\text{ }\mu\text{m}$ from the nearest capillary. The capillaries have no muscle layer and are incapable of changing their diameter to any extent. Blood flow through them is controlled by constriction or dilation of the arterioles, whose walls contain smooth muscle, and of the sphincter muscles at the ends of the arterioles. Oxygenated blood, red; deoxygenated blood, blue.

Figure 19.18 The structure of an artery and a vein. Their walls contain elastic and collagen fibres and smooth muscle. They are therefore tough but stretchable and can constrict or dilate. The vein has a thinner wall and wider lumen than the artery as you can see clearly in the photomicrograph below. The diagrams show the arrangement of the different types of tissue in the walls.



John

Lesson three - comprehension questions.

Read "The Capillaries"

What is the relevance of pavement endothelium to a capillary?

What is the relevance of sphincter muscles to a capillary network?

What is the relevance of phunt vessels to a capillary network?

John

Lesson three - OHT of capillary network used

Figure 17.20 A capillary network, and the origin of a lymph capillary

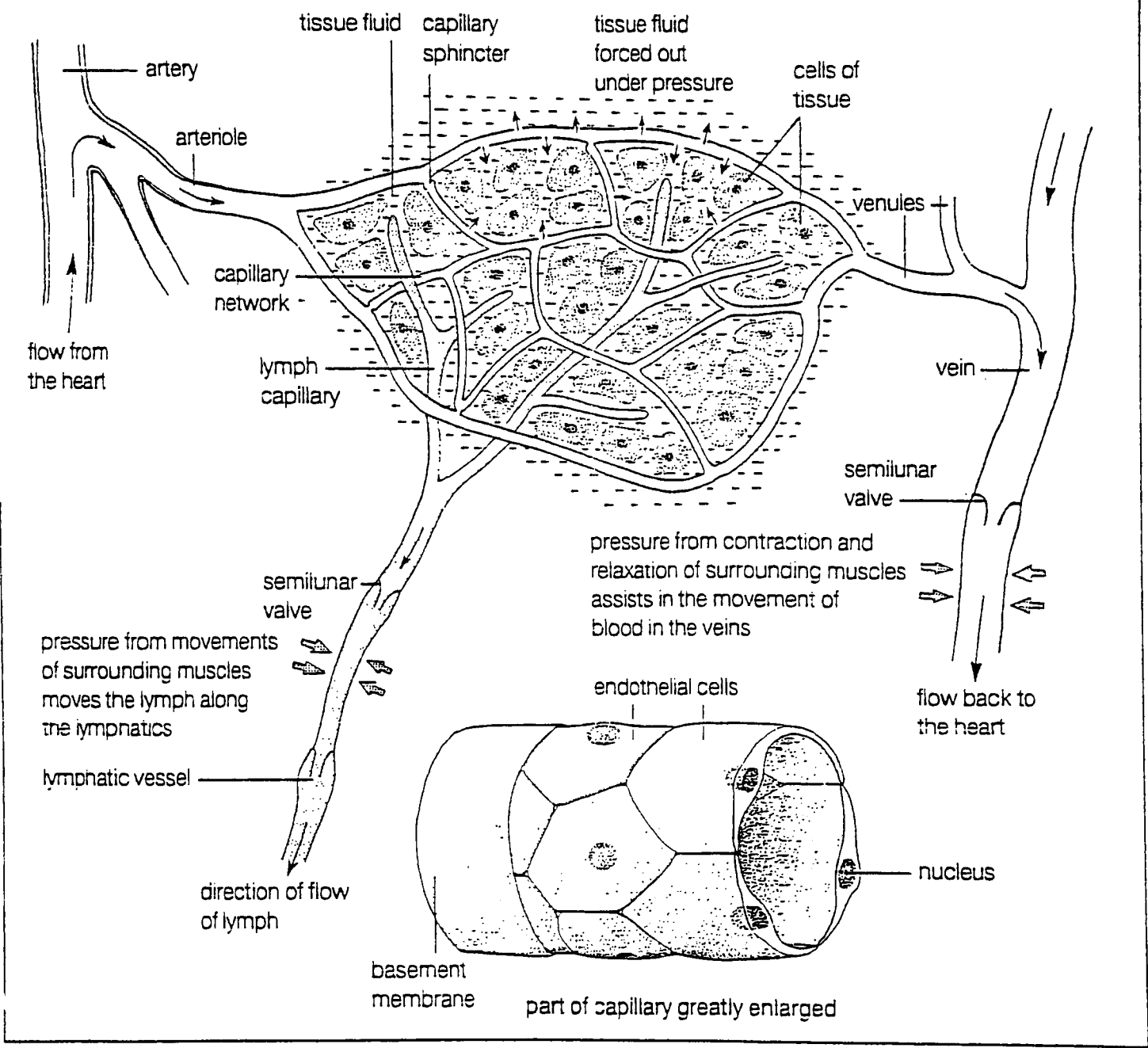
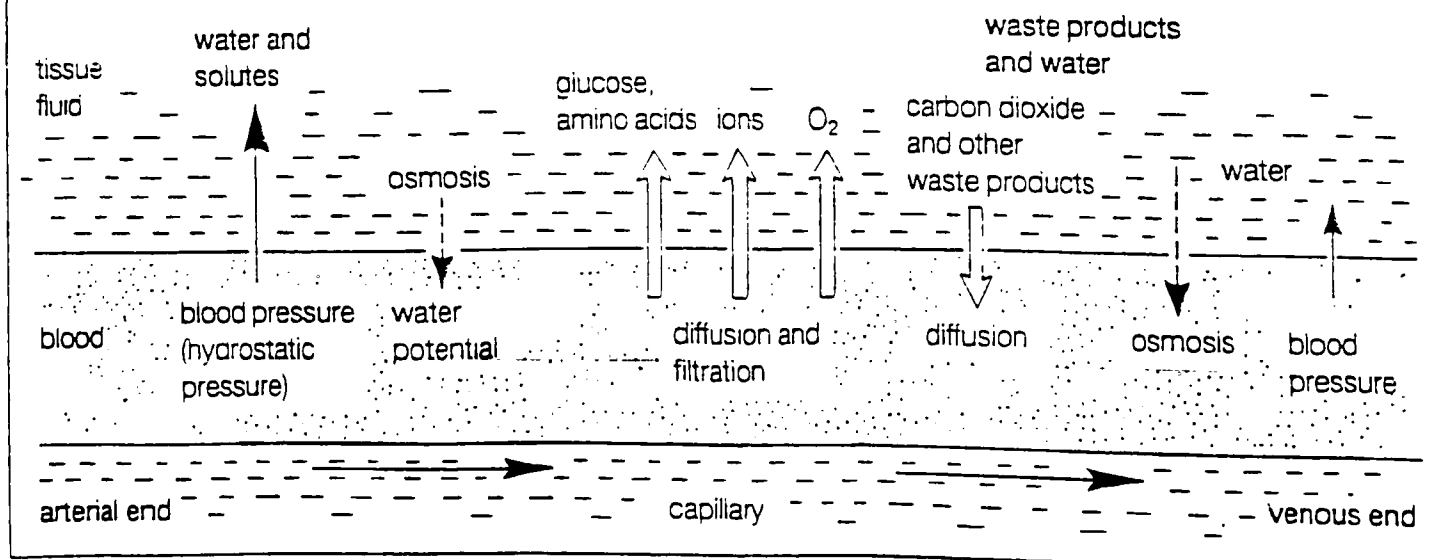


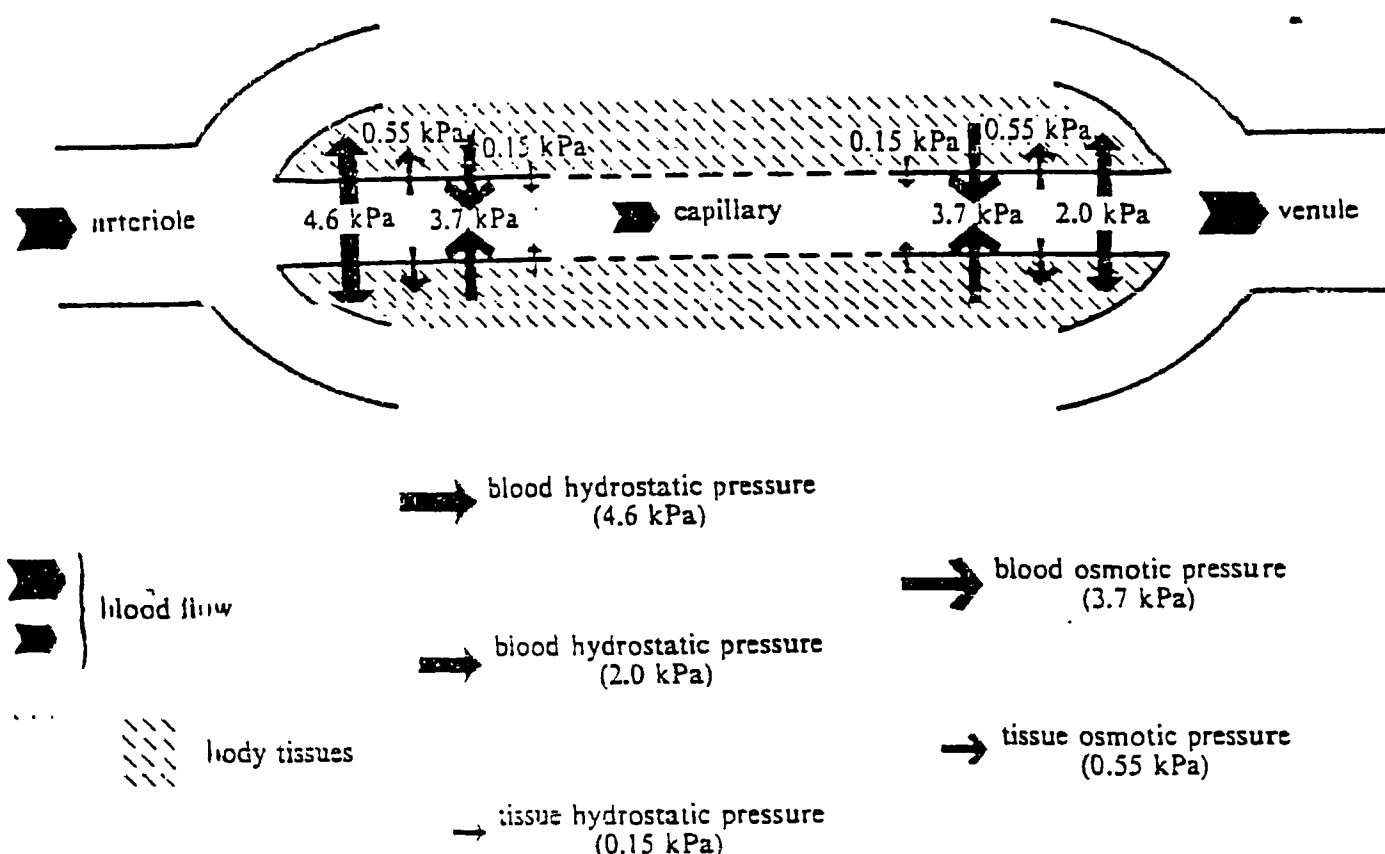
Figure 17.21 Exchange at the capillaries



John

Lesson three - worksheet concerning the formation and fate of tissue fluid.

- 3 The diagram shows the forces acting on water in and around a capillary. Arrows show the direction in which water would move if there were no other forces acting on it. The size and shape of the arrows gives an indication of the magnitude and nature of the forces.



Hydrostatic pressure describes the tendency of water to pass away from a region in this system. Osmotic pressure (which is sometimes described in terms of water potential) describes the tendency of water to pass into a solution.

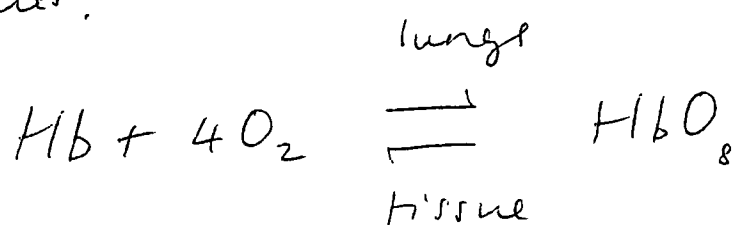
- Describe the structure of the surrounding layer of a capillary. (4 marks)
- What causes each of the four pressures shown in the diagram?
 - Blood hydrostatic pressure. (2 marks)
 - Blood osmotic pressure. (2 marks)
 - Tissue osmotic pressure. (1 mark)
 - Tissue hydrostatic pressure. (1 mark)
- Explain why blood hydrostatic pressure falls between one end of the capillary and the other. (2 marks)
- What is the pressure, in kilopascals, with which water moves *out of* the capillary at the arteriole end? (Show your working.)
 - What is the pressure, in kilopascals, with which water moves *into* the capillary at the venule end? (Show your working.) (5 marks)
- Usually the balance shown in the diagram is not achieved and more fluid is passed out of the capillaries than is reabsorbed by the capillaries. Explain how accumulation of this fluid is prevented (3 marks)

John

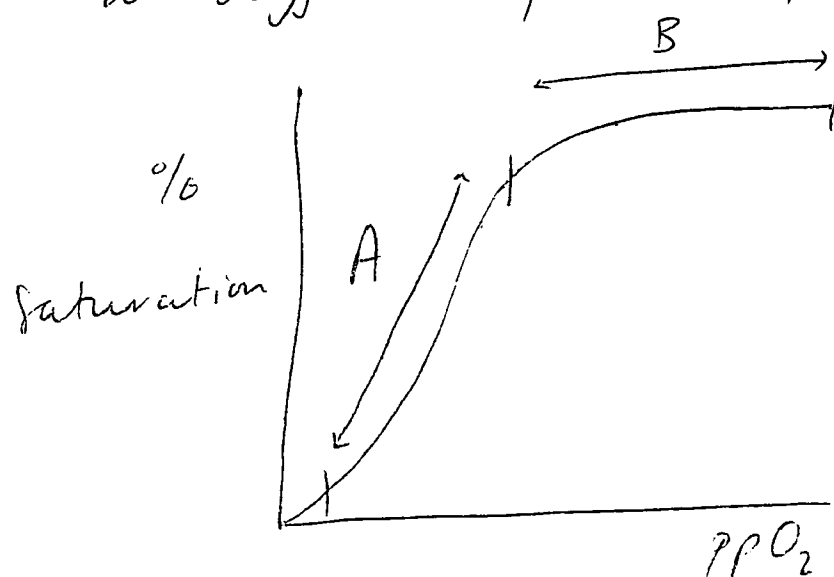
Notes taken during lesson 57x from OHT.

Haemoglobin

- A complex protein containing 4 haem groups
- Each of the 4 haem groups can combine with one molecule of oxygen
- The association is loose - collected in the lungs and released in the capillaries near the tissues.



- Haemoglobin has a high affinity for oxygen. By experiment it is possible to show how readily oxygen combines at different partial pressures.



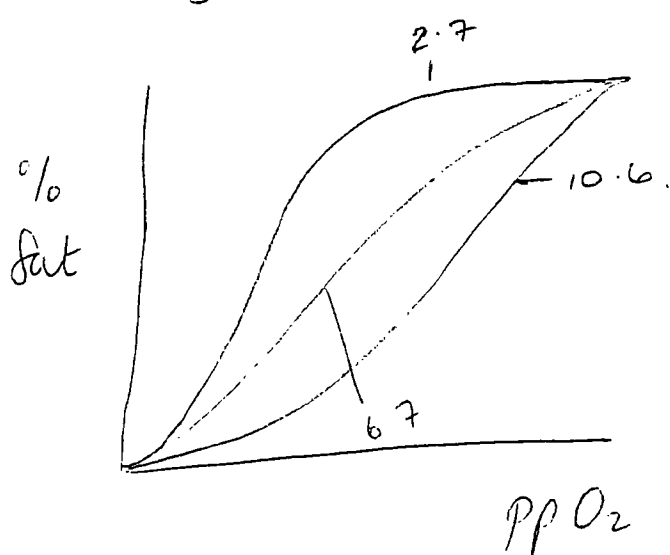
John

Notes taken during lesson six from OHT

Features of the graph

- ① It is sigmoid (S shape)
- ② when picking up oxygen:
 - Ⓐ small increase in pp achieves a high satⁿ
 - Ⓑ even if lung ppO_2 drops, % saturation is maintained
- ③ when releasing oxygen:
 - Ⓐ small decrease in pp achieves a significant drop in saturation.
 - Ⓑ a drop at the higher partial pressures will not bring about the release of O_2 .

BOHR EFFECT.



Bohr effect
 $\uparrow CO_2 = ODC \rightarrow$ Right
 $\downarrow CO_2 = ODC \leftarrow$ Left

John

Lesson six - questions on the oxygen dissociation curve and Bohr effect.

O₂ carriage by blood

2

The oxygen dissociation curves (Fig. 7.9) represent the relationship between the partial pressure of oxygen and the percentage oxygen saturation of two respiratory pigments. Curve A shows the response of myoglobin in muscle and curves B, C and D the response of haemoglobin in the blood at three different partial pressures of carbon dioxide.

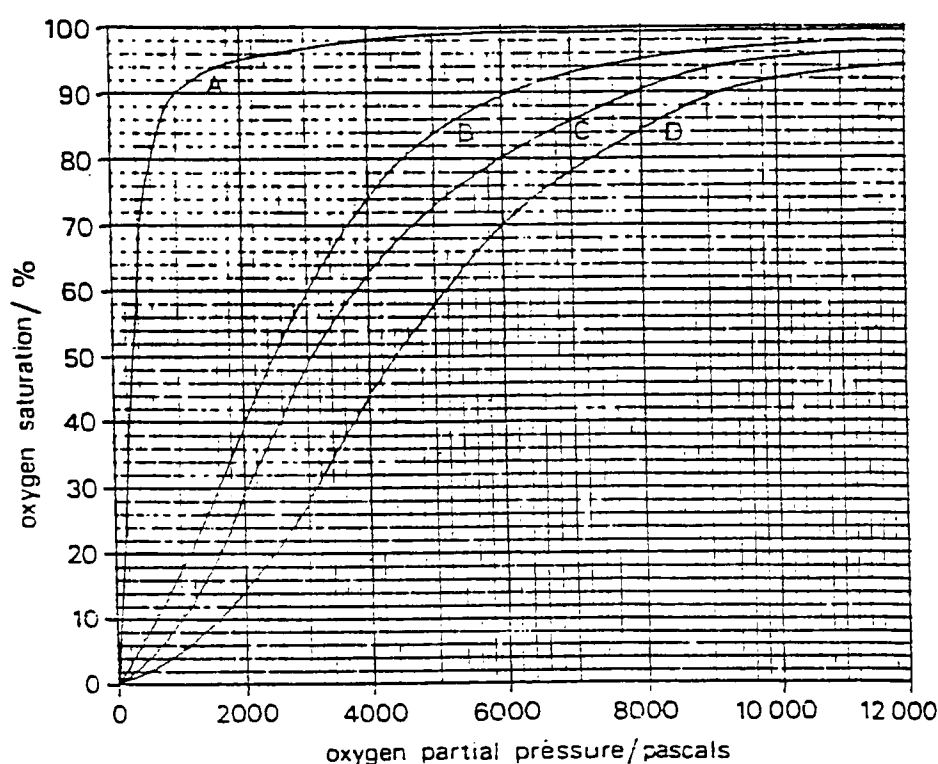
KEY

A = myoglobin in muscle

B = haemoglobin at CO₂ partial pressures 2666 Pa (20 mmHg)

C = haemoglobin at CO₂ partial pressures 5332 Pa (40 mmHg)

D = haemoglobin at CO₂ partial pressures 10 664 Pa (80 mmHg)



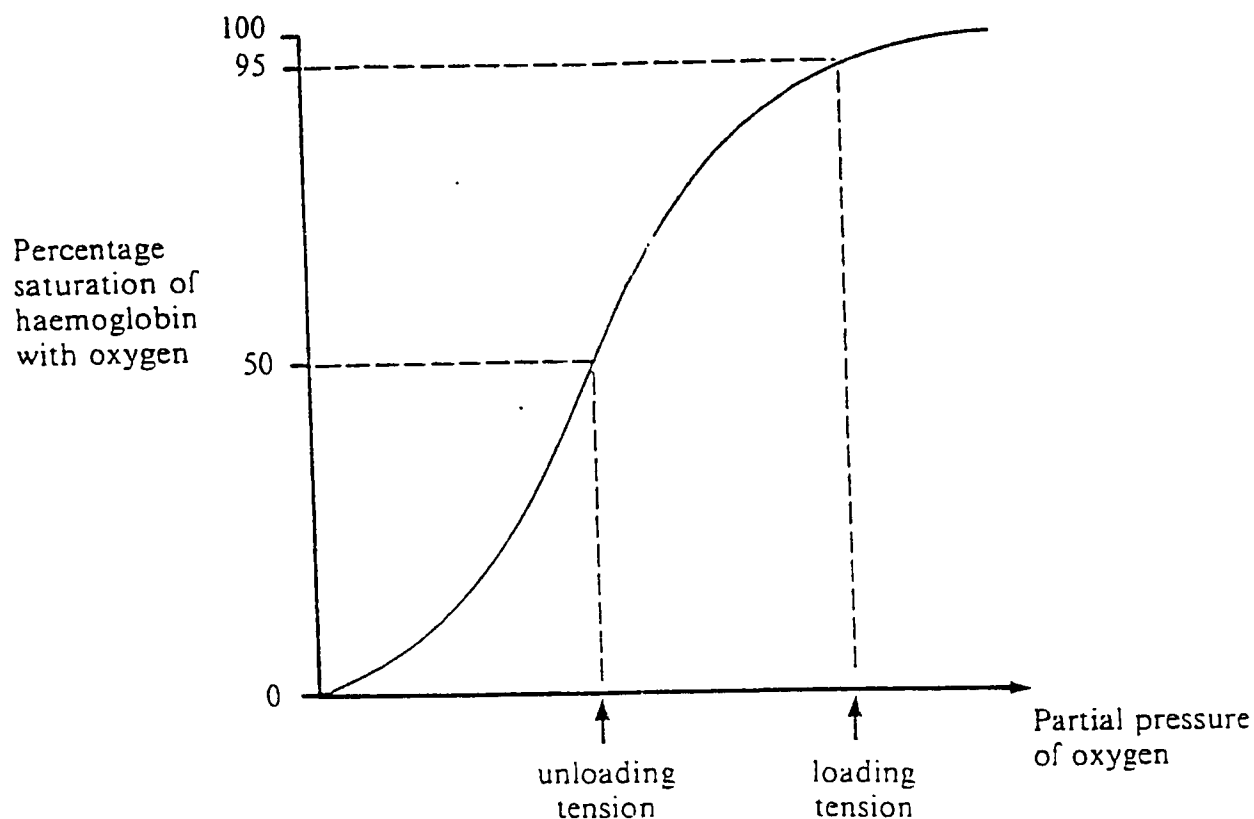
- For curve B, briefly describe the effect of increasing P_{O_2} has on the saturation of the respiratory pigment. [2]
- Over which range of P_{O_2} does the most rapid reaction with hemoglobin occur for (i) Curve B (ii) Curve D. [2]
- Where in the body of a mammal is the P_{CO_2} likely to be as high as in curve D? [1]
- Suggest reasons for the differences in curve A and curve D. [3]
- Name the phenomenon shown by curves B, C and D. [1]
- Curve A is similar to that of the respiratory pigment of an aquatic worm which burrows in mud.
 - Name one such worm.
 - Explain how this curve indicates the worms adaptation to its environment. [3]

John

Lesson six - questions on the oxygen dissociation curve and Bohr effect

Total for this question: 6 marks

The graph shows an oxygen dissociation curve for human haemoglobin.



The loading tension is the partial pressure at which the haemoglobin is 95% saturated with oxygen. The unloading tension is the partial pressure at which the haemoglobin is 50% saturated.

- (a) (i) What would be the effect on the unloading tension of an increase in the partial pressure of carbon dioxide? (1 mark)

.....

- (ii) Explain how this may be of value in supplying tissues with oxygen. (2 marks)

.....

- (b) The prairie dog is a small mammal that spends much of its life in an extensive system of burrows where the air may have a low partial pressure of oxygen.

- (i) Sketch a curve on the graph which would represent an oxygen dissociation curve for prairie dog haemoglobin. (1 mark)

- (ii) Explain why you have drawn the curve in this position. (2 marks)

.....

John

Notes taken during lesson six from OHT.

The role of Haemoglobin and hydrogencarbonates in the carriage of respiratory gases and the control of pH.

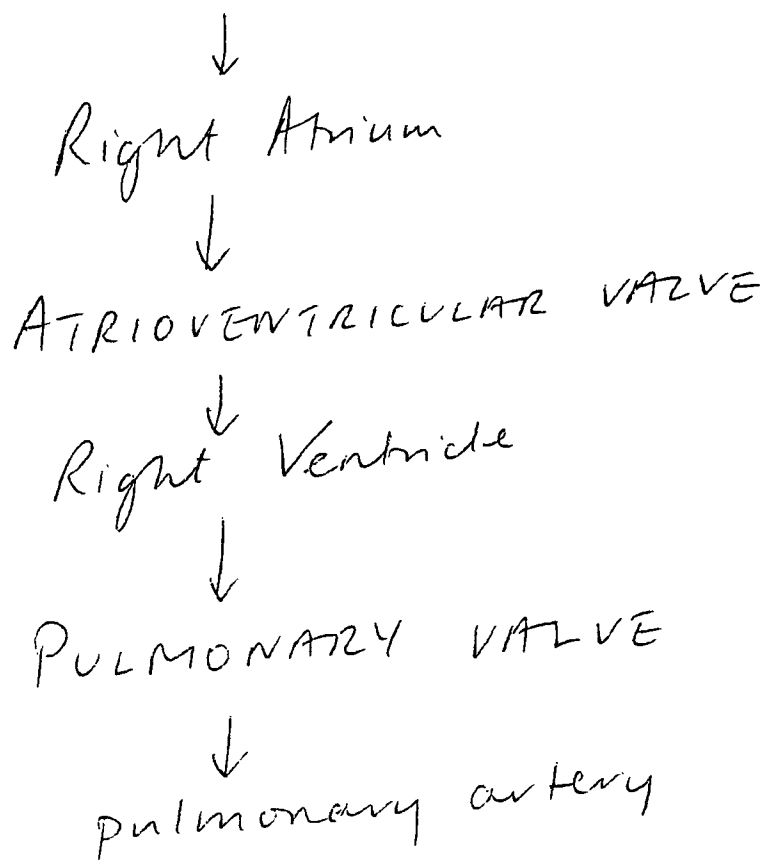
John

Notes taken during lesson seven from OHT.

3.10 The Heart

- The function of the heart is to pump blood around the body
- The heart undergoes contraction (SYSTOLE) and relaxation (DIASTOLE)

• Blood from V.C.



John

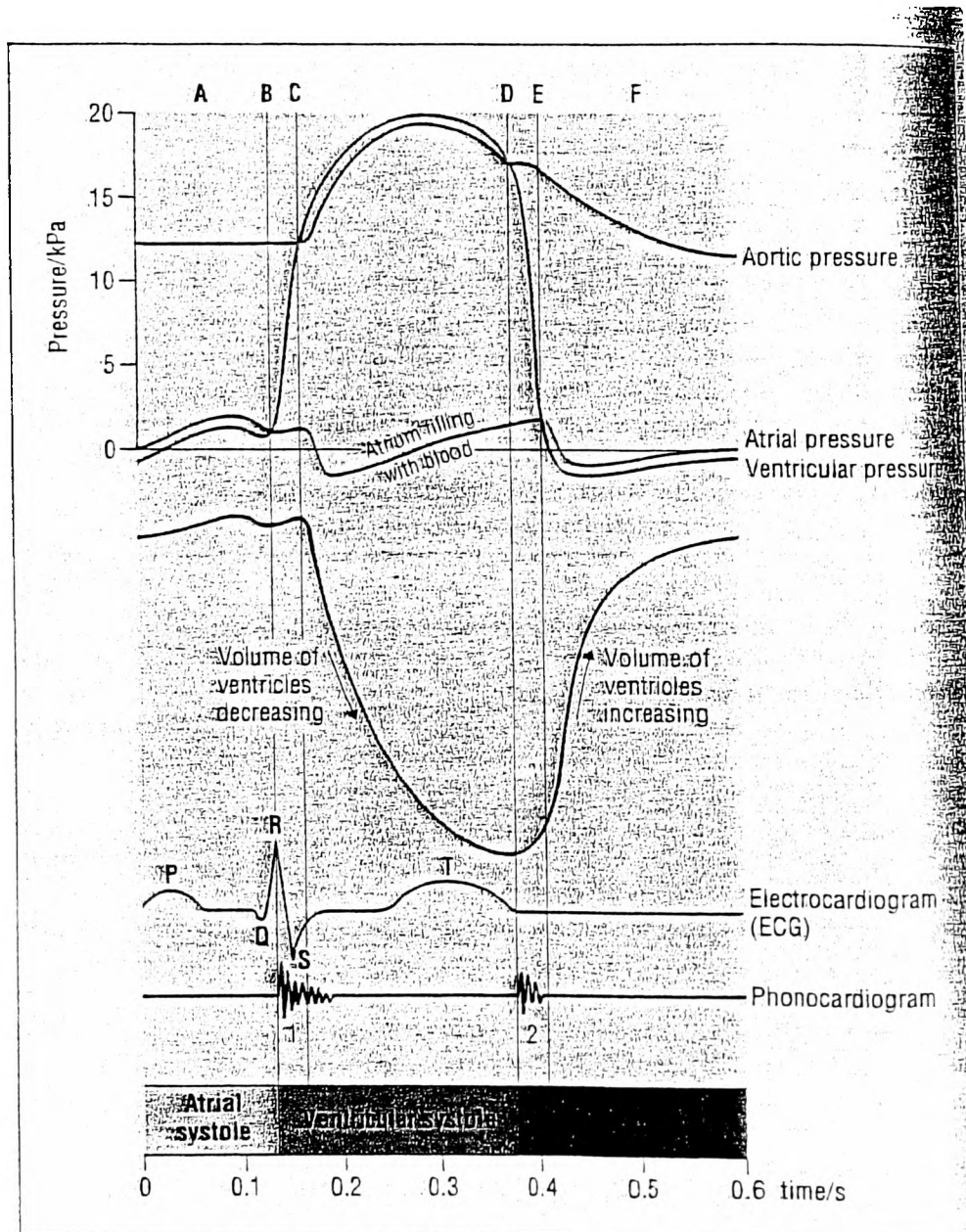
Lesson seven - diagram of the pressure and volume changes and associated valve movements during a cardiac cycle.

Figure 19.12 Graphs illustrating the pressure and volume changes that occur during the mammalian cardiac cycle (dog). Pressure changes were measured in the left atrium and ventricle, and the aorta. Volume changes were measured for both ventricles. The electrical activity in the heart wall (electrocardiogram) and heart sounds (phonocardiogram) as recorded in a human subject are also shown. The actions at different points on the graphs are as follows:

- A** Atrium contracting: blood flows into ventricle.
- B** Ventricle starts to contract: ventricular pressure exceeds atrial pressure so atrioventricular valve closes.
- C** Ventricular pressure exceeds aortic pressure, forcing aortic valve open: blood therefore flows from ventricle into aorta, and ventricular volume falls.
- D** Ventricular pressure falls below aortic pressure resulting in closure of aortic valve.
- E** Ventricular pressure falls below atrial pressure so blood flows from atrium to ventricle; ventricular volume rises rapidly.
- F** Atrium continuing to fill with blood from pulmonary vein: atrial pressure exceeds ventricular pressure so blood flows from atrium to ventricle.

Electrocardiogram (ECG): P wave corresponds to wave of excitation spreading over atrium; QRS and T waves correspond to wave of excitation spreading over ventricle.

Phonocardiogram: the first and second heart sounds (labelled 1 and 2 in the diagram) are due to sudden closure of atrioventricular and aortic valves respectively.



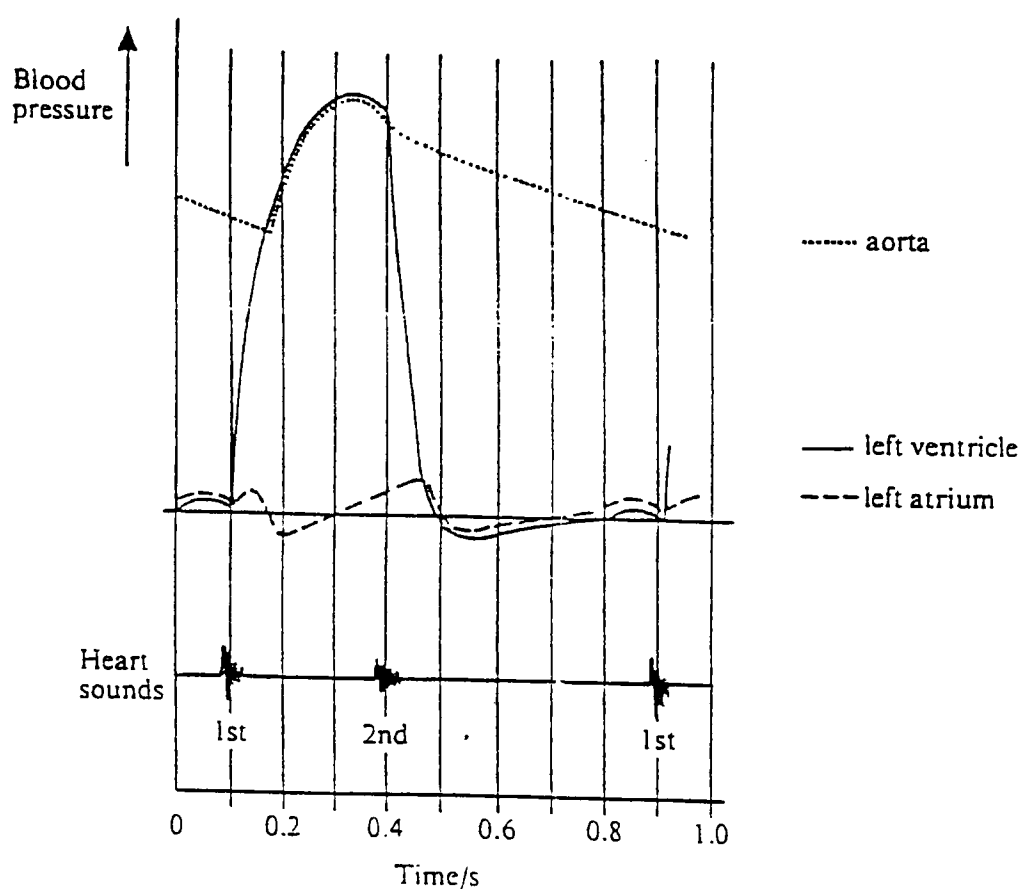
John

Lesson seven - past paper examination question concerning pressure and volume changes and associated valve movements during a cardiac cycle.

9

9. (5 marks)

The diagram shows some of the changes that take place during a cardiac cycle.



(a) Calculate the heart rate in beats per minute.

..... 1 mark

(b) The heart sounds are associated with the operation of the heart valves.

(i) What causes the first heart sound?

.....

(ii) Give the evidence from the diagram that supports your answer.

.....

.....

..... 3 marks

(c) Explain how a higher blood pressure is produced in the aorta than in the pulmonary artery.

.....

..... 1 mark

John

Notes taken during lesson eight from OHT.

3.11 Immunity

Diseases are caused by the invasion of micro-organisms in the body.

These microorganisms are called PATHOGENS

Pathogens enter the body through openings (nose, mouth etc) and through broken skin.

Once inside, they "feel" on the body, and may release toxins into the bloodstream.

There are 2 levels of defence:

① Preventing entry

- skin, waterproof
 - blood clotting - fibrin forms net to catch platelets
 - coughing and sneezing
 - mucus
 - lysozyme - enzyme kills pathogens
- tears, urine, saliva

John

NOTES taken during lesson eight from OHT.

② Once inside ...

There are various different mechanisms to deal with the pathogens. These can be split into 2 main groups:

- i) Natural immunity
- ii) Acquired immunity

i) Natural immunity

Phagocytosis (cells that eat the pathogens)

Read page 415

State the function of Neutrophils and Macrophages

Why do skin infections swell and go red?

What are the limitations?

ii) Acquired immunity.

This is "specific" (different cells attack different types of micro-organisms)

The cells have a "memory"

- i) B lymphocytes
- ii) T lymphocytes.

John

Notes taken during lesson eight from OHT

Any substance that initiates an acquired immune response is an ANTIGEN (eg on bacteria, pollen, toxins).

When a B lymphocyte encounters an antigen it produces an ANTIBODY.

An antibody is a protein molecule called an immunoglobulin.

John

Notes taken during lesson note from OHIT.

During embryonic development B lymphocyte cells are formed in the bone marrow. At birth there are 10 million clones that can recognise any antigen that may invade the body.

How do they work?

On the lymphocyte surface are found the antibodies which it can produce. The antigen combines with one of the receptors and activates the cell to produce antibodies in the blood or lymph. This type of B cell is called a Plasma cell.

There are other types called Memory cells which are able to remember the antigen for a future invasion.

This type of action is called Humoral Immunity (referring to blood and lymph circulation)

John

Notes taken during lesson nine from OHT.

② T lymphocytes

These also originate in bone marrow - but pass through the thymus gland during development. They do not PRODUCE ANTIBODIES.

They produce cellular responses as opposed to a Humoral response.

3 main types of T lymphocyte.

- T helper cells (help B lymphocytes work)
- T suppressor cells (stop B lymphocytes working)
- T killer cells (attack foreign cells)

John

Lesson nine - monoclonal antibodies

handout

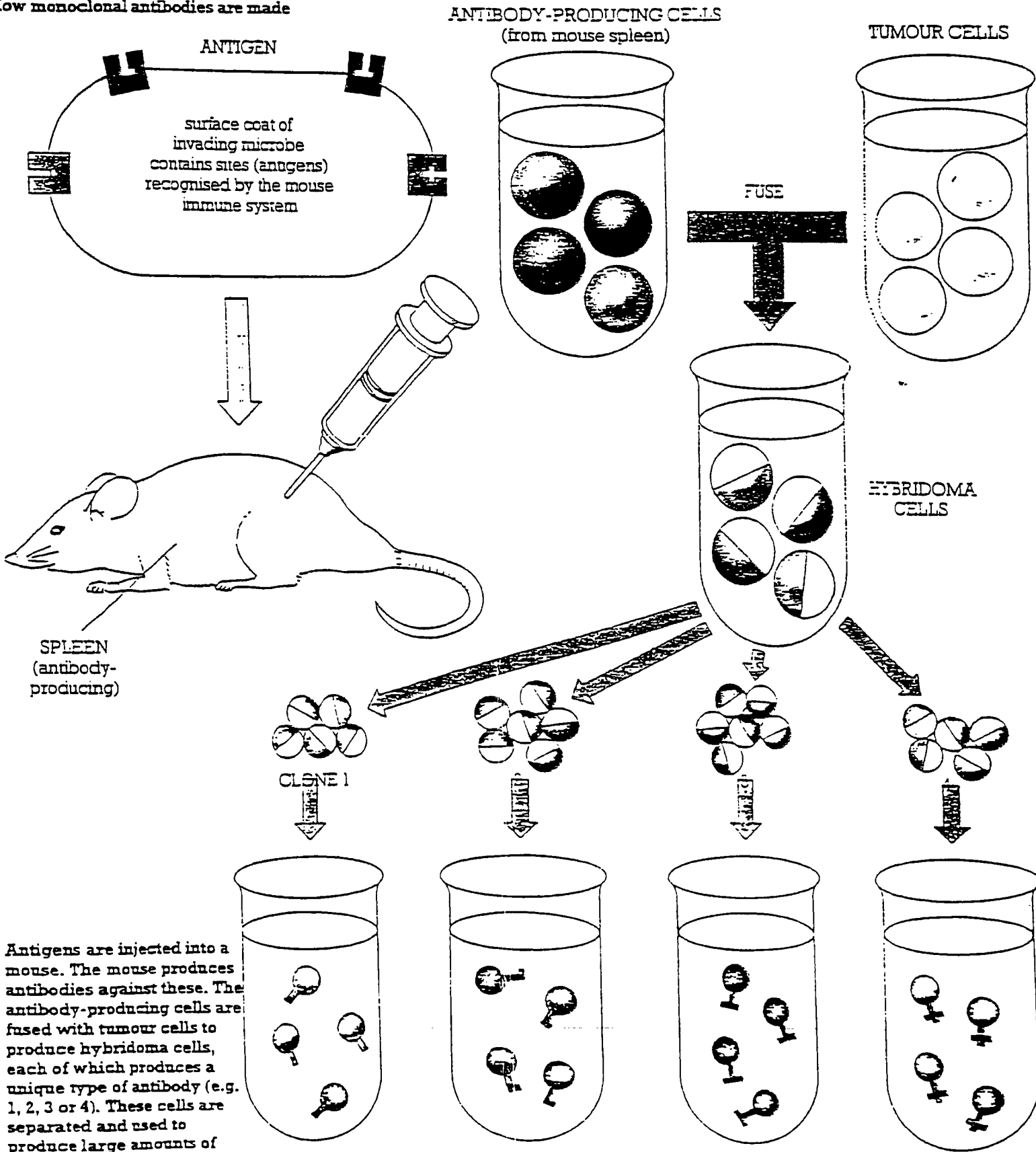
It has long been the dream of scientists and doctors to produce a drug that could kill microbes without affecting any other cells of the body. So far no such drug can quite do that, and even the best drugs occasionally produce harmful side-effects. In 1975 scientists working in Cambridge took a step nearer the dream when they discovered how to produce substances called monoclonal antibodies.

made by special cells and are proteins with the amazing property of recognising 'foreign' substances, either in the blood stream or in tissues. This means that they are useful for helping doctors to detect and treat many types of disease, and will eventually help to treat cancers in man. The special cells which make monoclonal antibodies are called hybridomas and are made in test tubes by joining a special rapidly dividing cancer cell with an 'educated' normal cell which knows

these hybridomas can therefore divide and multiply vigorously, producing large amounts of identical monoclonal antibody molecules

Diagnosis
Monoclonal antibodies can be used in the development and manufacture of new vaccines. They are made to recognise the virus protein, which the body's own defence mechanism detects, and can then be used to purify large amounts of this protein. This is

How monoclonal antibodies are made



Antigens are injected into a mouse. The mouse produces antibodies against these. The antibody-producing cells are fused with tumour cells to produce hybridoma cells, each of which produces a unique type of antibody (e.g. 1, 2, 3 or 4). These cells are separated and used to produce large amounts of each antibody.

MONOCLONAL ANTIBODIES

John

Lesson nine - organ transplants
article and questions.

Defence against disease

Organ transplantation

Sir Roy Calne, a leading transplant surgeon, explains some of the problems and achievements in transplantation surgery

Since the first transplant operations were carried out in the 1960s, organ grafting has emerged from being a perilous final attempt at saving life to become the standard treatment for many major diseases of vital organs. More than 200 000 organ grafts have been performed worldwide, and results continue to improve.

The problem of rejection

The greatest problem facing the transplant surgeon is rejection of the transplanted organ. Unless special treatment is given to suppress the patient's immune system, a graft between members of the same species is rejected after 5 to 14 days. The body destroys the foreign tissue as it would a bacterium or virus. The speed of rejection depends on how closely matched the tissues of the donor and recipient are. Thus, grafts between identical twins are accepted permanently, since identical twins have the same genes and are perfectly matched. In grafts between siblings, there is a one in four chance that the main tissue types will match each other. In grafts between unrelated people, the chance of the tissues matching is remote.

The chief factors that determine rejection are the ABO blood groups and the tissue typing of the white blood cells. However, even if these are matched, rejection may still occur because there are minor tissue groups that we cannot yet identify. Therefore, in all cases except identical twins, drug treatment to prevent rejection is necessary after a transplant operation. The drugs prevent the recipient's lymphocytes attacking the graft. Their dosage needs to be carefully watched: too low a dose results in the graft being

rejected; too high a dose suppresses the immune system to such an extent that the patient readily succumbs to infection.

The surgical procedure

We can now transplant all vital organs except the brain – and even if it were possible to transplant the brain so that it functioned, the outcome would be a body grafted to the brain rather than the other way around.

Of course, the grafted organ must continue to function properly after the transplantation operation. It is therefore necessary to join up the arteries and veins of the donor organ to those of the recipient, and if the organ has a duct this must also be dealt with. Speed is essential, for the circulation to the organ must be re-established before the cells die.

Donors

For paired organs such as the kidneys, a volunteer – usually a close relative – can be a donor, provided the blood group and tissue match are satisfactory. The donor can manage with the one remaining organ. In the same way, a lobe of the liver can be removed for grafting without jeopardising the donor's health. It is even possible for a donor who happens to be receiving a combined heart-lung transplant to give his or her own heart to another patient – the so-called 'domino' operation.

However, most human transplants are taken from recently dead donors. Organs from patients dying of cancer or an infectious disease cannot be used for fear of transmitting the disease to the recipient. In practice, most donors have died from brain injury caused by trauma or haemorrhage following a ruptured brain artery. In such patients the heart can be kept beating only by ventilating the lungs with a machine. When tests make it absolutely certain that the donor's brain is irreversibly damaged, the

ventilator should be stopped since to continue resuscitation in these circumstances would be fruitless and very distressing for the relatives. If permission has been given, organs may then be removed for transplantation.

Which organs are transplanted?

Vital organs commonly grafted to replace those that have become diseased are the following:

- **Kidney.** This was the first organ to be transplanted. The donor kidney is usually placed on one side of the lower abdomen. The current success rate is encouragingly high: in cases where the donor and recipient are unrelated 80 per cent of transplanted kidneys are functioning after one year; and in cases where the kidney comes from a matched sibling, the figure is over 90 per cent. The longest survivor with graft function is over 25 years. Should a kidney graft fail, the patient can be kept in a reasonable state of health by repeated dialysis until another kidney becomes available for transplantation. Some patients have had as many as five or six kidney transplants.
- **Heart and lungs.** These are grafted in their normal positions after removal of the diseased organs. They may be grafted together or separately. Heart transplants are more successful than lung transplants since the latter are more prone to infection and rejection. Approximately 70 per cent of heart grafts, and 60 per cent of lung grafts, are functioning after one year whether they are grafted separately or together.
- **Liver.** This is the most difficult organ to transplant because of its multiple connections and complex blood supply. Moreover, in liver

John

Lesson nine - organ transplants article and questions

Defence against disease

disease, blood clotting is impaired and serious bleeding can occur, making surgery difficult. However, the procedure has improved and 70 per cent of liver grafts are now functioning after one year. The longest survivor had the operation 23 years ago.

Suppressing the immune system

In principle, all recipients of organ grafts receive the same drugs to inhibit rejection, whatever the transplanted organ. Each drug has particular advantages and disadvantages. Their combined action is to inhibit the production or action of lymphocytes.

Patients generally receive small doses of azathioprine, corticosteroids and cyclosporin. This 'triple therapy' combines the effectiveness of all three drugs but avoids most of the more serious side effects. If rejection starts to occur, extra doses of corticosteroids or anti-lymphocyte proteins usually reverse the rejection.

For the majority of patients who respond well, their quality of life can be virtually normal. They can participate in active sports and have children, but they need to continue taking immunosuppressive drugs in low doses indefinitely. As a result, they are more susceptible to infection and cancer than normal people are.

The future

Most transplant failures are caused by the graft being rejected, or from infection resulting from excessive immunosuppression. No doubt safer and more effective drugs will be developed. As the results of organ grafting within the human species improve, efforts may be made to use organs taken from other animal species. This will introduce new moral dilemmas.

Another development will be the grafting of non-vital organs. Already, more than 2000 pancreas grafts have been performed to combat diabetes,



Illustration 1 A human liver being transported before being used in a transplant operation.

but there is controversy over whether this treatment is better than insulin-injection. The first successful bowel grafts have been reported. Grafts of testes and ovaries will raise new ethical debates!

But whatever the ethical problems, organ grafting is now an established and preferred treatment for many previously fatal diseases and its continued development will form one of the main branches of surgery.

- 1 What do you think Sir Roy Calne means when he says that a brain transplant would be 'a body grafted to the brain rather than the other way round'?
- 2 Consider the ethical issues that might arise from:
 - (a) transplanting organs from humans to other animals,
 - (b) transplanting ovaries and testes from one human to another.



Illustration 2 Four years after receiving a new heart, Alex Walker completes an eight-mile post round twice a day and trains at his local athletics club three times a week.

John

Lesson nine - questions re blood groups

Explain i) ABO system

ii) Rhesus system

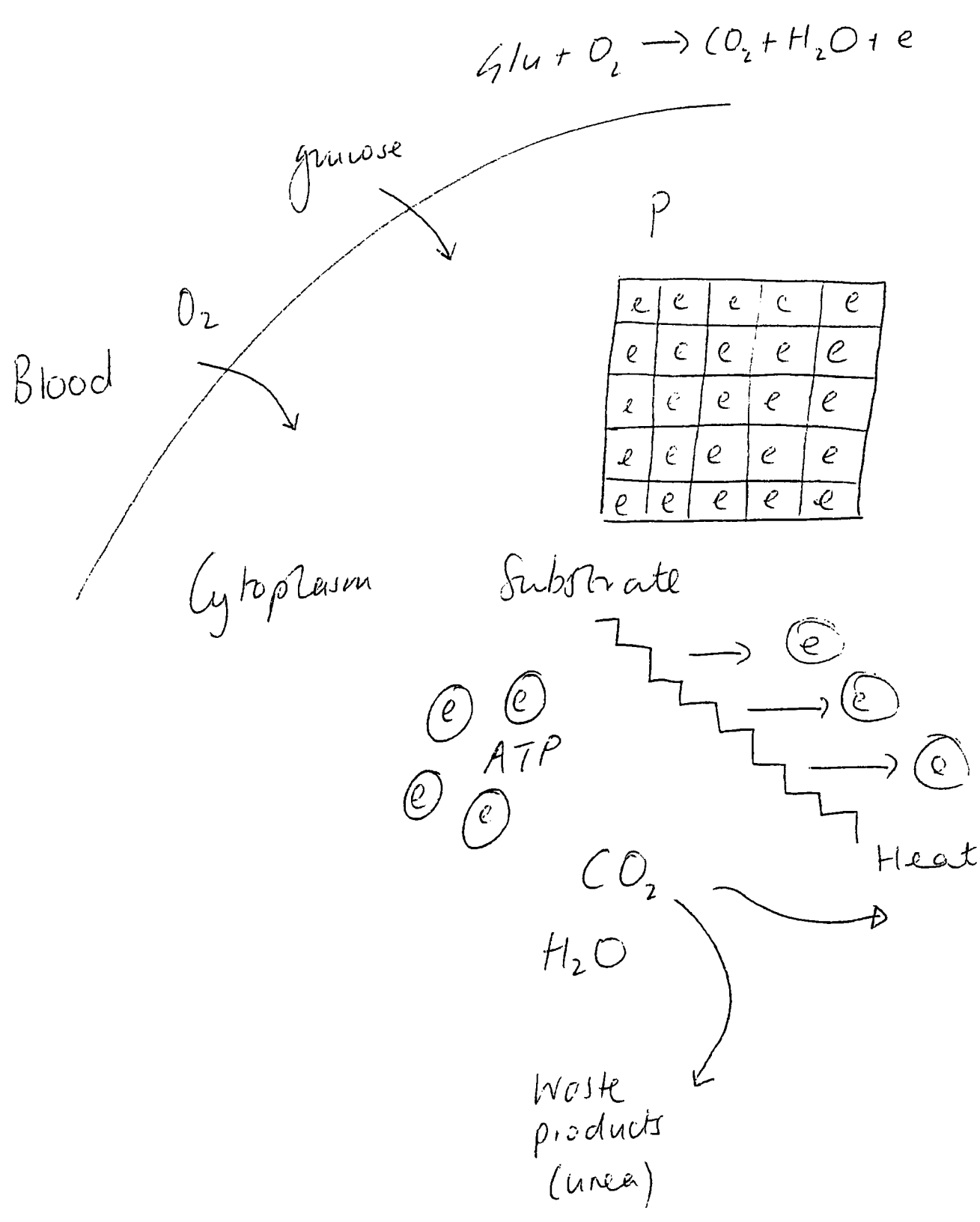
iii) Haemolytic disease of the newborn

Appendix I

Curriculum materials and copies of all notes put on the board/OHT during Catherine’s unit-of-work

Catherine

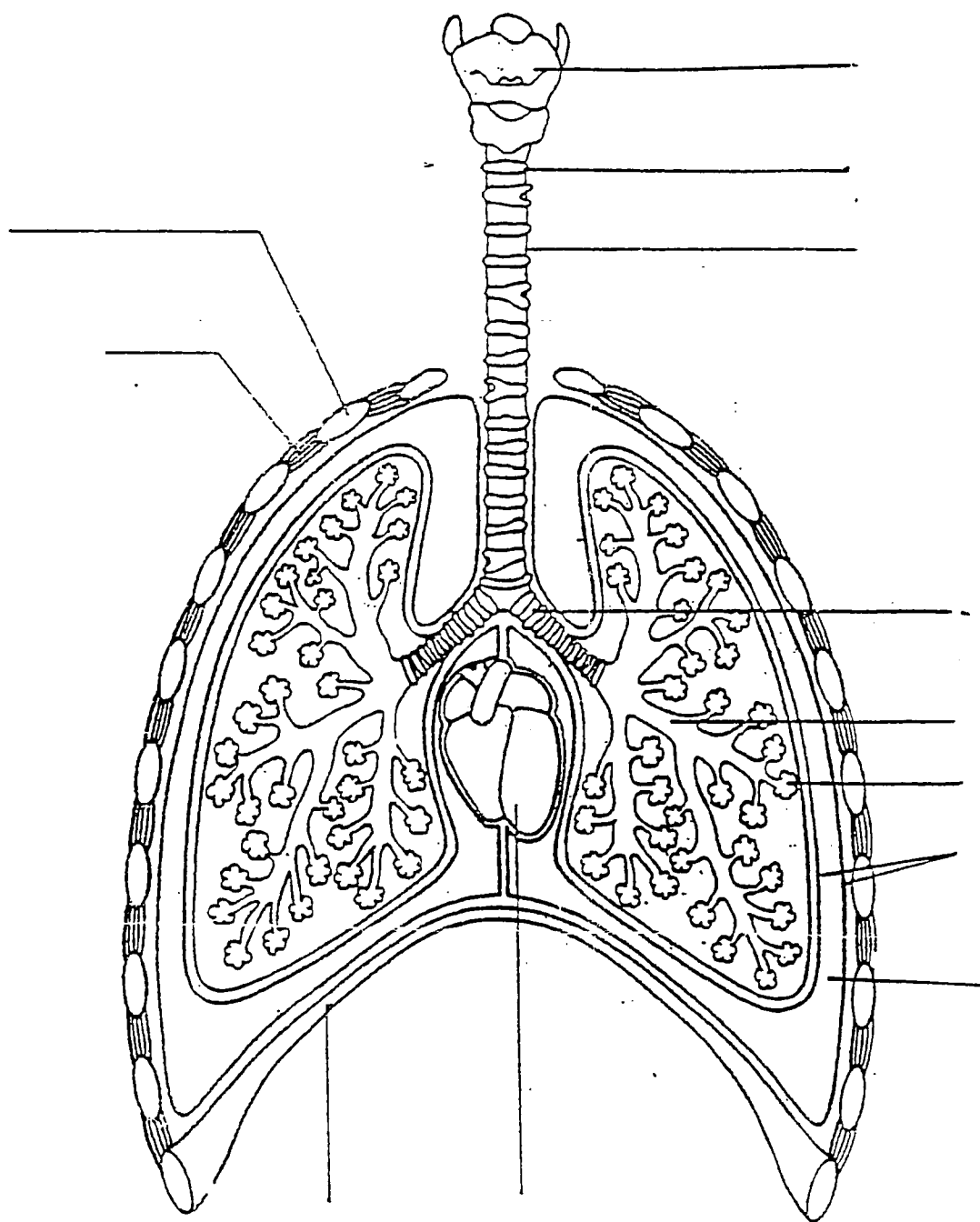
Notes taken during lesson one from board.



Catherine

Lesson one - diagram of a section through a thorax for labelling

Section through the thorax



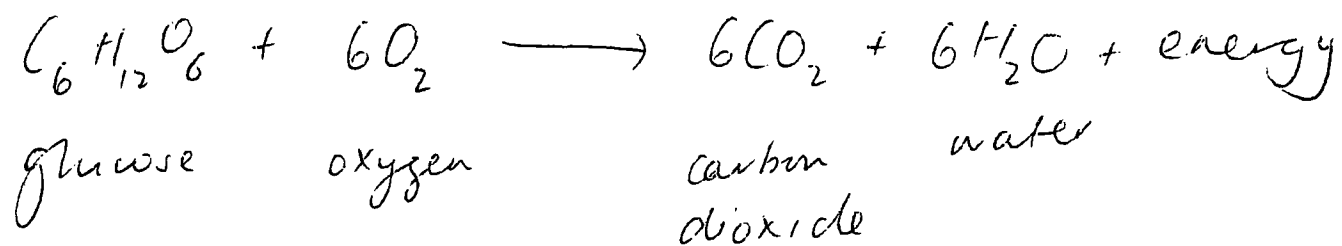
Questions

- 1- What are the respiratory organs of man called?
- 2 What is the diaphragm?
- 3 What happens to the air as it goes through the nose?
- 4 Explain what happens to the dust and dirt in the air breathed in through the nose.
- 5 Why are there rings of cartilage round the trachea?

Catherine

Notes taken during lesson one from board.

Overall reaction of aerobic respiration:



Stage ①

Glycolysis - ^{cytoplasm} anaerobic
generates ATP but also
uses ATP.

enters
cell

Glucose + NAD + 2 ATP.

6C

nicotine
adenine
dinucleotide
(hydrogen acceptor)

adenosine
triphosphate

→ 2 pyruvate
+ 2 ATP (net yield)
+ 2 NADH₂

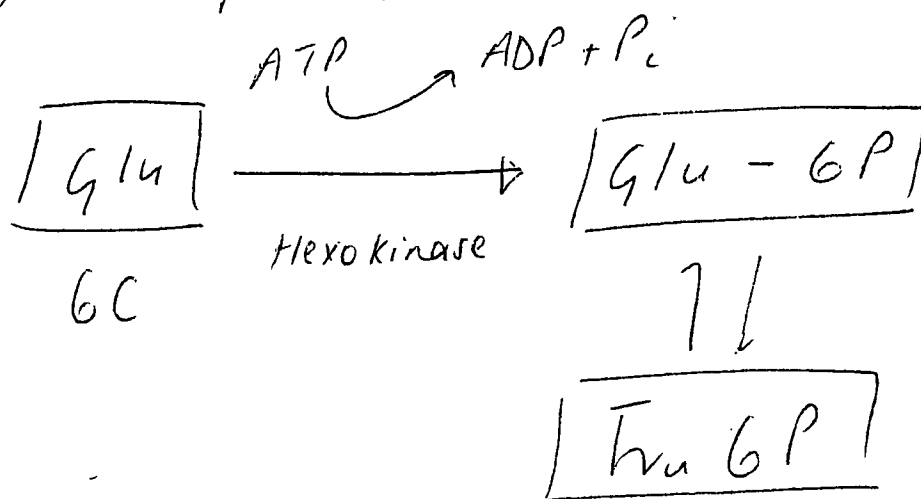
$\begin{array}{c} \sim \\ A \sim P \\ \backslash P \end{array}$ ATP

$\begin{array}{c} P \\ \sim \\ A \sim P \\ \backslash P \end{array}$
(~ high energy, - low energy)
 $\begin{array}{c} \sim \\ A \sim P \\ \sim P \end{array}$ ADP

Catherine

Notes taken during lesson one from board.

① Phosphorylation



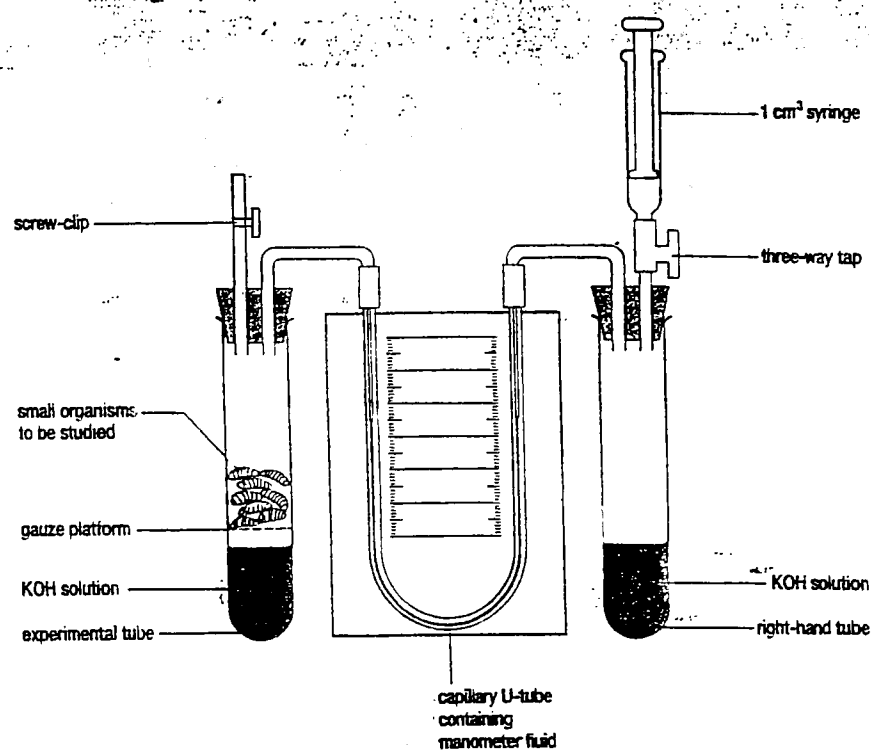
Cartmear

Lesson Two - respirometer practical

Measuring respiratory quotients

This exercise involves interpreting the way in which an item of experimental apparatus works.

The RQ of small organisms, such as woodlice or germinating seeds, can be determined using the apparatus in Fig 6.15. This apparatus actually allows us to measure changes in pressure inside the boiling tubes. To understand how it works you need to know that potassium hydroxide absorbs carbon dioxide.

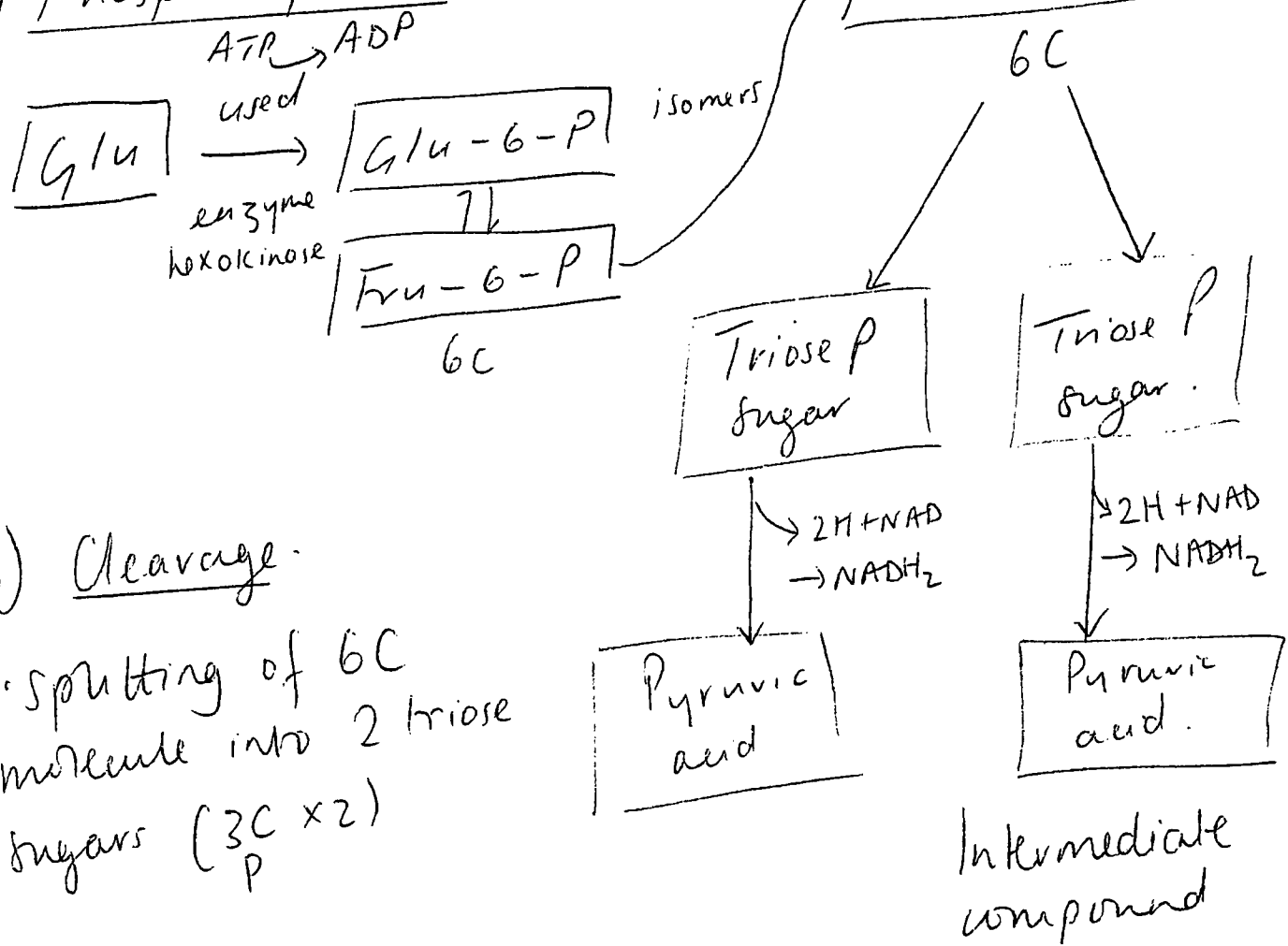


Catherine

Notes taken during lesson two from board.

Stage 1 GLYCOLYSIS

a) Phosphorylation.



b) Clearance.

• splitting of 6C molecule into 2 triose sugars (3C x 2)

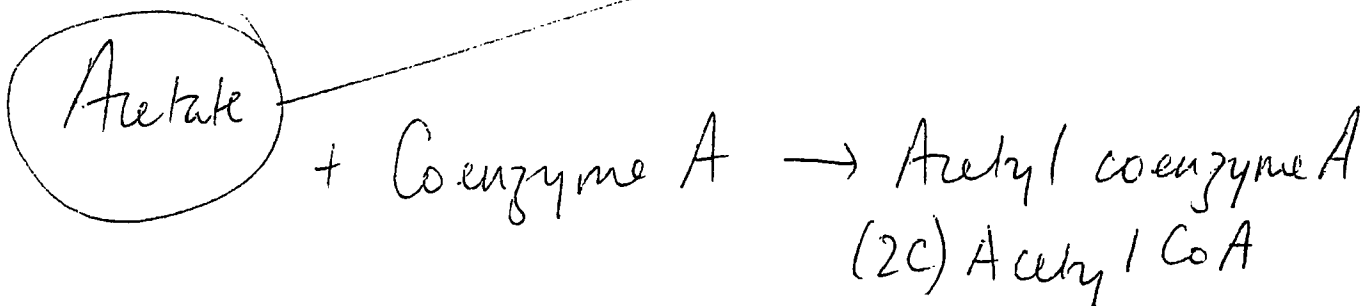
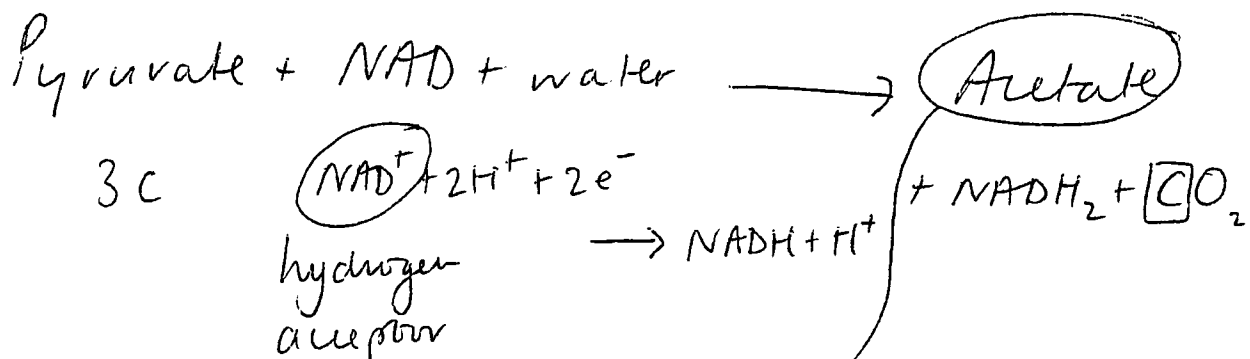
c) Oxidation

- by removal of H_2
- electron acceptor H^+ - Nicotine adenine dinucleotide.

Catherine

Notes taken during lesson three from board

② The Link Reaction (matrix of mitochondria)
- location -

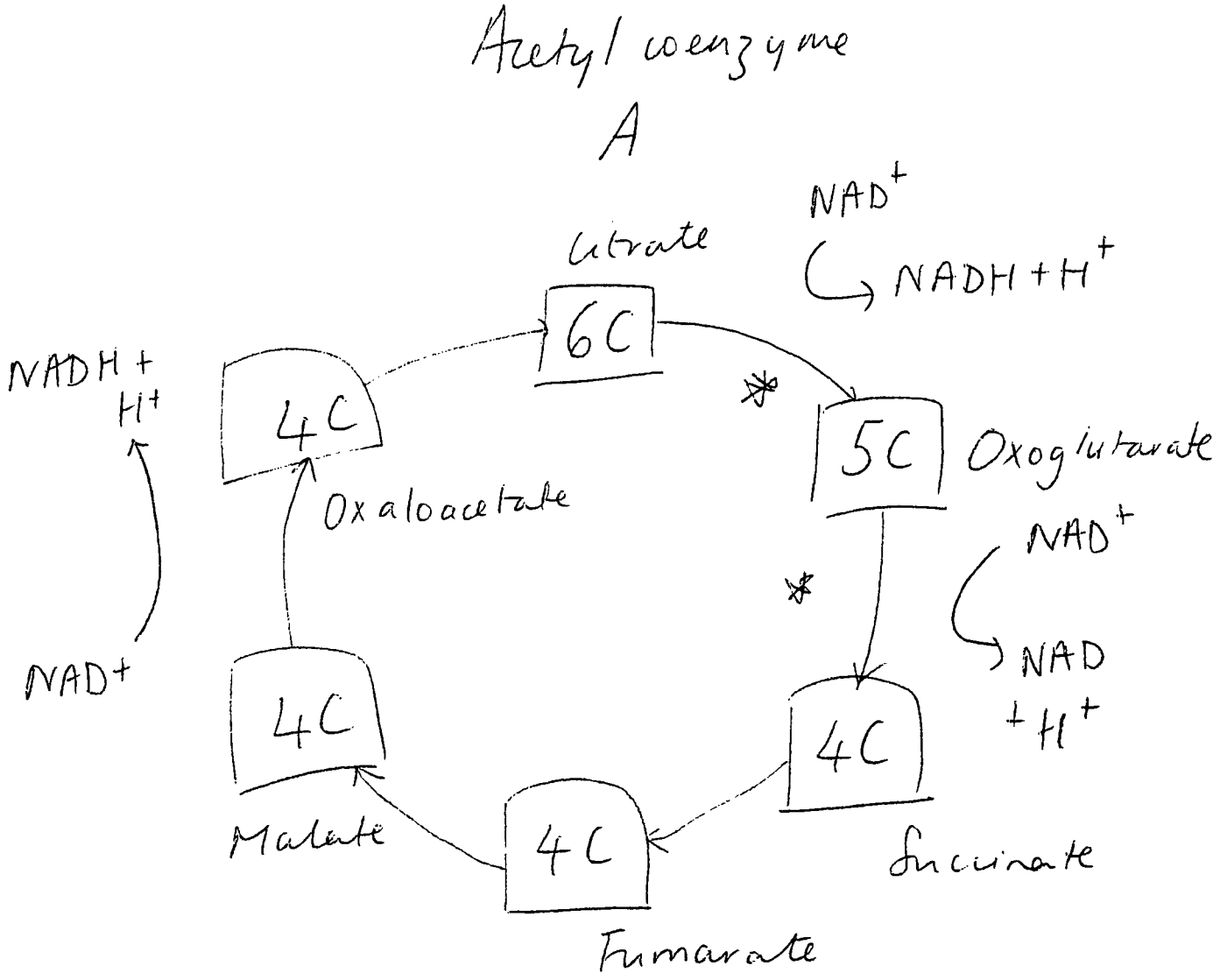


Step 3 - mitochondrial matrix - location
- aerobic process

KREBS CYCLE Tricarboxylic acid cycle $\equiv$ TCA cycle

Catherine

Lesson three - Krebs Cycle 01/17



* loss of $C + O_2 \rightarrow CO_2$

Catherine

Lesson three - Krebs Cycle handout

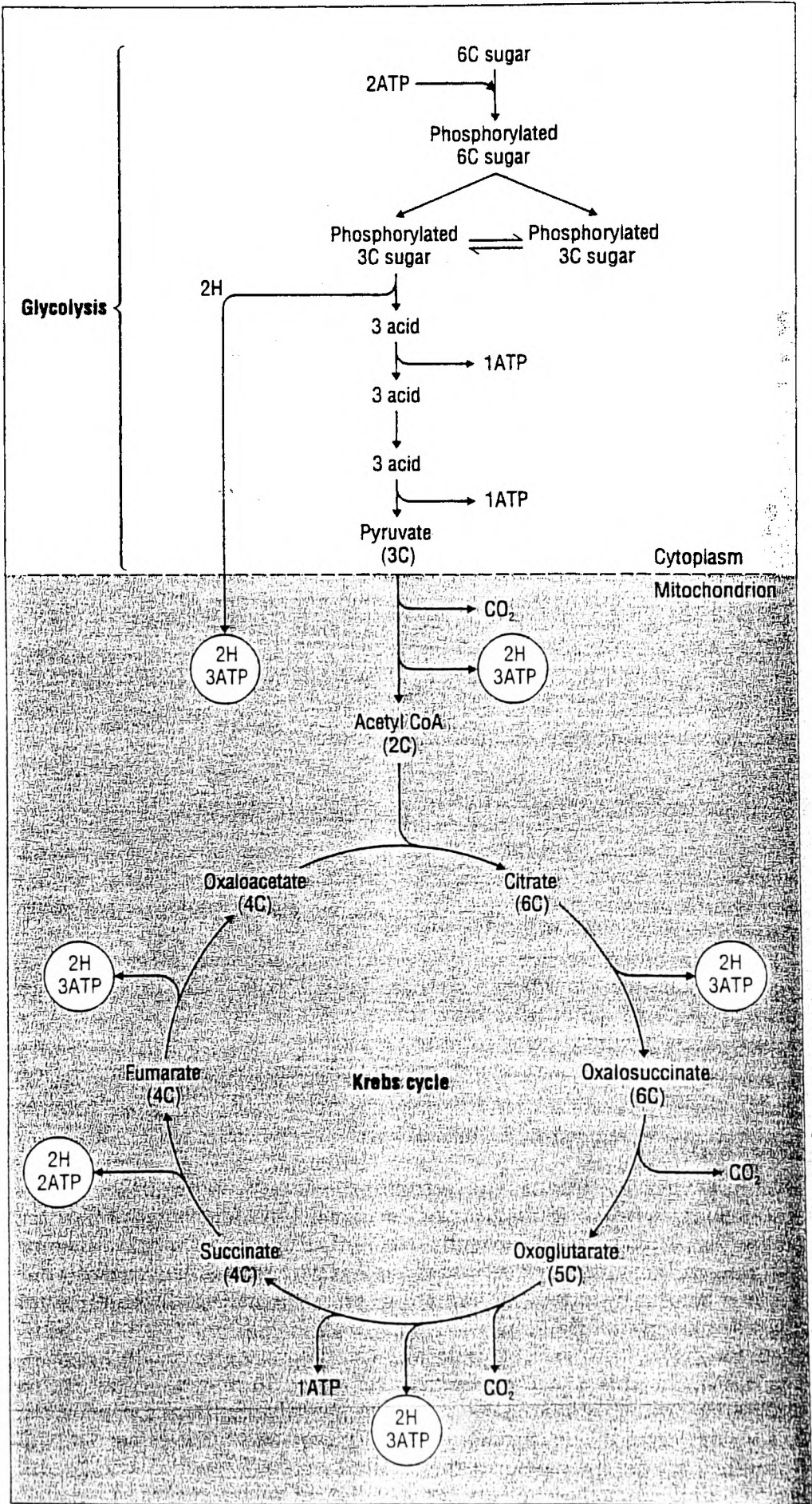
The release of energy

Figure 14.5 The metabolic pathway in which sugar is broken down in respiration. The process starts with phosphorylation of 6-carbon sugar (glucose). In the diagram this is shown happening in one step but in fact it involves several steps. In the first a phosphate group is added to the glucose molecule, resulting in the formation of **glucose 6-phosphate**, so-called because the phosphate group is attached to the glucose molecule at position 6 (see page 126). A second phosphate group is then attached to the sugar which is subsequently split into two molecules of 3-carbon sugar. These are in equilibrium with each other and normally both are converted into pyruvic acid and fed into the Krebs cycle.

The overall function of the pathway is to produce ATP molecules. Energy is transferred to ATP mainly as a result of the removal of pairs of hydrogen atoms from intermediate compounds in the pathway. The diagram shows the stages at which hydrogen atoms are removed, together with the numbers of ATP molecules synthesised. The ATP molecules circled are produced via the hydrogen carrier system which is explained on page 234. Usually three ATP molecules are synthesised every time two hydrogen atoms pass through the carrier system. However, in the conversion of succinate to fumarate only two ATPs are produced because in this case the initial carrier (NAD) is absent.

One of the most important intermediates in the pathway is acetyl CoA because it links glycolysis with the Krebs cycle. Coenzyme A is a complex molecule derived from the vitamin pantothenic acid (see page 149). Its function is to transfer an acetyl group (CH_3CO) from pyruvate to oxaloacetate. In this way two carbon atoms are added to the oxaloacetate with the formation of citrate.

The process outlined here is called **oxidative phosphorylation**. It is oxidative in the sense that hydrogen atoms are removed from certain compounds and combined with oxygen. It is phosphorylation in that phosphate groups are added to ADP to give ATP. The process also involves **decarboxylation**, the removal of carboxyl groups with the formation of carbon dioxide.



Catherine

Lesson four - assignment on RQ's

ANALYSIS

P.T.O.
for instructions

Measuring respiratory quotients

This exercise involves interpreting the way in which an item of experimental apparatus works.

The RQ of small organisms, such as woodlice or germinating seeds, can be determined using the apparatus in Fig 6.15. This apparatus actually allows us to measure changes in pressure inside the boiling tubes. To understand how it works you need to know that potassium hydroxide absorbs carbon dioxide.

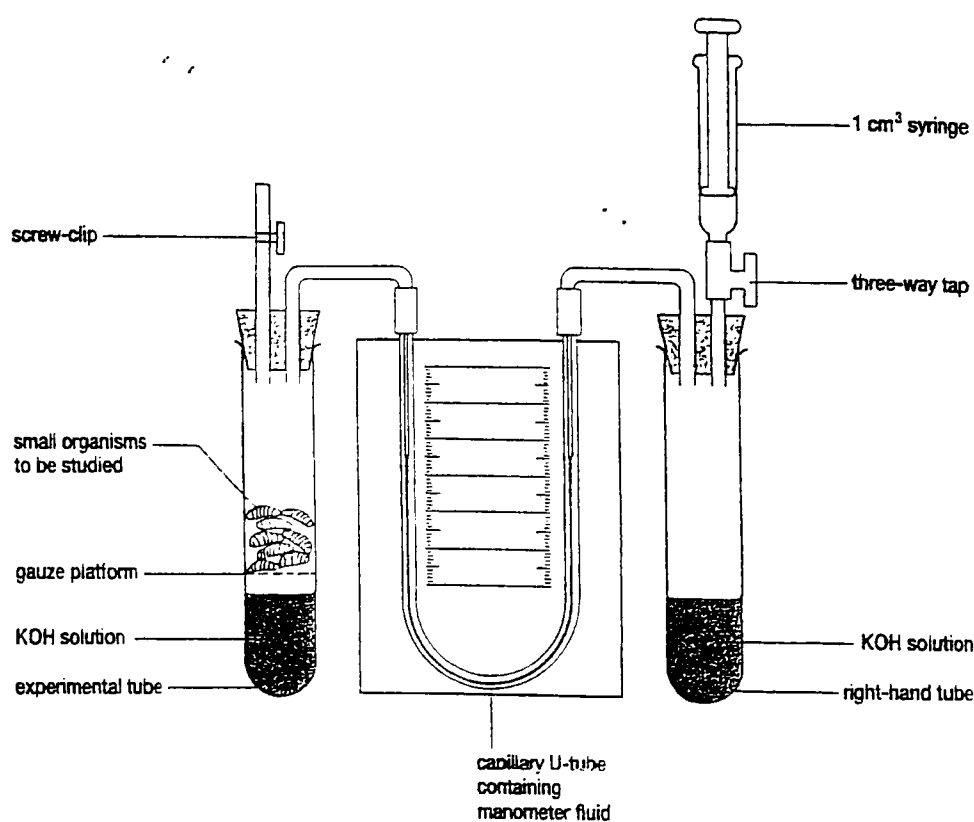


Fig 6.15 A respirometer: this apparatus is used to measure oxygen consumption, from which the respiratory quotient (RQ) is calculated.

- What will happen to the number of oxygen molecules in the experimental tube as the organisms respire?
- What will happen to the carbon dioxide molecules produced by respiration?
- As a result, what will happen to the total number of gas molecules in the left-hand tube as the organisms respire?
- How will this affect the gas pressure in the left-hand tube? (Look back at Fig 2.7 if you are not sure about this.)
- As a result of this pressure change, which way will the fluid in the manometer be pushed?
- If you knew the internal diameter of the manometer tube, how would you calculate the volume of oxygen consumed by the organisms in the respirometer?
- Why are the tubes (containing KOH solution) kept in the waterbath throughout the investigation?
- What is the purpose of the right-hand tube?
- In a second experiment, the potassium hydroxide was replaced with water. How would this enable you to determine the amount of carbon dioxide produced by the respiration of the organisms in the respirometer?

Calvin

Lesson four - assignment on RQ's

ANALYSIS continued

- (j) The results of an experiment using this apparatus are given in Table 6.3. Use this information to calculate the RQ of the respiring organisms. What does this value suggest about the nature of their respiratory substrates?
- (k) Suggest possible sources of error in this experiment.

Table 6.3 Results of experiment using respirometer

Solution in tube	Direction of movement of fluid in left-hand arm of manometer	Volume change /mm ³ h ⁻¹
potassium hydroxide	upwards	20
water	upwards	2

QUESTION

- 6.4 The equations below show the catabolism of (a) glycerol (b) oleic acid, a fatty acid.
- (a) glycerol: $2C_3H_8O_3 + 7O_2 \rightarrow 6CO_2 + 8H_2O$
- (b) oleic acid: $2C_{18}H_{34}O_2 + 51O_2 \rightarrow 36CO_2 + 34H_2O$
- What is the RQ for each of these reactions?

Table 6.2 Aerobic RQ values of different respiratory substrates

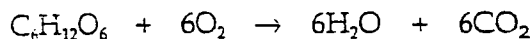
Respiratory substrate	RQ
glucose	1.0
triglycerides	0.7
protein	0.9

The respiratory quotient (RQ)

The ratio of carbon dioxide produced and oxygen consumed per unit time by an organism is known as the respiratory quotient (RQ). As it is a ratio, the RQ has no units.

$$RQ = \frac{\text{volume of carbon dioxide produced}}{\text{volume of oxygen used}} \text{ per unit of time}$$

Look at the simplified equation for the aerobic respiration of glucose:



Six carbon dioxide molecules are produced and six oxygen molecules are consumed. The RQ for this reaction is therefore $6/6 = 1$.



Which tissue in your body would you expect *always* to have an RQ of 1?

The RQ value can be used to tell us something about the substrate which an organism is using for respiration (Table 6.2).

Use the information above on
RESPIRATORY QUOTIENTS (RQ)
to answer the analysis question
over. Hand in at the end

the the

Catherine

Notes taken during lesson four from board

Electron Transport Chain - takes place
on cristae
of
mitochondria

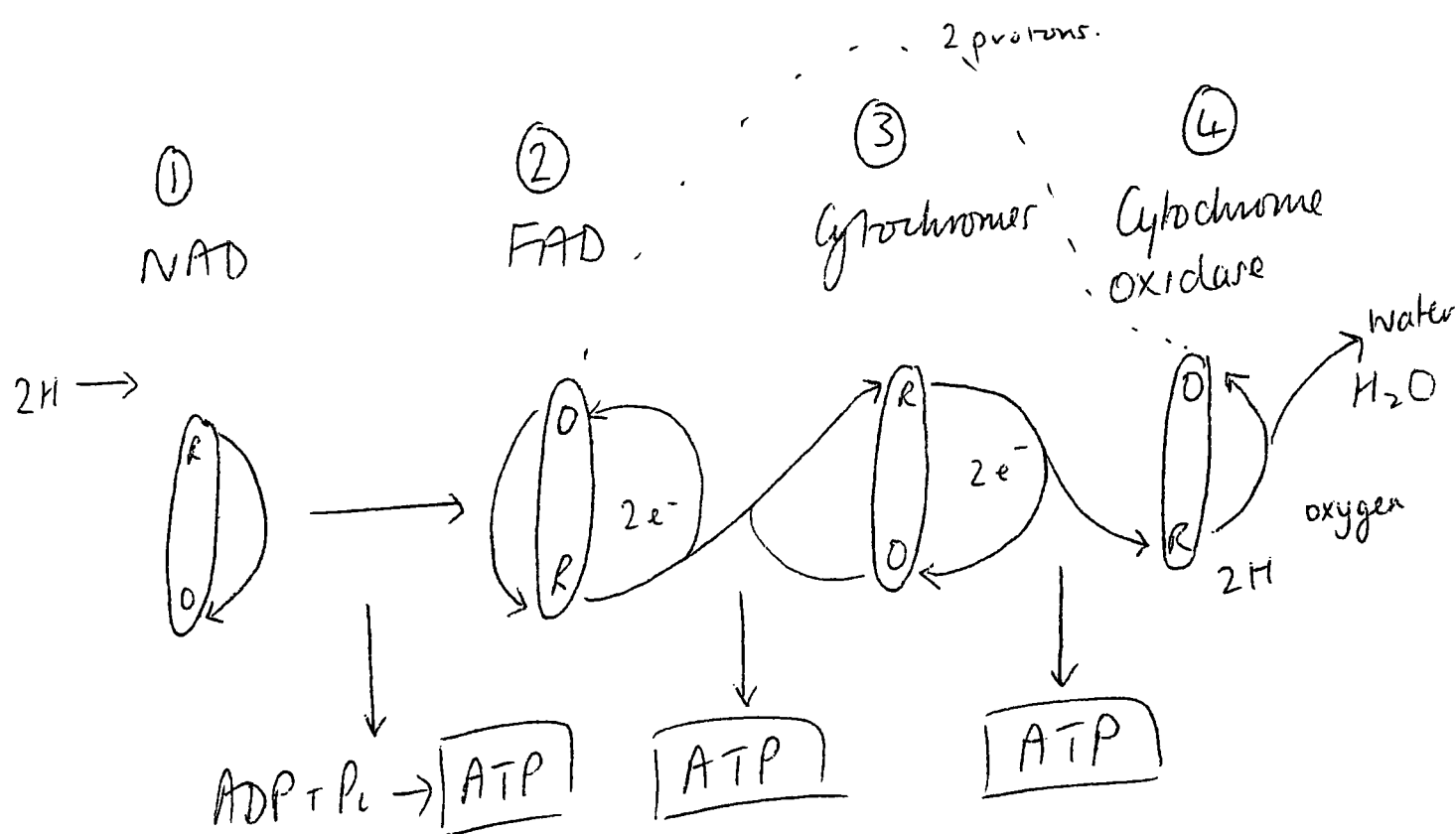
- Purpose - to make energy
(ATP) also hydrogen
carrier system.

Catherine

Notes taken during lesson five from OHIT

Electron Transport Chain - takes place on cristae of mitochondria.

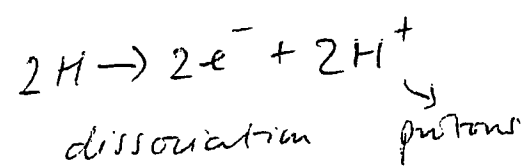
also hydrogen carrier system



NAD / FAD = oxidised

NADH₂ / FADH₂ = reduced

For every $2H \rightarrow 3ATP$ molecules



Between carriers 2+3 they dissoiate into electrons and protons

Cathennu

Notes taken during lesson given by dictation

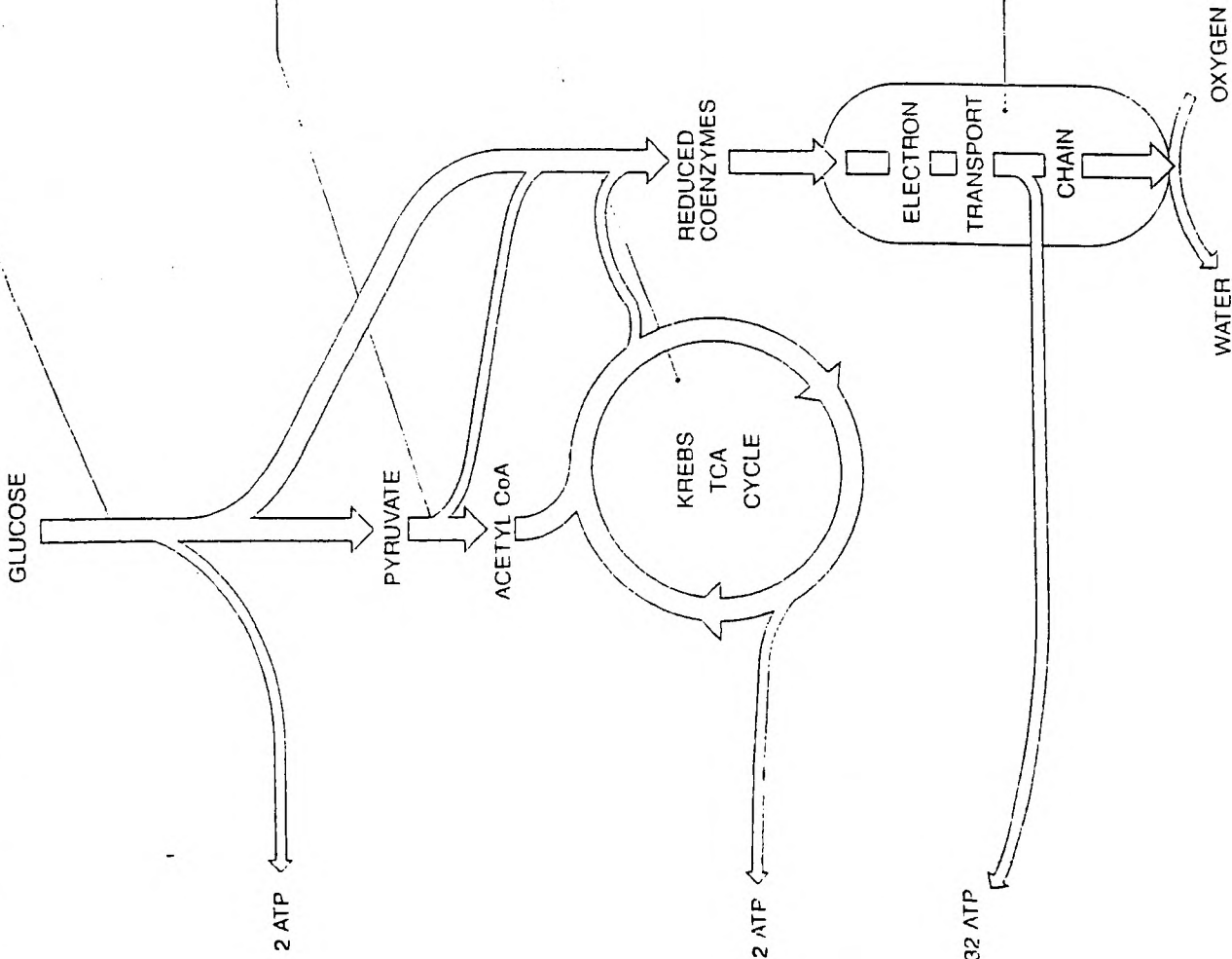
The Electron Transport Chain involves a series of oxidation/reduction reactions. It involves a series of hydrogen carriers which accept hydrogens brought first of all from the intermediate compounds removed by dehydrogenase enzymes. The hydrogen atoms or their electrons are then passed along the hydrogen carriers, finally combining with oxygen to form water. At each step energy is transferred and is used for the synthesis of ATP from ADP and P_i . Usually a total of 3 ATP molecules are produced for every 2 H that enter the system. For one molecule of glucose a total of 38 ATPs are formed.

Catherine

Lesson five - handout on cellular respiration

Summary 0.

Cellular respiration occurs in a series of localized stages.

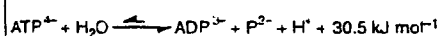


Catherine

Lesson five - handout on ATP.

ATP: the energy currency of the cell

ATP hydrolysis is favoured

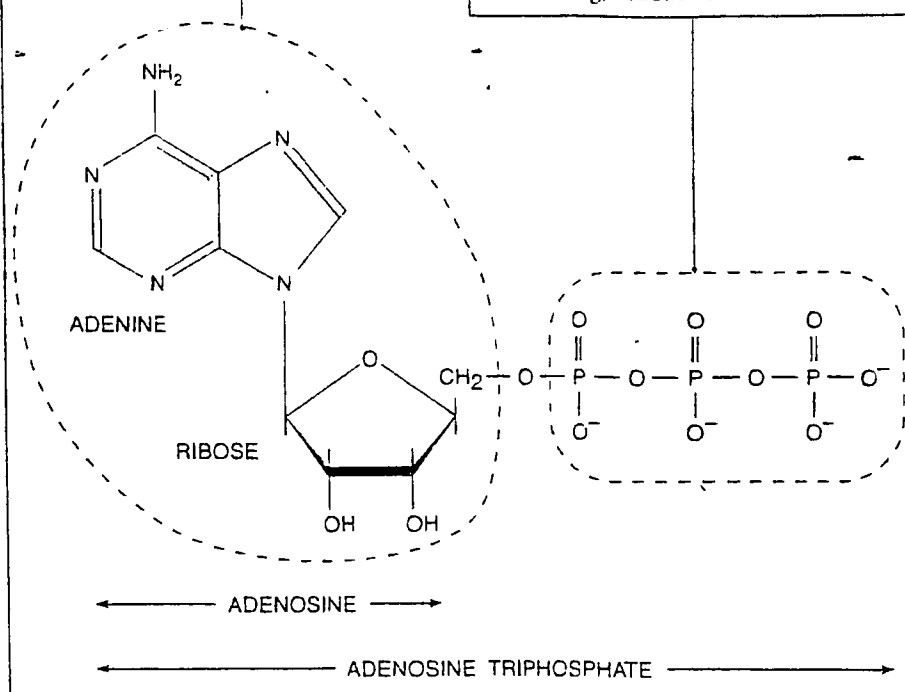


i.e. ATP has a strong tendency to transfer its terminal phosphoryl group, a reaction associated with the release of 30.5 kJ mol⁻¹ of ATP, because

1. the repulsion between the four negative charges in ATP⁴⁻ is reduced when ATP is hydrolysed because two negative charges are removed with phosphate.
2. the H⁺ ion which is released when ATP is hydrolysed reacts with OH⁻ ions to form water – this is a highly favoured reaction.
3. the charge distribution on ADP + P is more stable than that on ATP.

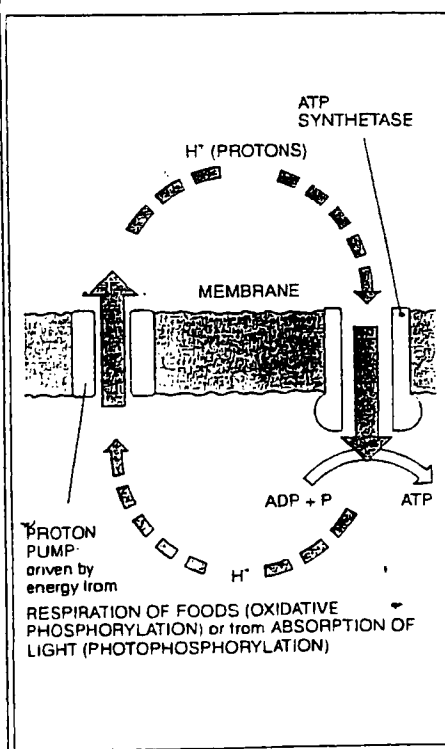
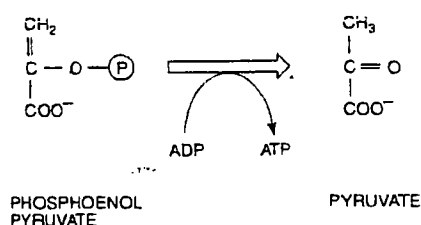
This part of the molecule acts like a 'handle' – it has a shape which can be recognized by highly specific enzymes.

This part of the molecule contains anhydride bonds (O-P) which can be hydrolysed in reactions which are **exergonic** (energy-yielding) and can be coupled to **endergonic** (energy-demanding) reactions.



Substrate level phosphorylation: A phosphate group is transferred from a phosphorylated compound to ADP.

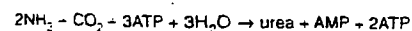
e.g



ATP: THE CENTRAL MOLECULE IN METABOLISM

Muscle contraction: ATP hydrolysis changes the position of the myosin 'head' relative to actin.

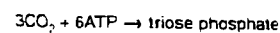
Urea synthesis: ATP hydrolysis drives the ornithine cycle which removes toxic ammonia.



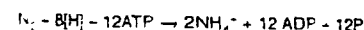
Protein synthesis: ATP is used to 'load' amino acids onto transfer RNA.

Active transport systems are driven by the phosphorylation of membrane-bound proteins.

Calvin cycle (dark stage of photosynthesis): ATP hydrolysis drives the cyclic reduction of CO₂ to triose phosphate.



Nitrogen fixation involves the ATP-driven reduction of molecular nitrogen.



Bioluminescence: ATP hydrolysis drives the oxidation of luciferin which releases some energy as visible light – useful for fireflies!

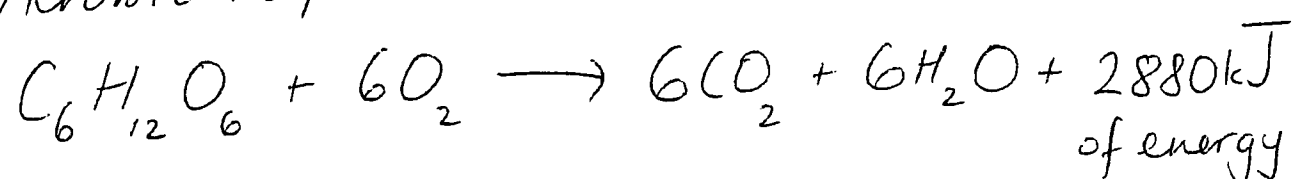


Chemiosmosis: A proton gradient across an impermeable membrane is dissipated and the energy released is used to drive the phosphorylation of ADP.

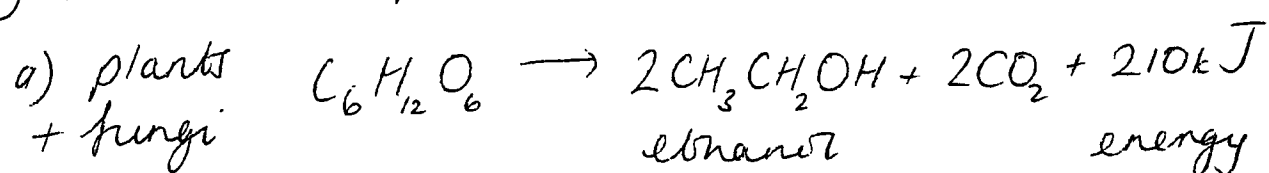
Catherine

Notes taken during lesson from board/
dictation.

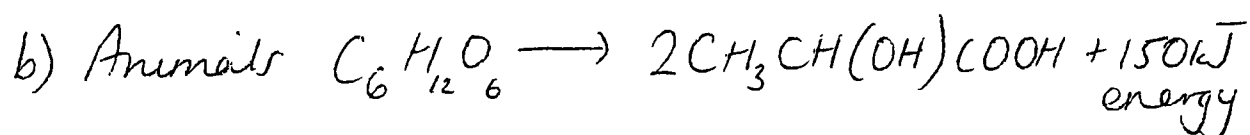
① Aerobic resp ⁿ



② Anaerobic resp ⁿ



③ Anaerobic resp ⁿ

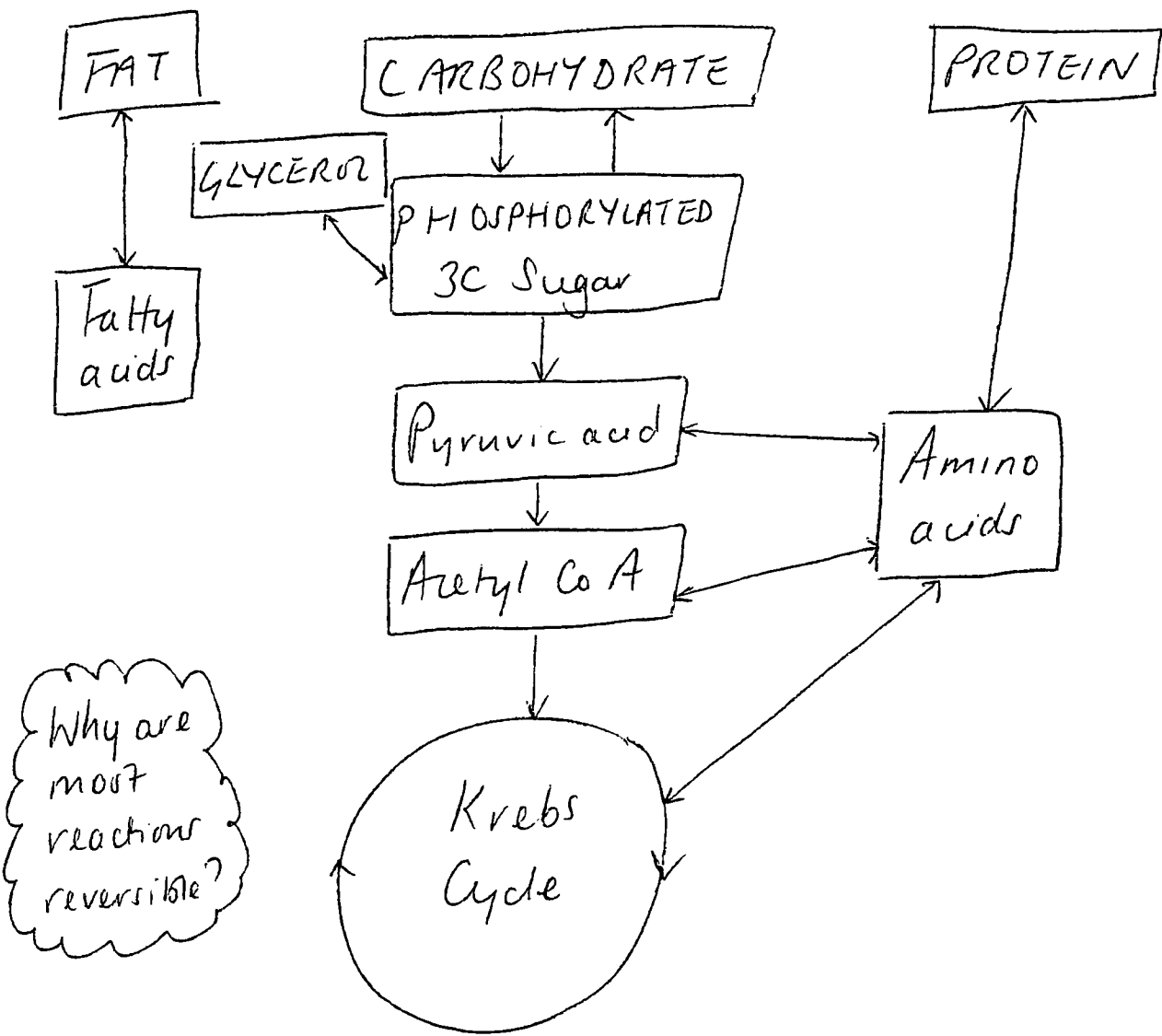


Anaerobic respiration means respiration without oxygen. There is no O_2 to accept the H atoms as they come off the electron transport system. This means that the carrier system cannot operate in anaerobic conditions. With no carrier system there can be no Krebs Cycle and this does not take place. Glycolysis however occurs in the usual way, indeed it is speeded up, but the pyruvate is not converted into AcetylCoA, but is converted into lactic acid or ethanol.

Catherine

Notes taken during lesson six from the board

Energy from non-carbohydrate sources



Cathenne

Notes taken during lesson or from board/dictation

Carbohydrates can be converted into fat for storage or used for the synthesis of certain fatty acids and amino acids.

Carbohydrates are not the only substances which give energy. Energy can also be derived from the oxidation of fats and proteins.

Most of the pathways lead to AcetylCoA which is the crossroads of metabolism.

Fat

Fat is used as a source of energy when carbohydrate is in short supply or when the demand for energy is particularly great. First the fat is split into fatty acids and glycerol. Glycerol is phosphorylated into a triose sugar which is then converted into pyruvate and fed into Krebs Cycle. Meanwhile each fatty acid goes through a series of reactions in which carbon atoms are split off the hydrocarbon chain, two at a time. Each 2 carbon unit is actually an acetyl group (CH_3CO) which then combines with coenzyme A to form AcetylCoA which enters Krebs Cycle. The breakup of the long chains takes place in the mitochondrion in a series of small steps and is known as β -oxidation.

Catherine

Notes taken during lesson six from board/dictation

Pairs of hydrogens pass through the carrier system where ATP is synthesised. The number of ATP molecules produced by the complete oxidation of a fatty acid varies considerably.

Energy from protein

Proteins are not stored so our only reserves are the tissues themselves.

The protein is first split into amino acids. Each amino acid is then deaminated (the NH_2 group is split off with the formation of ammonia).

The ammonia is quickly converted into urea and happens in the liver - called the ornithine cycle. The urea is excreted.

Meanwhile the carbon fragment left after the removal of the amino group is fed into carbohydrate metabolism. Depending on which amino acid it is, it may enter one of 3 points.

ATP molecules are synthesised in the usual way.

Appendix J

Curriculum materials and copies of all notes put on the board/OHT during Sally’s unit-of-work

Sally

Notes taken during lesson one from board

3.5 Digestion in Mammals.

mouth
teeth enzymes
saliva
grinding and breaking down
smaller food particles

oesophagus (gullet) peristalsis
small intestine - villi - 'things'
absorbed
diffusion

large - colon - anus

Stomach - digestion

gastric juices

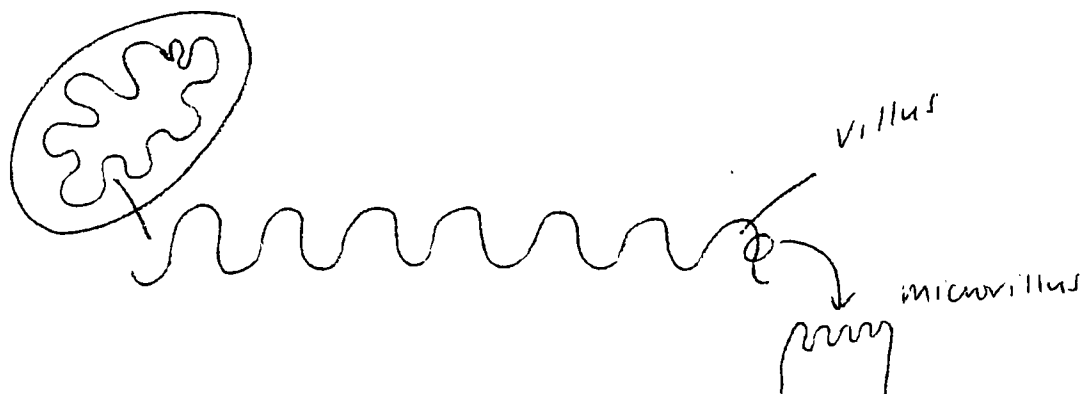
acids breaking
'down food'
pH=2.

'good parts' kept

'bad parts' thrown away

Waste products - urea

Kidney



Sally

Lesson one - handout on the anatomy and microanatomy of the gut

SIXTH FORM - HETEROTROPHIC NUTRITION
ANATOMY / MICROANATOMY OF THE GUT I

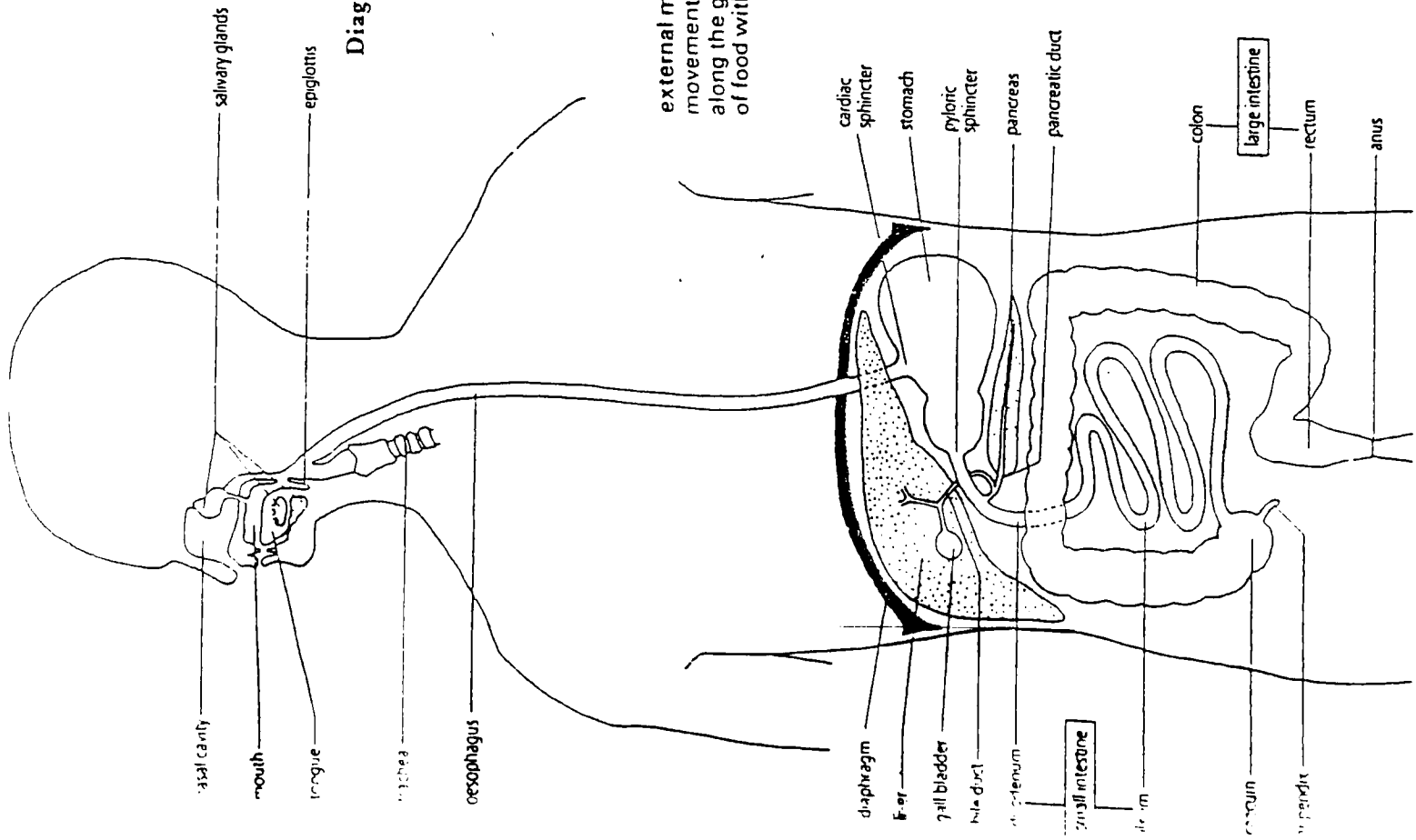
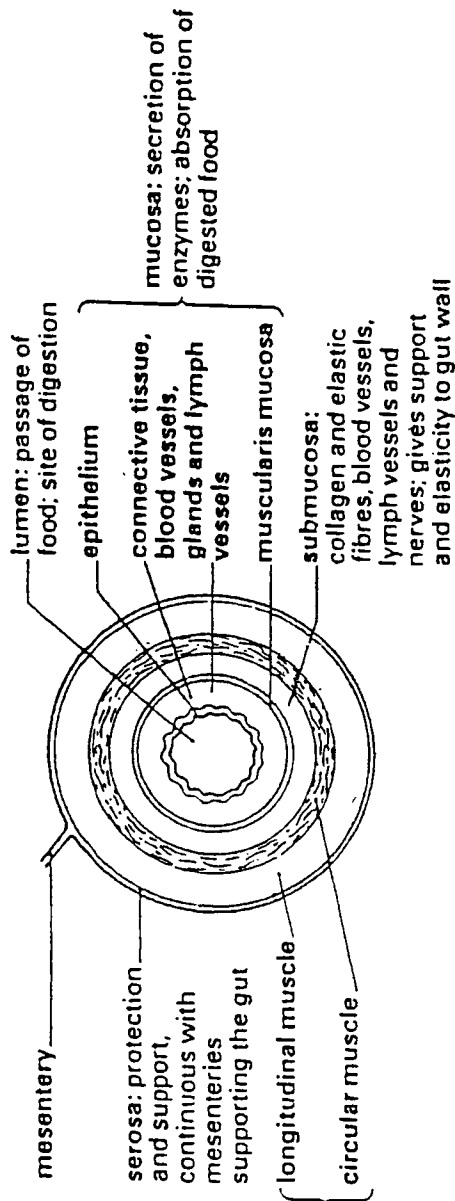
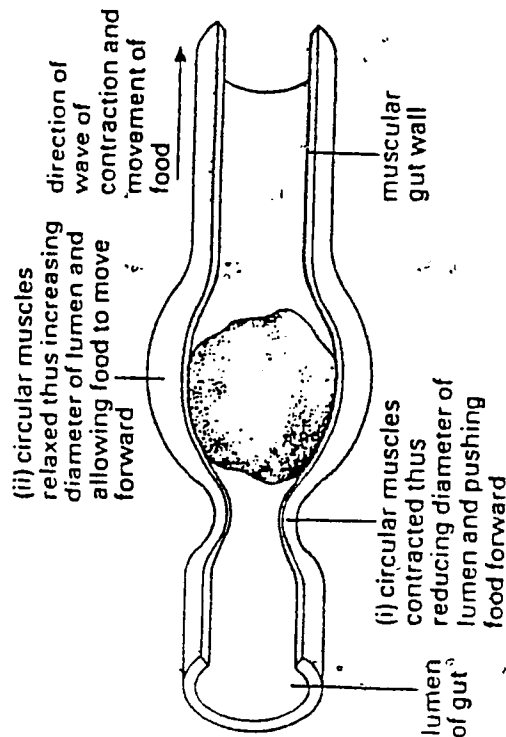


Diagram showing the main regions of the gut wall



external muscle coat: movement of food along the gut; mixing of food with enzymes

Peristalsis - moving food along the gut



Sally

Notes taken during lesson two from board.

DIGESTION IN THE MOUTH

Digestion is the breakdown of complex organic molecules into smaller soluble molecules.

This can be brought about by enzymes (chemical digestion) or physical (mechanical) breakdown.

Sally

Lesson two - practical ~ Digestion of starch in humans

3

84 BIOLOGY: A FUNCTIONAL APPROACH

Investigation 9.3 Digestion of starch in humans

CAUTION:

Because of the risk of infection, do not let your mouth come into contact with a test tube containing someone else's saliva.

Starch is a polysaccharide which has to be broken down into free sugar molecules before absorption can take place.

The purpose of this experiment is firstly to test the hypothesis that saliva contains an enzyme which breaks down starch to sugar; and secondly to investigate the properties of the enzyme and the conditions under which it works most effectively.

Starch is mixed with saliva under various conditions and after a given period of time the mixture is tested for starch with iodine solution and for sugar with Benedict's reagent. (For details of these tests see page 42).

It is of course important to set up the necessary controls and to carry out standard tests on starch and sugar with which to compare the experimental results. The sugar used should be a reducing sugar, e.g. glucose.

Procedure

1 Collect 20 cm³ of uncontaminated saliva in a measuring cylinder: the flow can be increased by chewing paraffin wax.¹

2 Transfer one quarter of the saliva to a test tube and place this in a boiling water bath for 15 minutes. Transfer a further quarter to another test tube: add four drops of hydrochloric acid (1.0 mol dm⁻³), mix well and leave for at least 15 minutes. Keep the rest of the saliva untreated at room temperature.

3 Now set up six pairs of test tubes as follows. Label each test tube with its code number, using a wax pencil.

- Pair A (1) 4 cm³ sugar only
(2) 4 cm³ sugar only
- Pair B (3) 4 cm³ starch only
(4) 4 cm³ starch only
- Pair C (5) 4 cm³ untreated saliva only
(6) 4 cm³ untreated saliva only
- Pair D (7) 4 cm³ starch plus
2 cm³ untreated saliva
(8) 4 cm³ starch plus
2 cm³ untreated saliva
- Pair E (9) 4 cm³ starch plus
2 cm³ pre-heated saliva
(10) 4 cm³ starch plus
2 cm³ pre-heated saliva
- Pair F (11) 4 cm³ starch plus
2 cm³ acidified saliva
(12) 4 cm³ starch plus
2 cm³ acidified saliva

4 Leave the test tubes for at least 10 minutes before you proceed further (why?).

5 Test the contents of each pair of test tubes (a) for starch by adding two drops of iodine solution and (b) for sugar by heating with one-eighth test tube of Benedict's reagent. Do the starch test on the first of each pair of test tubes, and the sugar test on the second of each pair.

6 It is important to be able to compare the results: this is why separate test tubes are used and it is also why the same quantities of substrate, saliva and test-reagent must be used in each case. To facilitate comparison place the test tubes in a rack in numerical order.

7 Record your results in a table, indicating which test tubes give a positive and which ones a negative result for starch and sugar. It is possible that some may give a result in between: if so, say so.

For Consideration

(1) What is the purpose of testing test tubes 1 to 6?

(2) In which test tubes have you actually tested the hypothesis that saliva contains an enzyme which breaks down starch to sugar? Does the hypothesis turn out to be correct? Would you say it was proved?

(3) Which test tubes provide information on the properties of the enzyme?

(4) What tentative conclusions can be drawn as to the chemical nature of the enzyme and what further experiments could be done to confirm these conclusions?

(5) What is the name of the enzyme in saliva and what compound does it produce from starch?

Requirements

Test tubes × 12
Test tube rack
Measuring cylinder (20 cm³)
Water bath (250 cm³ beaker)
Bunsen burner with tripod and gauze
Wax pencil

Starch suspension
Dextrose (glucose)
Iodine solution
Benedict's reagent
Hydrochloric acid (1.0 mol dm⁻³)
Paraffin wax

¹ If you cannot produce 20 cm³ of saliva, make do with 10 cm³ and halve all subsequent quantities and reagents.

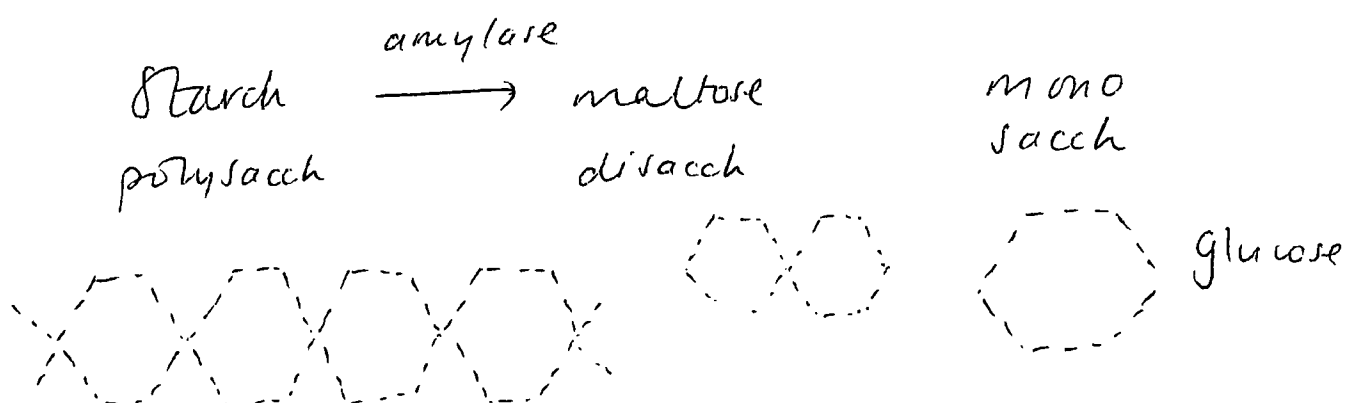
0.5g Amylase → 100 ml
+ pinch salt.
(usually need 300 ml)

Sally

Notes taken during lesson two from board

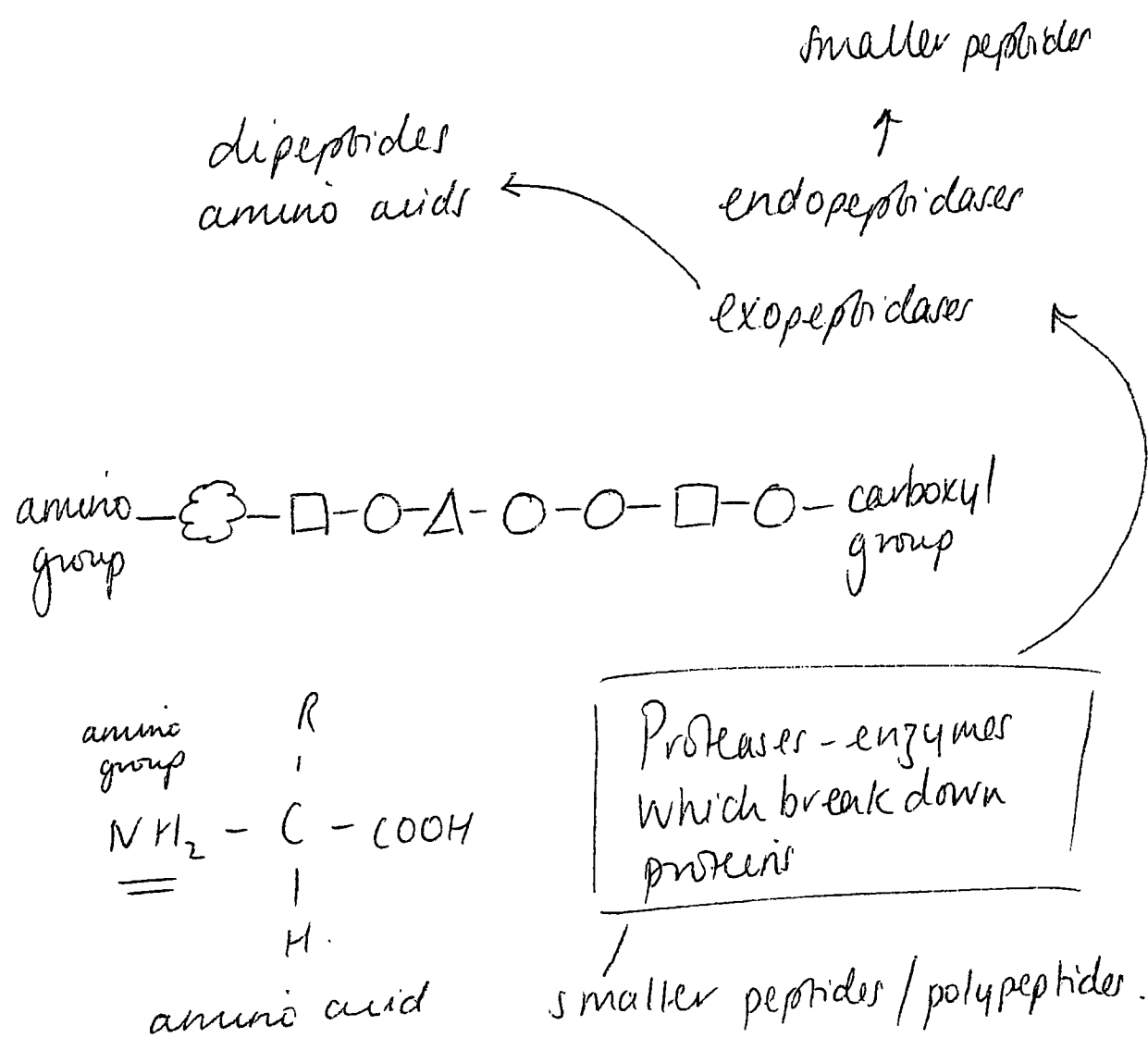
In your write up include:

- ① The purpose of the experiment - (read the intro)
- ② Stick in the procedure
- ③ Results (see point 4) - Keep your tubes until
Thurs (we will leave them
to allow the precipitate to
settle). Put them on a shelf
safely.
- ④ For consideration -
all of them.
- ⑤ What factors other than pH affect enzyme
action? (Just a list).
- ⑥ What is special about an enzyme - nature of
chemical (3-D etc...) and its substrate - (clue-
Lock + Key etc!)



Sally

Notes taken during lesson three from board



Sally

Notes taken during lesson four from board

Slides of the layers of the gut wall

Adaptations shown by various regions of the digestive system.

- ① OESOPHAGUS - Draw a section under medium power to show the layers. Label (use the M+E book to help).

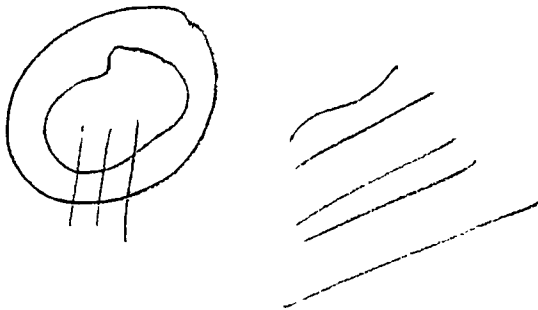
p. 28

- Draw the T.S. part of the wall and label.

- ② STOMACH - Draw a section as above p 28 - draw the L.S. part of wall of stomach

- ③ DUODENUM - " " " " " p 29 - draw the L.S. part of wall + diagram of mucosa.

- ④ RECTUM - " " " " " p. 30 - draw the T.S. part of wall



Sally

Lesson four - homework questions

DIGESTION IN MAMMALS

1. What stimulates the salivary glands to secrete saliva?
2. What is the role of mucus in saliva?
3. Describe the action of the enzyme AMYLASE. What pH is its optimum?
4. How would you test for a reducing sugar? For starch?
5. How is mechanical digestion brought about in the mouth?
6. Name the 4 basic GUT LAYERS.
7. Write a definition for DIGESTION.
8. What is PERISTALSIS?
9. What happens in the OESOPHAGUS?
10. There are 3 sphincters (CARDIAC AND PYLORIC) where are they found and what is their purpose?
11. Rennin is in gastric juice. What does it do?
12. Which cells produce PEPSINOGEN? Why is pepsinogen produced? What converts it to PEPSIN? What does pepsin do? Is it an endopeptidase or exopeptidase?
13. Which cells produce hydrochloric acid? What is its job?
14. How does the stomach stop from digesting itself?
15. How would you test for a protein?
16. How is mechanical digestion achieved in the stomach?
17. Is the production of gastric juice as a result of nerves or hormones? Explain.
18. How do hormones reach their target organ?
19. What are the names of the regions of the small intestine?
20. The duodenum produces many enzymes. Name these, the substrate they act on and the end products of digestion. Distinguish between aminopeptidases and carboxypeptidases.
21. What is bile? Where is it made? Where is it stored? What is its purpose?
22. What are the following: secretin, pancreaticozymin and cholecystokinin and what do they do?
23. What are the enzymes in pancreatic juice?
24. How can we test for lipids (fats and oils)?
25. In the ileum are villi. Draw a diagram (and label) of a villus. What are the advantages of the villi and microvilli?
26. How can the rate of glucose absorption be increased? (in the epithelial cells). Draw a diagram of an epithelial cell.
27. Why is (and what is) active transport necessary?
28. How is absorption of fat droplets (chylomicron) achieved?
29. What is the hepatic portal vein? Where is it? What does it carry?
30. What are the regions of the large intestine?
31. What happens in the caecum and appendix of some herbivores e.g. rabbit? (Hint: Bacteria)
32. The colon is where faeces are formed. Explain how the structure of the colon enables this to happen. Why is fibre useful?
33. What type of muscle is the rectum?
34. Distinguish between ingestion, absorption and egestion.
35. Ask for a sweetie!!

Sally

Notes taken during lesson live from board.

protein $\rightarrow$ polypeptides $\rightarrow$ dipeptides $\rightarrow$ amino acids
 endopeptidases $\rightarrow$ exopeptidases
 eg. pepsin eg. carboxypeptidases
 aminopeptidases

sodium glycolate
 sodium hydrogencarbonate } bile salts
 sodium taurocholate

biliverdin } bile pigments
 bilirubin }

waste products
 of metabolism.

emulsify lipids

break down into smaller
 droplets, increasing the
 surface area, to increase
 digestion by LIPASE
 (more efficient)

excretory products
 breakdown of
 haemoglobin
 excretion defaecation

Sally

Lesson here - handout re structure of gut wall

Structure of the gut wall.

The basic structure of the gut wall is made up of four layers. These are:

MUCOSA-This is the innermost layer of the gut and is composed of glandular epithelium which secretes mucus and digestive enzymes. The mucus lubricates food and facilitates its easy passage along the digestive tract. It also prevents digestion of the gut wall by its own enzymes. The lamina propria is a basement membrane on which the epithelial cells are located. It contains connective tissue, blood and lymph vessels. Outside this is a thin layer of smooth muscle, the muscularis mucosa.

SUBMUCOSA-This is a layer of connective tissue containing nerves, blood & lymph vessels, collagen & elastic fibre. It may contain some mucus secreting vessels which deposit the contents onto the surface via ducts such as the Brunner's gland in the duodenum.

MUSCULARIS EXTERNA-This layer is composed of an inner circular and an outer longitudinal layer of smooth muscle. The two layers cause wave like peristaltic activity of the gut wall which propels food along. The circular muscle thickens in places forming sphincters, when these relax or contract they control the movement of food. They are found at the junction of the oesophagus and the stomach, stomach, duodenum, ileum, large intestine and at the anus. Auerbach's plexus is found between the circular and longitudinal muscle layers. This consists of nerves from the autonomic nervous system which control the peristalsis. Impulses travelling along sympathetic nerves cause the gut muscles to relax and the sphincters to close whilst impulses travelling via the parasympathetic nerves stimulate the gut wall to contract and the sphincters to open.

SEROSA-This layer is composed of loose fibrous tissue. Peritoneum covers the outer surface of the gut and lines the abdominal cavity and constitutes the mesenteries which suspend and support the stomach and intestines.

Sally

Lesson Two - handout re main function and adaptations of different regions of the gut

Region	Structure	Function of the Gut	Adaptation of Muscle	Adaptation of Submucosa	Adaptation of Mucosa
oesophagus	peristalsis	two layers - thick in order to force solid food into the stomach	two layers - thick in order to force solid food into the stomach	contains mucous glands to lubricate	lining of several layers of flattened cells. (outer layers are rubbed off)
stomach	temporary storage of food mixing up of contents	three layers - to churn stomach contents	three layers - to churn stomach contents	elastic to allow expansion	folded to allow expansion
duodenum	digestion absorption of soluble food products	same digestion (protein)	many blood and lymph vessels	abundant glands which secrete enzymes	abundant glands to produce enzymes, acid, mucus
jejunum	absorption of water and some food	two layers - for peristalsis	many blood and lymph vessels	absorbed food products pass into these vessels	folded + villi + microvilli to increase surface area for absorption
ileum	movement of faeces	two layers - outer layer thick and divided into 3 layers to aid peristalsis	two layers - outer layer thick and divided into 3 layers to aid peristalsis	tubular glands which secrete mucus to aid the passage of faeces	tubular glands which secrete mucus to aid the passage of faeces

Sally

Notes taken during lesson six from board.

Digestion of proteins

(albumin/gelatin
on film)

Write up an introduction - include the source of
protein, the 2 enzymes
+ where they are
produced + their role

Remember both are endopeptidases

(use your notes on T+T)

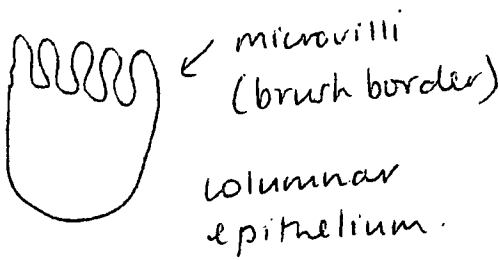
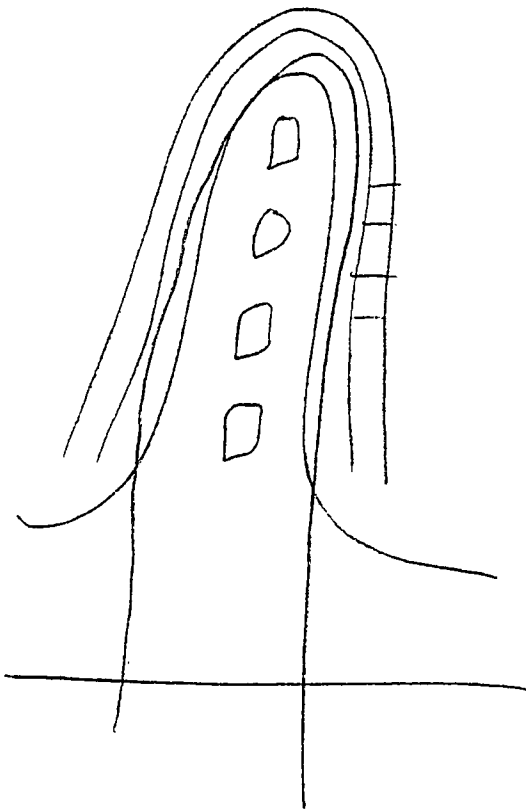
No method

Include a results table

Treatment	Observation
	What are the optimum conditions for each enzyme? What is the role of endo/exopeptidases? Why are endop's used before exop's?

Sally

Notes taken during lesson six from board



facilitated diffusion
carrier

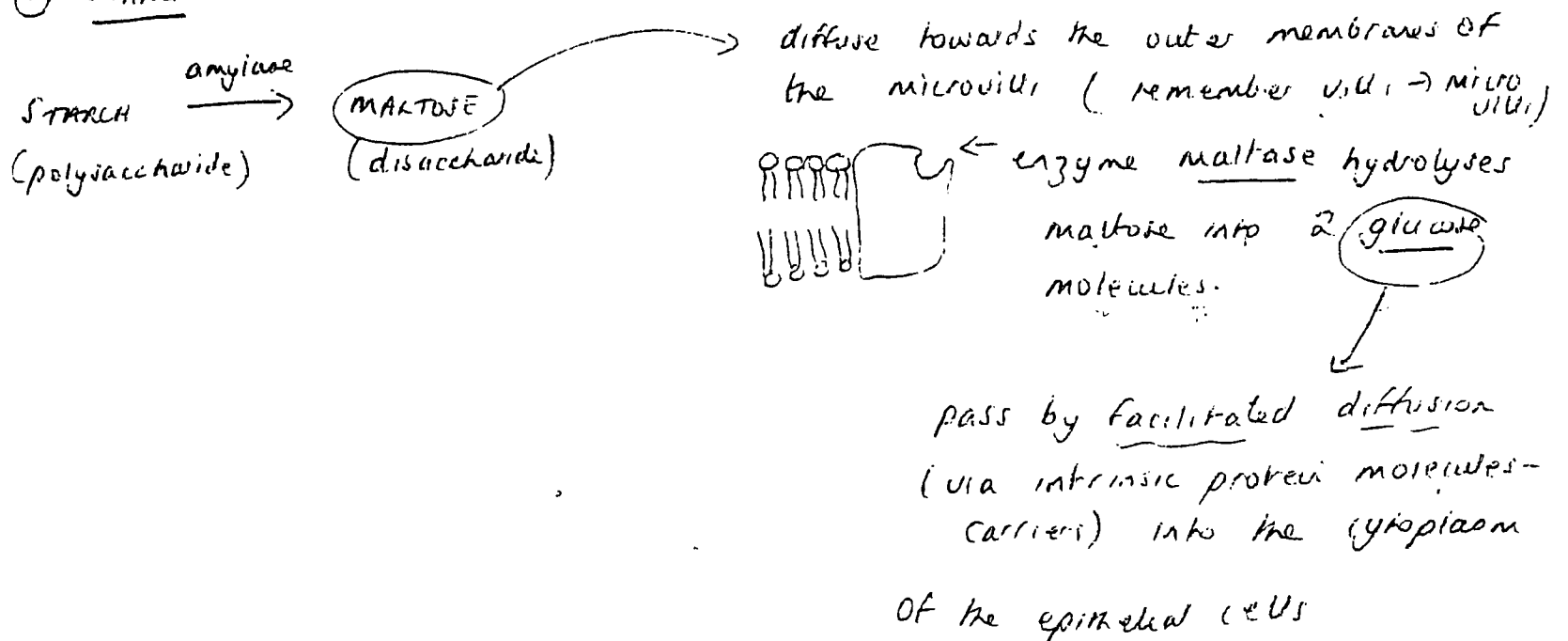
Sally

Lesson seven - handout summarising digestion and absorption.

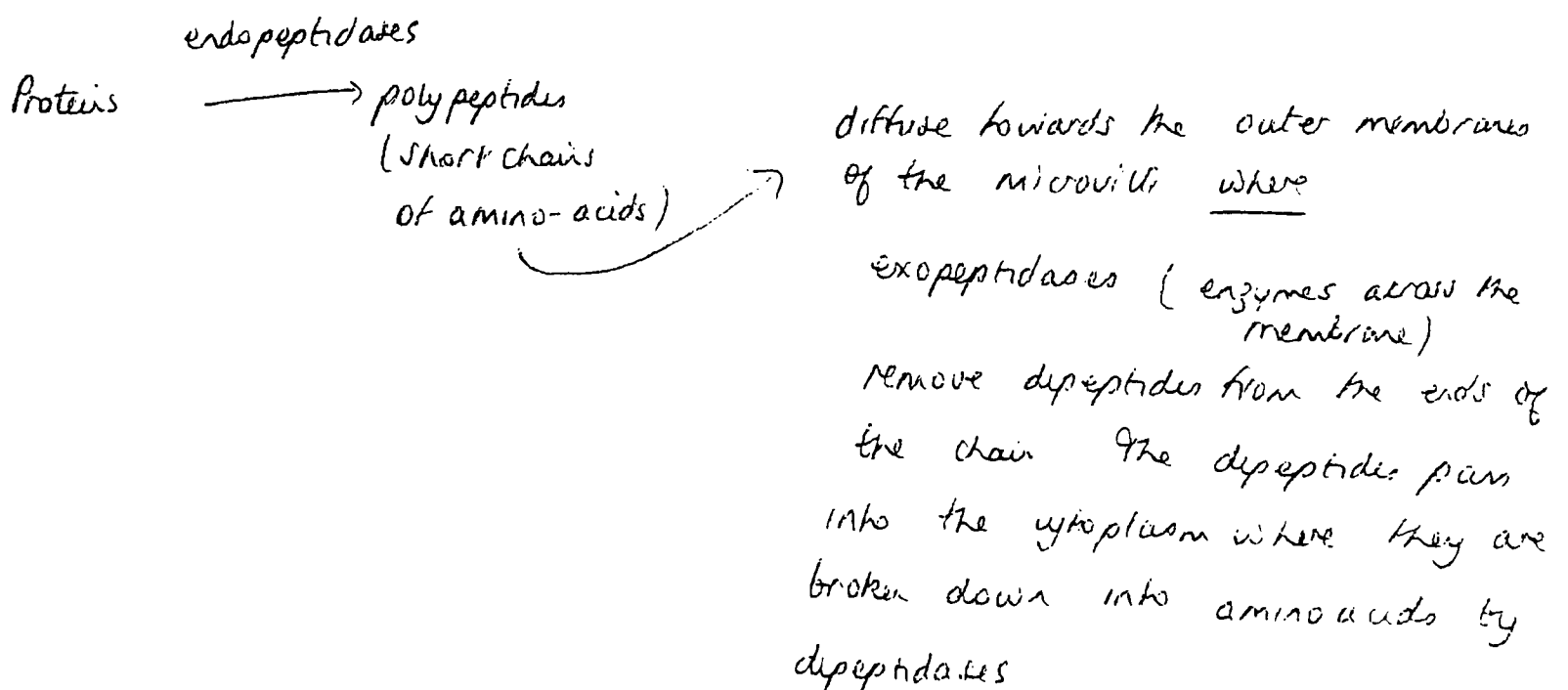
F

DIGESTION - A SUMMARY

A STARCH



B PROTEINS



Again intrinsic protein molecules help facilitated diffusion of amino-acids

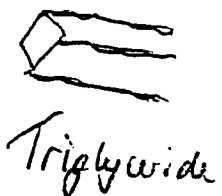
Sally

hesson seven - handout summarising digestion and absorption.

③ FAT DIGESTION

Fat droplets are emulsified (broken down into smaller droplets) by bile salts. Emulsion droplets are formed (< 1 μ m diam.) This increases their surface area for digestion by lipase.

→ breaks the bonds joining 2 of the fatty acid molecules to the molecule of triglyceride producing 2 fatty acid molecules (~~~~) and a monoglyceride (~~~~).



The lumen of the duodenum contains fatty acids, monoglycerides, phospholipids, cholesterol. These can all quickly diffuse through the outer membrane of the microvilli.

Once inside the epithelial cells they reform into triglycerides.
 Triglycerides + phospholipids = chylomicrons (droplets which are too large to enter the blood stream)
 → enter the lacteals which drain into lymph vessels

Sally

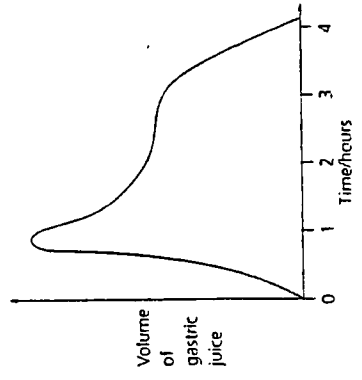
Lesson seven - worksheet on the role of neurons and hormonal stimulation in digestion

Questions

- 1 a There are two stages in the digestion of starch:
starch → maltose → glucose
Name: _____
(i) the enzyme responsible for digesting starch to give maltose.
(ii) two glands in the body that produce this enzyme.
(iii) the part of the alimentary canal where the second stage in the digestion (maltose → glucose) takes place.
b The secretion of saliva is controlled by a reflex action. Copy and complete the table to give the components of this reflex.

Stimulus	
Receptor	
Effector	
Response	

- 2 a Describe the part played by gastric juice in the digestion of proteins.
The graph shows the amount of gastric juice produced by a person in the four hours following a meal.



- b The secretion of gastric juice is partly controlled by a reflex, and partly by the hormone, gastrin. Giving a reason for your answer, say which of these two controls you would expect to be mainly responsible for controlling the secretion of gastric juice:
(i) immediately after a meal has been eaten;
(ii) three hours after the meal had been eaten.

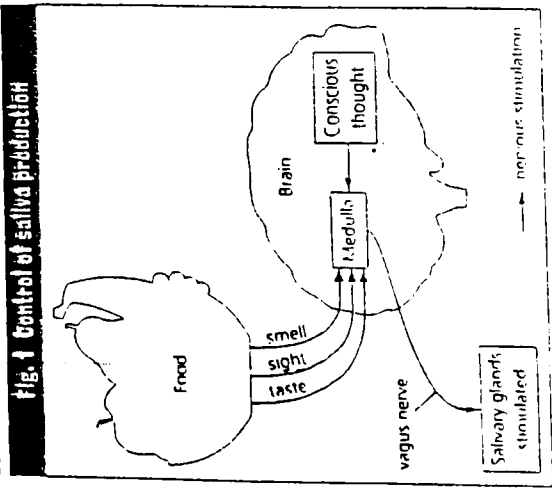
16 Controlling digestion

The body has a series of mechanisms to ensure that digestive secretions are only produced when food is present in the gut. The main digestive secretions are shown in Table 1.

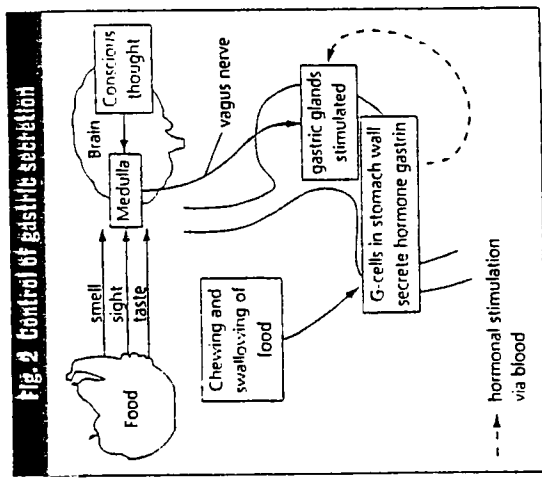
Table 1. Digestive secretions		
Secretion	Source	Function (enzyme)
Saliva	salivary glands	soften food and begin digestion of carbohydrates (amylase)
Gastric juice	gastric glands in stomach wall	digest proteins (endopeptidase) and start fat digestion (lipase)
Pancreatic juice	pancreas	digest fats (lipase), carbohydrates (amylase) and proteins (trypsin)
Bile	liver (stored in gall bladder)	and digestion by emulsifying fats
Intestinal juice	held in cells in wall of small intestine	digest disaccharides (maltase) and polypeptides (exopeptidase)

Secretion into the digestive system is controlled by three mechanisms:
• reflex stimulation from the brain, through the vagus nerve;
• action of hormones secreted by glands in various parts of the digestive system;
• stretching of the gut wall caused by movement of food.

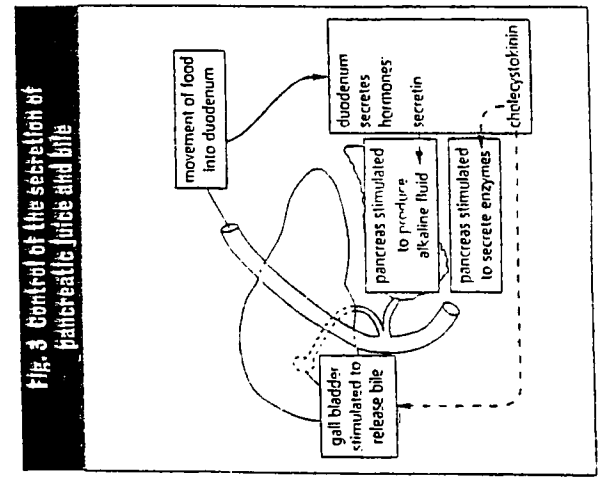
Saliva
Saliva production (Fig. 1) is controlled by a reflex action.



Gastric juice
All three mechanisms are involved in controlling the secretion of gastric juice (Fig. 2).



Pancreatic juice and bile
The hormones secretin and cholecystokinin are most important in controlling these secretions (Fig. 3).



Large Intestine

Most of the water drunk by humans and other carnivores is absorbed by the stomach. The large intestine or colon is partly responsible for reabsorbing the water from the digestive secretions. With the gastric and intestinal juices each producing up to 3 litres of secretion everyday and the saliva, pancreatic and bile juices each adding a further 1.5 litres, the total volume of the digestive secretions may exceed 10 litres. Most of this is water. While most water is absorbed in the ileum, the large intestine plays an important role in reabsorbing the remainder. This changes the consistency of the faeces from liquid to semi-solid.

Peristalsis gradually pushes the contents of the small intestine into the large intestine, or colon. The material that enters the colon has had most of its nutrients removed, but it contains a lot of water and inorganic ions. The colon reabsorbs the ions and the water producing a semi-solid slurry of indigestible material. Faeces stored in the last segment of the colon are periodically excreted.

The large intestine has a large surface area in order to increase the rate of absorption.

Immense populations of bacteria live within the colon. One of the resident species is E.coli. Vitamin K and biotin are synthesised by the bacteria and absorbed across the wall of the colon. (Vitamin K is used for blood clotting, biotin is used for skin ??) The intestinal bacteria produce gases such as methane and hydrogen sulphide as by products of their largely anaerobic metabolism.

Did You Know ?

The record for constipation is 102 days!!

Ruminants : Herbivores have a stomach with four chambers to harbour the cellulose digestive bacteria. The first two chambers, the Rumen and Reticulum ferment the cellulose. The products of this fermentation (ethanolic, propanolic and butanoic acids) are used by

the bacteria. The inner surfaces of the reticulum and the rumen are like honeycomb providing a large surface area for the absorption to work. Carbon dioxide and methane are also produced and expelled via the mouth. Partially digested food can be regurgitated and chewed and on the second swallowing food quickly passes through the third chamber (the omasum) and then the true stomach (the abomasum) and from there normal digestion takes place. Some herbivore animals (such as rabbits) even eat their own faeces because ??

Fully
Lesson seven - handout on the
large intestine

Sally

NOTES taken during lesson seven from board

crypts of Lieberkuhn

Sucrase

sucrose
 { glucose
 { fructose

maltase

maltose
 glucose + glucose

Muscularis mucosa

mucosa

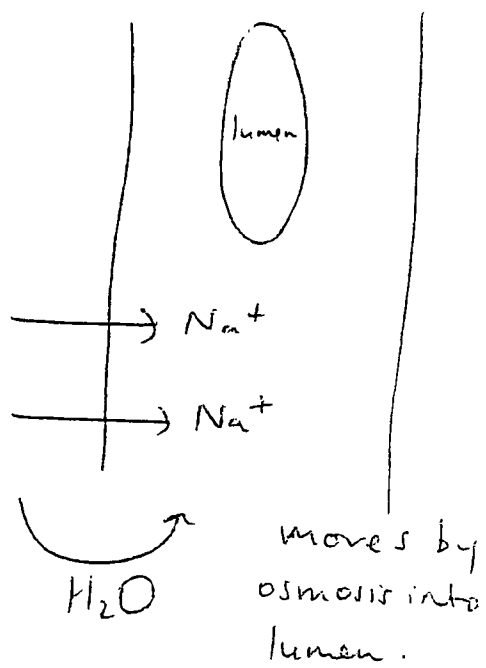
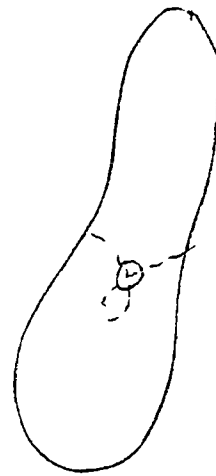
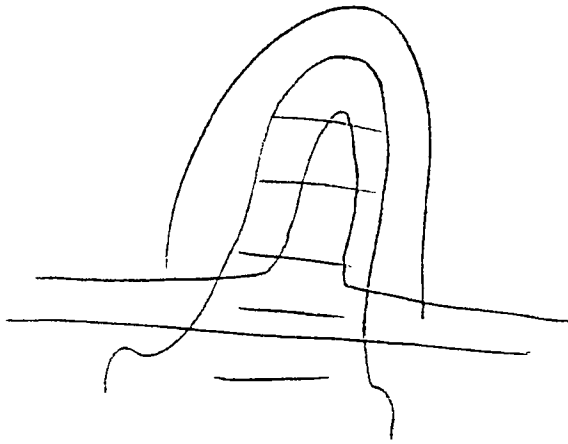
submucosa

external m. coat

serosa

Sally

Notes taken during lesson seven from board



ψ_w

high $\rightarrow$ low

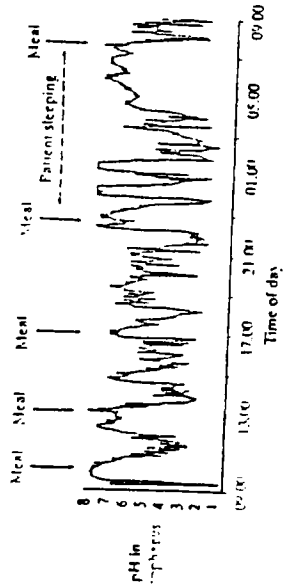
ψ_w ψ_w

0

Sally

Lesson seven - past paper examination questions on digestion + absorption

2. Absorption of sodium ions called acid reflux. To find out if acid reflux was the cause of a patient's heartburn, a pH probe was inserted into the oesophagus and pH levels in the oesophagus were recorded over a period of 24 hours. The patient was asked to avoid the times at which drinks were taken during the 24 hour period. The graph shows the results of this investigation.



1a) Suggest how the stomach contents are normally prevented from passing into the oesophagus

1b) (i) Describe the relationship between taking a meal and the pH in the oesophagus

(ii) Suggest why the pH in the oesophagus was very low between 02:00 and 04:00, but high between 05:00 and 07:00

1c) The secretion of acid by the stomach is partly controlled by the hormone gastrin.

(i) Describe the physical characteristics of hormones

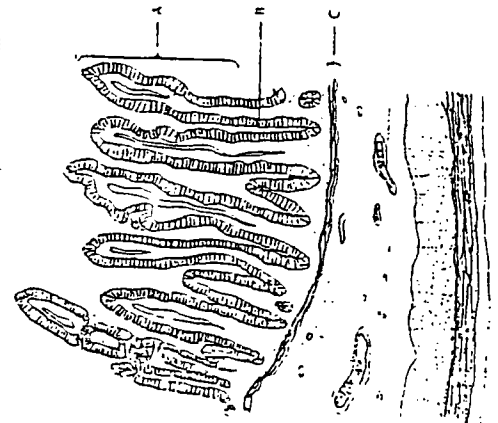
(ii) Describe the role of gastrin in the control of gastric secretions

HETEROTROPHIC NUTRITION

A-level questions

9

The diagram below shows a longitudinal section of part of the ileum wall.



2a) adaptations for digestion and absorption. List three adaptations for digestion and absorption in humans, a named saprophyte (saprobium) and a named parasite. (Total 10 marks)

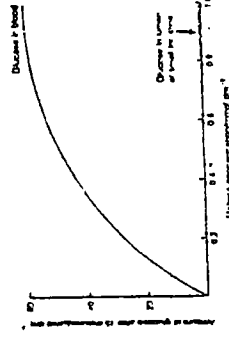
2b) A person ate a piece of cheese consisting mainly of lactose and protein. Describe the processes which enable these lactose and proteins to be digested and absorbed. (Total 20 marks)

2c) Write an essay on the adaptations of parasites to their way of life. (Total 14 marks)

2d) Complete the table which refers to enzyme activity in the mammalian gut. (Total 5 marks)

Name of enzyme	Site of production	Substrate	Product
Lactase	Duodenum	Lactose	Glucose
Trypsin	Pancreas	Proteins	Amino acids
Steapsin	Pancreas	Fats	Fatty acids
Chymotrypsin	Pancreas	Proteins	Amino acids

2e) Different concentrations of maltose were placed in the small intestine of a mammal. The amount of glucose appearing in the blood and in the small intestine were measured. The results are shown in the graph.



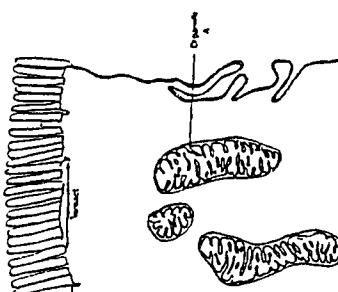
3a) Name the blood vessel most likely to have been sampled for glucose. (1 mark)

3b) Describe the chemical process by which a molecule of maltose is converted into two molecules of glucose. (2 marks)

3c) As a result of this experiment it was suggested that the enzyme involved in the breakdown of maltose is located in the cell-surface membrane of the epithelial cells of the small intestine. Explain the evidence from the graph that supports the view that maltase breakdown does not occur in the lumen of the small intestine. (2 marks)

3d) Suggest an explanation for the shape of the curve showing the change in the amount of glucose in the blood. (3 marks)

The drawing has been made from an electron micrograph of part of an epithelial cell from the small intestine. The magnification of the drawing is $\times 20000$.



3e) (i) Name the organelle labelled A. (1 mark)

(ii) Describe the part played by organelle A in the uptake of substances from the small intestine. (3 marks)

3f) Calculate the actual length of one microvillus in micrometres. Show your working. (2 marks)

3g) By how many times does the possession of microvilli increase the surface area of the cells along the brush border in the drawing? Explain how you arrived at your answer. (3 marks)

9a

Name the structures labelled A, B and C.

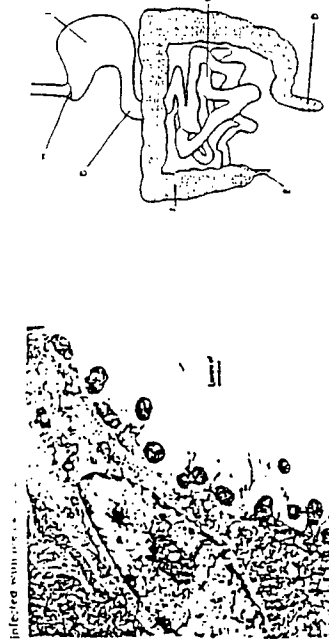
9b

Describe one way in which the structure of the ileum is adapted to the function it performs.

10

Complete the table which refers to the structures in the mammalian gut.

Name of enzyme	Site of production	Substrate	Product
Lactase	Duodenum	Lactose	Glucose
Trypsin	Pancreas	Proteins	Amino acids
Steapsin	Pancreas	Fats	Fatty acids
Chymotrypsin	Pancreas	Proteins	Amino acids



Villi differ from most other nutrient in that, with the exception of vitamin D, they cannot be synthesised by humans and so must be obtained from the diet.

(i) State three consequences of vitamin A deficiency. (3 marks)

(ii) Suggest why deficiency of vitamin A is more likely to occur in vegetarians. (1 mark)

(iii) Explain why it is not possible to see the detail shown in this photograph when using a light microscope at the same magnification. (2 marks)

(iv) Describe how the bacteria have damaged the tissue. (1 mark)

(v) Suggest one way in which this damage might lead to diarrhoea in the animal concerned. (2 marks)

(Total 14 marks)

AEB November 1992, Paper 1, No. 5

The diagram shows the human gastrointestinal tract. Name the parts labelled A to H. (4 marks)

(i) Different regions of the tract have different pH values. Suggest why it is important to have a particular pH in a particular region. (1 mark)

(ii) Name a region which has a low pH. (1 mark)

(iii) Use one of the letters A to H, to indicate the main region where absorption of the following compounds occurs. (3 marks)

(a) digested protein; (b) glucose; (c) water. (3 marks)

(Total 7 marks)

ULEAC January 1994, Paper 1, No. 2

See Further questions pp. 614-20 questions 6, 9, 19, 307

Sally

Lesson eight - written test.

ALIVA-GLANDS	ORGAN / SECRETION	VERY ACID	BILE PIGMENTS	pH 6.5-7.5	SODIUM GLYCHOLATE
NEUTRAL				CHYME	GASTRIC JUICE - GASTRIC GLANDS
	PRESENCE OF FOOD	AMINO PEPTIDASE	MUCUS	EMULSIFY FATS	PEPTIDES → AMINO-ACIDS
OLE CYSTOMININ		SODIUM HYDROGEN CARBONATE		BREAK INTO SMALLER DROPLETS	PANCREAS - PANCREATIC JUICE
	BILE SALTS	BRUNNERS GLANDS	pH 2-0	TRYPsin (OGEN)	WALL OF SMALL INTESTINE
LYOSE → MALTOSE		EXOPEPTIDASE		SITE OF ACTION	PANCREATIC AMYLASE
MYLOSE → MALTOSE	MINERAL SALTS	CLOTS MILK PROTEIN	STOMACH	CAECUM	DUODENUM AND ILEUM
		DUODENUM	LARGE INTESTINE		SMELL, SIGHT, REFLEX
	PEPTIDES → AMINO ACIDS	COLON		PERTIN (OGEN)	PROTEIN → PEPTIDES + AMINO ACIDS
FOATES EPSINOGEN	pH		BILE JUICE		FATS → FATTY ACIDS + GLYCEROL
	VILLI	REABSORB WATER		OPTIMUM pH FOR ENZYMES	SEMI-SOLID FAECES
MALTAse	SECRETIN		STIMULUS	CONTENTS	STIMULATES PRODUCTION OF BILE
VARICATES + EVENTS AUTOLYSIS	RECTUM	ZYMOGEN CELLS	INTESTINAL JUICE		PANCREADYMIN
XYNTIC CELLS		LIPASE	MADE BY LIVER	ALKALINE	NEUTRALIZE ACID CHYME
RORENNIN	EFFECT	EGESTION		RENNIN	BINDS FOOD PARTICLES INTO A BOLUS
VEL-TRAL			MOUTH	DIPEPTIDASE	NO REAL FUNCTION IN HUMANS
	SUCRASE		SODIUM THUROCHOLATE		GASTRIN AND ENTEROGASTRONE
	NEUTRAL	DEFAECATION		DUODENUM	SUCROSE → GLUCOSE + FRUCTOSE
			CARBOXY-PEPTIDASE		MALTOSE → GLUCOSE
FOOD IN MOUTH STOMACH	DIPEPTIDES → AMINO ACIDS				SALIVARY AMYLASE
			COMPLEX GREEN FLUID		ANUS
ROTEINS → PEPTIDES		MUCIN		ENDOPEPTIDASE	MINERAL SALTS
	LACTASE	HYDROCHLORIC ACID			CHOLESTEROL
NEUTRALIZE SID CHYME					LACTOSE → GLUCOSE + GALACTOSE