Science and Mathematics Education Centre

Biology Teachers' Use of Their Interpretational Frameworks for Assessing Students' Understandings in Biology

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any person except where due acknowledgement has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Abstract

This study about biology teachers' assessments of the written work of senior high school students developed from my observations over many years as a practising biology teacher. Experienced biology teachers use processes and understanding in their assessment of students' responses to biology examination questions that I argue are based on their interpretational frameworks. Researchers have referred to internalised frameworks, frames of interpretation or interpretational frameworks as different terms for describing how teachers interpret and organise their experiences and knowledge. In this study the term interpretational framework refers to a teacher's construction composed of multiple integrated parts for making sense of situations and data. Consequently, the aim of the research was to investigate the different aspects of the interpretational frameworks used by biology teachers in assessing students' understandings in biology based on their written work and was guided by six research questions.

The data for this study came from interviews with six experienced biology teachers. The interviews were based on the teachers' analysis of their selected examination questions, their students' marked work samples and a common Test Question and Student Answer. Data were analysed using PaP-eR and case methods in order to identify particular views, dispositions, knowledge, experience and perspectives of individual teachers. A comparative analysis of the data was used to identify common themes and to develop assertions supported by evidence. Similarities, differences and idiosyncratic ideas and practices emerged that provided a rich understanding and comparison of these teachers' interpretational frameworks.

Six assertions were developed and grouped within three categories of *Making judgments of student achievement, Teachers' strategies for assessment* and *Frameworks for biology thinking.* These assertions were: 1. These biology teachers' assessment judgments are dependent on their expectations and interpretations of the students' biological explanations to questions. 2. These biology teachers award marks using a dynamic process consistent with their rationale and guided by a marking key. 3. These biology teachers design the most appropriate assessment strategies for their purposes and to meet internalised or external frameworks. 4. These biology teachers recognise the importance of feedback about assessments to student learning. 5. These biology teachers have a big picture, three-dimensional understanding of biology and prefer visual models. 6. These biology teachers consider that students differ from each other in their thinking, with most being linear thinkers who progress through shifts in learning. These assertions demonstrated substantial commonalities among the teachers as well as some differences

A comparison of the teachers in developing individual marking keys on a single, common Test Question and then making judgments of a resultant Student Answer noted variability in their construction of marking keys, patterns of marking and final judgments of the student answer. Marking keys showed a variety of formats and allocations of marks. In marking the common Student Answer, the pattern of allocations of marks for each section were different and final judgments varied.

The study suggests that these teachers interpreted students' written answers and made judgments based on their own expectations, knowledge and experience of biology, ideas on assessment, knowledge of the students' learning taxonomies and knowledge of education practices. Further, it was evident in this study that the experience, knowledge and processing of assessments becomes meaningful only through an internalised interpretational framework constructed by the teacher; that these experienced teachers had developed, and continued to develop, elaborate and sophisticated interpretational frameworks. It is concluded that biology teachers' interpretational frameworks in the assessment context are complex, three dimensional, relational, predominantly visual and incorporate dynamic decision-making processes in order to form judgments about their students' work. These experienced biology teachers had expectations of questions and answers, which influenced their judgments, but they also interpreted assessments from a student's perspective. They have views about the student's learning and their assessment responses and use strategies to maximise their students' potential in examination performance. The experienced teachers' interpretational frameworks took account of their knowledge and understandings about the interpretational frameworks held by their students. As well as this study having implications for expert/novice research, it is proposed that a major organising feature of the teachers' interpretational frameworks for assessment be termed Pedagogical Content assessment Knowledge (PCaK).

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Chapter 1

Introduction

1.1 Introduction

Teachers stand in a unique position within the lives of students and the community. It has been shown that teachers play a critical role in student achievement (Hattie, 2009), and are trusted with dual roles in teaching and assessing, particularly in developing and judging student achievement. These dual roles for the teachers necessitate a simultaneous operational role and regulatory role in the education of their students.

The aim of the research was *to investigate the interpretational frameworks used by biology teachers in assessing students' understandings in biology*. Italics have been used throughout this study for emphasis. Definitions and terminology are provided in 1.6. The aim assumed that teachers each had an interpretational framework based on their experiences and understandings of biology, education, their students and assessment strategies and in which they had organised their knowledge and practices in an integrated way. The research examined the unique perspectives of selected teachers in the specific contexts of the aim to achieve new understandings related to teachers' interpretational frameworks. Pedagogical Content Knowledge (PCK) and expert/novice lenses were used in the study to assist in the analysis of the research data and to create meaning. The investigation assumed that specific aspects of teachers' biology knowledge, practice and assessment strategies evident in their interpretational frameworks have been influenced by and assimilated from particular theories and propositions from relevant research literature. The investigation essentially sought to identify the premises and complex interplay of theory and practice in teachers' employment of biology organising structures, assessments of their students and expectations, preferences and why they make particular choices, in the context of the research aim.

It was important to examine teachers' interpretations, judgments and rationales as well as make comparisons between the teachers to find congruency and connections within this study. To address the aim, several research questions were devised to define the study and its outcomes. The research questions are outlined in Section 1.3.2. As the study focused on teachers, each with approximately 30 years experience, some of their influences may have been shaped by experiences and educational research literature from as long ago as the 1970s. A broad coverage of research was useful to enable insights into teachers' comments, which came from a range of research areas. These helped inform and locate directions, explanations and outcomes of this investigation.

Within education research, there is a view that teachers and students organise their understandings within internalised frameworks (Atkinson & Delamont, 2005; Gilbert, 2008). Erickson (1986) argued that frames of interpretation or schemata are brought to any experience. Pellegrino, Chudowsky, and Glaser (2001) stated that data could only gain meaning through an *interpretational framework*. The term *interpretational frameworks* was used by Gilbert (2008) to describe his findings that scientists tend to use different interpretational frameworks in different science specialty areas, for the same task. Bowen, Roth, and McGinn (1999) and Atkinson and Delamont (2005) used the phrase *interpretive frameworks.* Bowen et al. (1999) used *interpretive framework* in describing the interpretations of graphs by experts and novices suggesting that a range of *interpretive frameworks* are drawn upon by experts. Atkinson and Delamont (2005) discussed Geertz's (1973) notion of *interpretive frameworks* which they referred to as "multiple motivational frames that inform social events and actions" (p. 832).

For this study the term *interpretational frameworks* was deemed most appropriate. A teacher's *interpretational framework* has been defined in this study as a teacher's construction composed of multiple integrated parts for making sense of situations and data. The study aimed to identify those interpretational frameworks that biology teachers demonstrated in the context of assessment, if there were common interpretational frameworks, and if there were particular ways that biology teachers organised and selected from their ideas and thinking. During the study of these frameworks, the teachers' interpretations of student answers and their estimations of student achievement when they make judgments were examined. Are there considerations that impact on teachers' assessments, such as their own expectations of answers to questions, expectations of students, teachers' own preferred ways of learning or assessing that may emerge from the research? These aims and questions were deliberated based on data and analyses of the teachers' explanations of questions, their explanations of expected answers, analyses of their students' answers and each teacher's analysis of an independent student work sample.

Six expert teachers were selected as participants in the study in order to take advantage of the depth and breadth of their education and biological domain knowledge and their experiences in the nuances, multiplicity and complexity of students' learning experiences and knowledge. It is probable that the teachers selected had highly developed and practiced organisational structures forming coherent interpretational frameworks that they drew upon in their professional lives.

A sustained focus was applied in this research on what it is that teachers drew upon when considering assessments and in making judgments in the content domain of biology. Sadler (1998) identified the intellectual and experiential resources that teachers used in assessments, their dispositions and expertise in evaluation and feedback. Was there evidence of these or other prominent features within the teacher participants selected for this study?

This chapter introduces the study, providing a background and perspective to the research and an outline of the researcher's personal experience in Section 1.1. Section 1.2 describes and positions the study with Section 1.3 comprising the aim and research questions. The significance and limitations of the study are explained in Sections 1.4 and 1.5, while Section 1.6 specifies definitions and terminology. Section 1.7 describes the organisation and structure of the thesis in addressing the research questions.

1.1.1 Perspective

A notion proposed by Maxwell (2005) is appropriate for many aspects of this study: "Any view is a view from some perspective, and therefore is shaped by the location (social and theoretical) and *lens* of the observer" (p. 39). This notion was a useful reminder in the selection and development of the conceptual and theoretical framework for the study, the review of the literature, the selection of a theoretical research perspective and research methodologies, in analysing the data collected and in formulating the conclusions of the study. Maxwell's statement is applicable to the researcher, the participants and the choice of methods in the study. The researcher and each teacher had unique perspectives. The choices made by the researcher at each stage of the study and which had implications for the findings and conclusion, were shaped by the researcher's lenses. Views from different observers' *lenses* were explored through this study to answer the major research question.

1.1.2 Experiential knowledge of the researcher

A body of research recommends that explicit knowledge of a researcher's primary and personal experience, bias and identity be declared. Reason (1988) used the term "critical subjectivity" and explained its meaning as:

> a quality of awareness in which we do not suppress our primary experience; nor do we allow ourselves to be swept away and overwhelmed by it; rather we raise it to consciousness and use it as part of the inquiry process. (p. 12)

Other researchers support the disclosure of possible subjectivity and its incorporation into the research. The researcher's perspective and *lens* were reflected in the construction of the study and the conclusions drawn from it.

The researcher was a biology and general science teacher for over 20 years. In that capacity, she constructed and taught programs through many changes in curriculum and pedagogical paradigms. She introduced and led academic extension implementation within her school. Through involvement in conferences, she gained and experimented with new ideas in her classrooms. After additional experiences as a central science support officer to teachers, she returned to the classroom having modified an initial positivist theoretical position as a beginning teacher in the 1970s to a constructivist position. Further experiences as a science curriculum officer and an education manager for non-formal education centres developed her skills in listening to participant voices and designing experiences where the products or outcomes emerged from individuals or collaborations.

The researcher's philosophy changed through her professional life from teaching as an intervention, with teachers being the experts and believing they needed to transfer that expertise to students, to a more inclusive approach where attempts were made to engage participants with processes and curriculum negotiated to some extent. In classrooms and other educational environments, her aims towards the end of her teaching career included ways of working where the teacher and students helped shape and use particular ideas and skills together in order to develop learning goals and programs. The researcher for this study was essentially shaped by a lifetime of professional experiences and ideas to the point where the most recently adopted approaches and ideas seemed to dominate.

The researcher was concerned for over 20 years about the effectiveness of the education system, particularly schools and teachers, regarding students' achievement. Different ideas involved in teaching pedagogies, curriculum, learning environments, motivation, theories of learning and brain research, for example, were being explored and implemented in classrooms during that period. Part of the professional question about effectiveness within teaching and learning relates to the alignment in thinking between teachers and between the teachers' and their students' frameworks and the impact on achievement, particularly in the content domain of biology investigated in this study.

The researcher considered that a number of ideas could have an impact on the teachers' interpretational frameworks relating to assessment in biology. Awareness by the teachers of their own and their students' interpretational frameworks may be important in recognising students' answers and thinking in the classroom. Assessments and judgments by teachers have a considerable impact on students' lives. These judgments depend on a teacher's theoretical, interpretational and experiential frameworks, which is the focus of this study.

1.2 The Nature and Scope of the Study

The study was to determine (i) what interpretational frameworks teachers used in assessing their students' understanding of biology, (ii) what was the degree of alignment between teachers' interpretational frameworks in the context area and (iii) what views and perceptions do biology teachers have about assessment. Schon (1983) argued that the knowledge and theories that influenced teachers' practice are tacit. Loughran, Mulhall, and Berry (2004) contended that teachers have a mental construct in which they code their knowledge but according to Berry, Loughran, and van Driel (2008) teachers are often unaware of that knowledge. There are precedents for the use of *interpretational frameworks* in the literature and a challenge identified by Schon (1983), Loughran et al. (2004) and Berry et al. (2008) is teachers' identification of their frameworks and constructs.

Several researchers have described studying experienced teachers in order to provide an understanding of how aspects of teacher knowledge are utilised when teaching *(Berliner,* *1986; Shulman, 1986)*. This study aimed to make explicit those aspects of teachers' knowledge and theories and how they affected teachers' biology assessment interpretations, judgments and practice, through interviewing experienced teachers.

A framework for the review of the literature was developed identifying proposed connections between the research literature and the interpretational frameworks of the teachers.

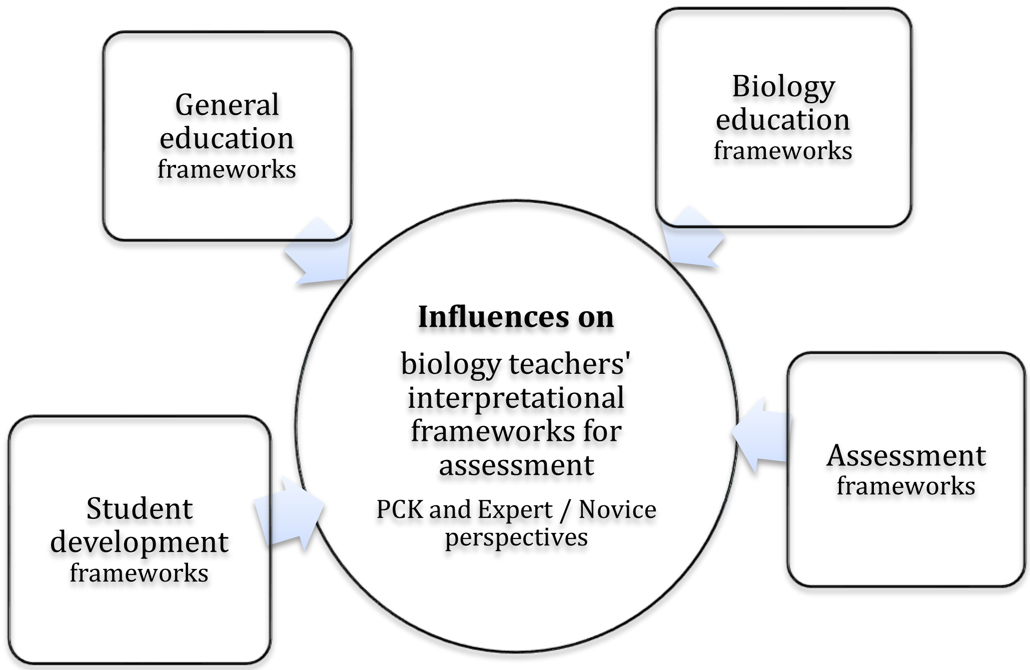


Figure 1.1 Framework for the review of the literature.

This was a qualitative study that used in-depth analysis of a small number of participants, similar to a *high-fidelity, narrow-bandwidth* study (Cronbach & Gleser, 1965). Methods used were in the form of interviews, analysis of student work and a triangulation exercise consisting of teachers' and students' responses to a single common question and student response. A family of research methods, based on interpretive methodology, was selected with the intention of highlighting the teacher voices, making sense of the data and discovering and communicating meaning-perspectives and interpretations.

Specifically, interviews (Minichiello, Aroni, Timewell, & Alexander, 1990; Patton, 1990), interpretation between interviewer and respondent in coding and decoding

(Foddy, 1993), the PaP-eR technique (Mulhall, Berry, & Loughran, 2003), cases (Lincoln & Guba, 1985; Merriam, 1998; Wallace & Louden, 2000; Yin, 1994), theory building (LeCompte & Preissle, 1993; Merriam, 1998; Miles & Huberman, 1994) and assertions (Erickson, 1986; Merriam, 1998) were used in informing the collection and analysis of data. The methodology and these methods were used to develop the emergence of assertions, individual teacher's views and perspectives and conclusions from the study. An important aspect of the study was a comparison between teachers in order to formulate assertions about their frameworks and alignment between individuals or groups of teachers.

1.3 Aim and Research Questions

1.3.1 Aim

The aim of the research was to investigate the interpretational frameworks used by biology teachers in assessing students' understandings in biology.

1.3.2 Research Questions

1. What are the views and perceptions of each teacher regarding assessment in senior school biology?
   This question is addressed in Chapter 4.
2. What are the influences on teachers' assessments and judgments of student achievement in senior school biology?
   This question is addressed in Chapter 5.
3. In what ways are different teachers consistent in their judgments of student achievement in biology?
   This question is addressed in Chapter 5.
4. What strategies do teachers use in assessing senior school biology?
   This question is addressed in Chapter 6.
5. What do teachers consider are their own and their students' frameworks for organising biology?
   This question is addressed in Chapter 7.
6. What are the commonalities and differences among the interpretational frameworks used by teachers in assessing senior school biology?
   This question is addressed in Chapter 5, 6 and 7.

In this research as shown in Chapter 3, the assertions and research questions were clarified when the data were analysed – there were no a priori decisions about the assertions and questions at the outset of the study.

1.4 Significance of the Study

The study is significant in examining the experiences of high school biology teachers, how they relate to, use, mark and make judgments about questions, concepts, strategies and responses. Judgment and inference making is at the centre of this work. Teachers' interpretations and judgments were examined and, in responding in interviews about students' questions, they explained their own frameworks, theory and practice. When, where, how and why the teachers used particular knowledge and practices in the context of this investigation and what meaningful patterns of understanding were evident, were ideas addressed in the study. This research provided authentic results, based on participant responses and ideas.

Teachers are increasingly encouraged to use their professional attributes (National Academy of Sciences, 2012), which may draw on their interpretational frameworks, to make consistent, reliable assessment judgments. Knowledge of teachers' interpretational frameworks in the context of assessment and judging student achievement would be useful for policy makers, in-service agencies, educational planners and teachers themselves. Assessment and learning outcomes could be improved as a result of better understanding in this area.

1.5 Limitations of the Study

Research in this study was limited to the thinking and practices that teachers draw on to assess answers and judge the quality of students' work and achievement in biology. It was limited by the explanations teachers provided in interviews as evidence in order to identify those interpretational frameworks that teachers used, teachers' personal and professional theories and commonalities among these teacher frameworks and theories.

The number of teacher participants in the study was limited in order to provide in-depth insights and understandings of six experienced individuals. This approach was judged more beneficial than a survey of the impressions of a large number of teachers. A limited number of written test questions on specific and limited numbers of concepts in biology were used. After discussion with the researcher, the teachers chose those test questions for the interview where the most expansive and useful information could be collected in exploring student answers. Familiarity with and the open nature of the assessment were judged important in facilitating the visibility of aspects of teachers' interpretational frameworks.

The assertions and conclusions of this study are limited in their generalisability. Exploring the assertions developed in this study to provide targeted directions for future research in testing throughout a wider population of teachers is included in the recommendations.

1.6 Definitions and Terminology

Conceptual framework. System of concepts, assumptions, expectations, beliefs and theories. Model. Tentative theory. The key factors, concepts or variables and the presumed relationships among them. (Maxwell, 2005, p. 33).

Dual-processing theories of judgment. Two qualitatively different but concurrently active systems of cognitive operations: System 1 thought processes are quick and associative, and System 2 thought processes are slow and rule governed (Kahneman & Frederick, 2002; Stanovich & West, 2002; Suto & Greatorex, 2008).

Expert / novice perspectives. It is in the context of classroom assessment that theories of cognition and learning can be particularly helpful by providing a picture of intermediary states of student understanding on the pathway from novice to competent performer in a subject domain (Pellegrino et al., 2001).

Framework. A structure composed of parts and united together or work done in, on or with a frame (Macquarie University, 2001, p. 745)

Interpretation. "Making sense out of a local situation" (Denzin & Lincoln, 2005, p. 17), elucidation, explanation, give a construction placed on something, the rendering… to bring out the meaning, translation (Macquarie University, 2001, p. 990).

Interpretational framework. A teacher's construction composed of multiple integrated parts for making sense of situations and data (adapted for this study from Bowen et al. (1999), Pellegrino et al. (2001), Atkinson and Delamont (2005) and Geertz (1973)).

Models of cognition. Created from data interpretations are proposed as conceptual tools to identify and discriminate among hypothesised constructs, and represent inferred relationships among constructs (Gess-Newsome, 1999, p. 3).

PaP-eR formats. The PaP-eR format is an explicit representation attempting to capture teachers' reasoned decision-making in the teaching context (Mulhall et al., 2003).

Schema. A cognitive construct that organises the elements of information according to the manner with which they will be dealt (Sweller, 1994, p. 296).

TEE. Tertiary Entrance Examination, Western Australia.

Theory. "The simplest form of a theory consists of two concepts joined by a proposed relationship" (Maxwell, 2005, p. 33).

1.7 The Organisation of the Thesis

This thesis has been written using the following structure:

- Introduction to the investigation (Chapter 1), the researcher and the development of research questions. Development of a framework (Figure 1.1) for the literature review.
- Literature review addressed what was already known of appropriate frameworks, exploring ways of viewing the study and what could inform or impact upon on this study (Chapter 2).
- Chapter 3 includes a review of the literature related to the methodology and an outline of the methodology and methods used in the study.
- Individual teacher's interpretational frameworks were analysed in the light of these reviews and selection of appropriate methods (Chapter 4).
- Analysis and evidence supporting assertions were presented to inform understanding of teachers' interpretational frameworks (Chapters 5, 6 and 7).
- Explanation of the evidence and findings on the research questions, conclusions and recommendations were made (Chapter 8).

The aim of the study was to understand the interpretational frameworks used by an individual biology teacher within their context and history, find what commonalities exist between biology teachers' interpretational frameworks and provide answers to the major aim of the research *to investigate the interpretational frameworks used by biology teachers in assessing students' understandings in biology*. For the purposes of the study,

In order to understand these frameworks, evidence was collected of what interpretations, understanding and decisions about assessments in biology were made by each teacher. The analysis of teacher's ideas and comments was presented to illuminate individual frameworks and compare understanding of responses, addressed within the results and discussion chapters. Data describing individual teacher's viewpoints, explanations and perceptions of assessments have been presented in Chapter 4 and provide understanding of research question 1. A case study method (Lincoln & Guba, 1985) was used to enable the teachers to tell their stories and the researcher to define each teacher's frameworks, views and dispositions. Assertions were developed to show comparisons between teachers' interpretational frameworks, so no assertions were developed for Chapter 4. A comparison was made of the expert biology teachers' frameworks to ascertain commonalities or differences. In Chapters 5, 6 and 7, six assertions (Erickson, 1986) developed from analyses have been proposed and used to develop a theoretical comparative organisation for the study. Assertions and descriptions of teachers' possible interpretational frameworks, drawn from the body of research, result in proposed answers to the research questions. Research Questions 2 and 3 are addressed in Chapter 5, Research Question 4 in Chapter 6, Research Question 5 in Chapter 7 and Research Question 6 in Chapters 5, 6 and 7. The research questions' locations in particular chapters are shown in Table 1.1. Chapter 8 presents findings in relation to the major research and subsidiary questions and conclusions to this study. Recommendations are suggested.

Table 1.1 Research questions in results and discussion chapters.

Research Questions	Assertions	Chapter
1. *What are views and perception of each teacher regarding assessment in senior school biology?*	No assertions. Individual teacher cases are built.	**Chapter 4** **Individual teacher's interpretational frameworks**
2. *What are the influences on teachers' assessments and judgments of student achievement in senior school biology? and* *3. In what ways are different teachers consistent in their judgments of student achievement in biology?*	1. These biology teachers' assessment judgments are dependent on their expectations of and interpretations of the students' biological explanations to questions. 2. These biology teachers award marks using a dynamic process consistent with their rationale and guided by a marking key.	**Chapter 5** **Making judgments of student achievement**
4. What strategies do teachers use in assessing senior school biology?	3. These biology teachers design the most appropriate assessment strategies for their purposes and to meet internalised or external frameworks. 4. These biology teachers recognise the importance of feedback about assessments to student learning.	**Chapter 6** **Teachers' strategies for assessment**
5. What do teachers consider are their own and their students' frameworks for organising biology?	5. These biology teachers have a big picture, three-dimensional understanding of biology and prefer visual models. 6. These biology teachers consider that students differ from each other in their thinking, with most being linear thinkers who progress through shifts in learning.	**Chapter 7** **Frameworks for biology thinking**
6. What are the commonalities and differences among the interpretational frameworks used by teachers in assessing senior school biology?	All of the assertions are relevant in answering this question.	**Chapters 5, 6 and 7**

Chapter 2

Review of Research Literature

2.1 Introduction

In this chapter definitions, purposes, usefulness and examples of applicable frameworks and theories from the most pertinent literature appropriate to the aim and research questions are examined. An iterative process was used in the development of the thesis including analysis of the research literature. Ideas that would provide potential direction were scrutinised, then as complex understandings arose from the teacher participant data, a process of returning to the literature was employed to find relevant models and research from studies that could further inform the analysis. This emergent and iterative approach used in the identification of research and analysis of the data was comparable to grounded theory methodology proposed by Glaser and Strauss (1967) and further described by Denzin and Lincoln (1994) and Maxwell (2005). This study was not set up to provide support for any particular theory. It was an emergent study, where qualitative methodology was applied to discussions between the researcher and teachers on their thinking and practices within their everyday contexts related to assessment in biology.

A plan for the review of the literature was developed which included influences of a range of frameworks on the biology teachers' interpretational frameworks in an assessment context. The ideas within the research literature also informed and gave coherence to the analysis and findings of this study. Frameworks related to four aspects have been investigated. These are general educational frameworks, student learning frameworks, biology domain frameworks and assessment frameworks. A summary of these frameworks is presented in Figure 1.1.

General education organising frameworks, which included assessment, were discussed. A range of knowledge frameworks were identified, including conceptual frameworks, theory, models of cognition, schema and mental models. These frameworks provided a way to understand the teachers' comments and analysis.

Frameworks for student learning were identified as a relevant aspect contributing to the biology teachers' interpretational frameworks. Developmental models describing taxonomies of objectives, levels of understanding and intellectual capacity, and students' multiple frameworks and cognitive strategies informed the study.

The chapter includes substantial discussion of frameworks for organising biology is a feature of Chapter 2. Biological philosophy, biological literacy, methods of instruction and organisational frameworks in relevant biology curricula used by these biology teachers are reviewed. Three-dimensional models of understanding biology are discussed as well as qualitative differences apparent in biology education research.

Assessment is the context within which these biology teachers' interpretational frameworks were investigated. Assessment ideas, including relevant definitions, processes, purpose, uses of inference, evidence, adequacy and assumptions were reviewed. Research on misjudgments and weak predictive power of national tests are considered. Assessment paradigms, theories and interpretational frameworks are discussed and specifically those relating to decision- and judgment-making. Cognitive load theory and personal assessment transactions are discussed in terms of teachers' assessment interpretational frameworks.

PCK and expert/novice research perspectives were investigated as being useful in understanding biology teachers' interpretational frameworks. PCK relates to the intersection between teachers' subject matter and pedagogical knowledge. A range of evidence from the PCK literature has been reviewed and related to biology teachers' frameworks and assessment contexts. An expert/novice perspective was considered relevant in exploring distinctive ways that these experienced biology teachers view knowledge and problems and their perceptions of their students.

In reviewing the literature, relevant general educational frameworks and theories are outlined in Section 2.3 and an examination of specific frameworks for understanding student and developmental learning is presented in Section 2.4. Frameworks specific to the biology domain are examined in Section 2.5. Relevant literature on assessment is outlined in Section 2.6. Particular ideas such as PCK and expert/novice perspectives are specific areas of the literature that resonate with the study and are examined in Section 2.7.

2.2 Interpretational Frameworks

Central to this study was the explanation of possible interpretational frameworks held by biology teachers in an assessment context. *Interpretation* was defined as "making sense out of a local situation" (Denzin & Lincoln, 2005, p. 17). Macquarie Dictionary definitions of interpretation are "elucidation", "explanation", "give a construction placed on something", "the rendering… to bring out the meaning" and "translation" (Macquarie University, 2001, p. 990). *Interpretational* is an adjective describing these processes. A *framework* is "a structure composed of parts and united together" or "work done in, on or with a frame" (Macquarie University, 2001, p. 745). Very closely associated is the term *frame of reference* defined as "a context, a set of considerations, factors… in the light of which a present concern is to be considered" (Macquarie University, 2001, p. 745).

In Chapter 1 the terms interpretational frameworks and interpretive frameworks were introduced into the study. The term *interpretational frameworks* was used by Gilbert (2008) and Pellegrino et al. (2001). Bowen et al. (1999), Atkinson and Delamont (2005) and Geertz (1973) used the term *interpretive framework.* Although Geertz and Bowen et al. used the word *interpretive* rather than the word *interpretational* chosen for the research aim and questions in this study, their notions were helpful. The word *interpretive* also has a well-defined association with certain epistemologies and methodologies, so that if it had been used in the study aims it may have caused confusion. A teacher's *interpretational framework* has therefore been defined as a teacher's construction composed of multiple integrated parts for making sense of situations and data. The idea of a context, in this case biology assessment, with a set of considerations of a current issue, concept or concern and used to inform events and actions taken by the teacher, is also important.

The development of frameworks for organising ideas, explanations and actions had a strong base in the research literature. An exploration of examples of frameworks that were used, suggested or implied within discussions with teachers are outlined. When teachers in this study revealed their own theories and explanations on teaching, learning, assessment and making judgments and interpretations in the results and discussions chapters, a comparison was made with specific published ideas within the research literature. Interpretational frameworks held by individual teachers in the learning and teaching context, were illuminated by a general understanding of the discussion in the literature of learning frameworks. This led to a more targeted review of ideas specifically concerning individual teachers' views and theories within an assessment context.

2.3 General Educational Frameworks

The needs of the child and the requirements of the curriculum being facilitated by teachers were discussed by Dewey (1902, cited in Darling-Hammond, Bransford, & LePage, 2005, p. 10). Darling-Hammond et al. (2005) outlined several models. One model included knowledge of learners, knowledge of curriculum content and goals and understanding teaching as components. Jenkins' *Tetrahedral model* (Darling-Hammond et al., p. 19) included teaching and learning activities, characteristics of the learner, criterial tasks and nature of the content. A *How People Learn* (HPL) framework (Bransford, Brown, & Cocking, 2000; Donovan, Bransford, & Pellegrino, 1999) was constructed upon four guidelines for thinking about learning which included the learner, the knowledge, the assessment and the community.

2.3.1 Conceptual frameworks, models of cognition and theories

In this study, what was embodied in a biology teacher's general educational framework could include a diversity of concepts, theories, processes, structural components, connections, memories, learning preferences and procedural and technical responses (Maxwell, 2005; Minsky, 1975; Strauss, 1995; Sweller, 1994).

Maxwell's (2005) definition of a conceptual framework included a "system of concepts, assumptions, expectations, beliefs and theories" (p. 33) held by an individual about a particular phenomenon. Maxwell also defined the conceptual framework as a "model" or a "tentative theory" and proposed that "the simplest form of a theory consists of two concepts joined by a proposed relationship" (p. 33). Miles and Huberman (1994, p. 18) defined a conceptual framework as "the key factors, concepts or variables and the presumed relationships among them". Maxwell (2005), in referring to research practice, outlined a conceptual framework that included methods, validity and justification that was useful for assessment.

In terms of identifying models of cognition, some insights were provided by Gess-Newsome (1999) who defined models of cognition as “created from data interpretations, are proposed as conceptual tools to identify and discriminate among hypothesised constructs, and represent inferred relationships among constructs” (p. 3). She defined good models as ways to “organise knowledge in new ways, integrate previous disparate findings, suggest explanations, stimulate research, and reveal new relationships”(p. 3). A more specific framework, a *schema*, was defined by Sweller (1994, p. 296) as “a cognitive construct that organises the elements of information according to the manner with which they will be dealt”. He described subject matter knowledge as being organised into schemas and gave an example of a tree schema, where people are influenced by the idea of a tree. The elements of a tree, such as leaves, branches, shape were seen as part of the tree schema. He equated this with an algebraic problem, made up from a number of symbols and equation elements that could be seen as a *chunk*. Sweller (1994) identified *chunk* as interchangeable with schema. He proposed that knowledge was dependent on *schema* acquisition and that “schemas provide the basic unit of knowledge and through their operation can explain a substantial proportion of our learning mediated intellectual performance” (p. 297). *Schema* has also been described and used by Rumelhart (1980) and Mislevy (1996). Other descriptions of knowledge frameworks have been termed *frames* (Minsky, 1975) and *mental models* (Johnson-Laird, 1983). These ideas are consistent with the aim of this study related to developing understandings of teachers’ interpretational frameworks.

Drawing on Strauss (1995), Maxwell (2005, p. 42) defined the purpose and use of theory: “A major function of theory is to provide a model or map of why the world is the way that it is.” Further, he commented that theory was not only a framework but “tells an enlightening story about some phenomenon, one that gives you new insights and broadens your understanding of that phenomenon”. In describing the process of theorising, LeCompte and Preissle (1993) highlighted the process as realising or operating abstract groupings and their relationships. Their research discussed frameworks and theories, how they connect and what purposes they serve.

In describing the functions of theories, metaphors have been used which are useful to the study and have provided a better sense and idea of theory to the researcher. Metaphors of theories have been explained in the literature. Metaphors include *theory* *as a coat closet* (Maxwell, 2005, p. 43) where the theory provided a framework of sense-making and related seemingly unconnected information. The coat hooks were considered as the concepts from which the appropriate information was hung. It provided an organisational structure. Another useful metaphor of theory was *theory as a spotlight* (Maxwell, 2005, p. 43) where the theory highlighted phenomena and relationships that otherwise may have been overlooked.

These ideas on conceptual frameworks, models and theories fit well with the current study and provided a way of considering and operationalising the notion of theory and interpretational frameworks. In terms of informing the research questions and definition of teachers' interpretational frameworks, the discussion in this section solidified ideas including definitions, purposes, uses and examples of relevant frameworks. Consequently, the researcher's *working definition* for this current study is that interpretational frameworks are composed of key concepts and their observed or inferred relationships and systems, teachers' expectations and beliefs, theories, data interpretations and ways of discriminating between hypothesised constructs. Examples include models of cognition, conceptual frameworks and theory. Purposes of a theory for this study are in providing models and telling stories about a phenomenon. Some uses of frameworks were suggested such as assessing, organising and integrating knowledge, inferring relationships and explaining.

2.4 **Student Development Frameworks** and cognitive strategies

Teachers may be influenced by theories or research on student learning during their training or through their working lives as teachers. Understanding student learning is important to teachers' lives and form a component of their interpretational frameworks. Examples of well-known research on student learning are presented here, that the teachers in this study would be familiar with, as well as lesser-known research that helps make sense of the teachers' ideas or comments.

2.4.1 Taxonomies of student learning

Levels of complexity in thinking and taxonomies of student learning have been a well-investigated topic since Bloom and Piaget. Bloom (1956) conceptualised taxonomies of objectives made up of cognitive, affective and psychomotor domains. The taxonomy domain that was expected to be significantly used by the teachers in this study in relation to their students was the cognitive domain, which has the hierarchy of knowledge, comprehension, application, analysis, synthesis and evaluation.

Certain schemas representing a conceptual or intellectual structure were defined by Piaget (1960) within stages of children's thinking. He stated that experiences were assimilated into a structure until these could no longer be incorporated within the existing structure. This lack of fit could then engender an *accommodation*, the changing of a current schema into a new schema. Piaget used this model to explain the development in children's intellectual capacities. He defined stages as sensorimotor (0-2 years), preoperational including pre-conceptual thought (2-4 years) and intuitive thought (4-7 years) and operational, including concrete operational (7-11 years) and formal (11-16 years). These two areas of research by Bloom and Piaget were widely presented in teacher training courses in the 1970s and 1980s. Within the teachers' comments implied or explicit ideas relating to Bloom's taxonomy and Piaget's stages in child development were explored in this study.

Another taxonomy was developed by Biggs and Collis (1982). Their taxonomy called the Structure of Observed Learning Outcome (SOLO) described increasing complexity of understanding of student development and work. This model included five levels - pre-structural, where the student does not demonstrate understanding and applies simplistic processes, uni-structural where the focus is on one relevant aspect, multi-structural, where several different aspects are treated independently, relational, where there is integration of different aspects into a coherent whole and extended abstract, where the integrated whole can be generalised or viewed within a higher level of abstraction. The SOLO levels developed by Biggs and Collis resonate with the stages developed by Piaget. The curriculum in Western Australia (Curriculum Council of Western Australia, 1998) at the time of the commencement of the study was structured around a combination of the research findings and taxonomies of Piaget (1960) and Biggs and Collis (1982), and these provide a context for comments made by the teachers. The data analysis in the study addressed which of these taxonomies were used by teachers.

2.4.2 *Students' multiple frameworks and cognitive strategies*

Research on students' cognitive frameworks elicited two predominant views. The first is that students have coherent and stable science ideas expressed in alternative frameworks (Andersson, 1986; Vosniadou, 1992). The second view is that students have erratic, fragmented science concepts that are highly contextual (BouJaoude, 1991; Claxton, 1993; diSessa, Gillespie, & Esterly, 2004). Both of these views have been challenged by Taber (2000) who proposed multiple frameworks, arguing that "an individual learner can simultaneously hold in cognitive structure several alternative stable and coherent explanatory schemes that are applied to the same concept area" (p. 399) and that these could also be applied across contexts. He postulated that students could select the most appropriate alternatives for particular contexts over time. The extent of change in this selection could indicate conceptual development.

In recent studies on children's learning, Siegler (2005) undertook an analysis of the alterations and improvements in young children's cognitive strategies, mostly in mathematics and science areas, that highlighted developmental change. Siegler (2005, p. 772) found that different approaches were used by different people and that "the same person often thinks about the same type of problem in multiple ways". Schauble (1996) commented that cognitive variability was evident even within a single person solving a single problem. The *encoding hypothesis* proposed by Siegler (2005), where students may fail to encode relevant information therefore explaining their failure, is relevant to this study. He maintained that students know and choose from a range of strategies or approaches to solve problems rather than a single consistent approach and that learning and development were processes of variability, choice and change. Siegler and McGilly (1989) described a study in which children switched strategies on a third of problems presented twice in the same week. New strategies were often constructed from components of existing approaches, particularly when relevant strategies have been used recently and thus are relatively active (Siegler & Araya, 2005). Recency of learning and recency of strategy development in biology may be an indicator of success in assessments and therefore important in timing of assessments. Siegler (2005) described Piagetian development as a progression of approaches to learning, when a developmental sequence of one approach supplanted the previous approach. Siegler postulated that developmental sequences involved a “variability of learning approaches and changing distributions of approaches” (p. 772).

The taxonomies and stages in learning, cognitive and strategy variability and the encoding hypothesis in this section are relevant to this study. Student learning research cited in this section is used to inform the analysis, comparisons and revelation of teachers’ interpretational frameworks undertaken in this study.

2.5 Biology Education Frameworks

Identification of preferred biological organisation used by teachers within their interpretational frameworks is an important aspect of this study. Erickson (1986, p. 126) compared biology with other sciences, stating that in biology, “relations among organisms are … ecological, that is causal relations are not linear in one direction, but because of the complexity of interaction among organisms within and across species, cause is multidirectional” and he argued that the causal relations were more complicated in biology than in physics or chemistry. From the *Biological Science Curriculum Study (BSCS)* courses (Biological Sciences Curriculum Study, 1963), Shulman (1986) described the way biology teachers organised knowledge of their discipline. He elaborated on three different ways to organise biological knowledge:

> (a) a science of molecules from which one aggregates up to the rest of the field, explaining living phenomena in terms of the principles of their constituent parts; (b) a science of ecological systems from which one disaggregates down to the smaller units, explaining the activities of individual units by virtue of the larger systems of which they are part; or (c) a science of biological organisms, those most familiar of analytic units, from whose familiar structures, functions, and interactions one weaves a theory of adaptation. A well prepared biology teacher will recognise all of these; and alternative forms of organization. (p. 9)

A subsequent response and suggested amendment to Shulman’s depiction of biology teachers’ knowledge came from Carlsen (1999). He suggested that Shulman’s three organisational frameworks for understanding Biology corresponded to the three versions of *BSCS* textbooks and that more recently “*BSCS* has decided that evolutionary theory provides a superior conceptual organiser for biological literacy” (p. 141). *BSCS* articulated the emphasis in a guide to teachers developing secondary and post-secondary biology curriculum (Biological Sciences Curriculum Study, 1993) under *Major*

Recommendations saying "the content of biology must be unified by the theory of evolution" (p. vii). The example provided was

> when *Evolution: Patterns and Products of Change* is used as a unifying principle of biology, cell parts, tissues, and hormones may be seen as adaptations that have contributed to an organism's successful reproduction and to a species' reproductive success through evolutionary history. (p. xiv)

The justification for the selection of evolution as the unifying principle was "Evolution is *the* unifying theory of biology because it has played a role in the history and lives of all living organisms on Earth today – and of those that are now extinct" (p. 58). In a 2007 interview with Lee Shulman, Berry et al. (2008) found a re-focusing in Shulman's initial view on biology where he recognised the centrality and complexity of evolutionary theory in biology and he combined domain understanding of biology with biology PCK (see section *2.6.1)*.

BSCS (Biological Sciences Curriculum Study, 1993) identified other unifying principles as: *Interaction and interdependence*, *Genetic continuity and reproduction*, *Growth development and differentiation*, *Energy, matter and organisation* and *Maintenance of a dynamic equilibrium*. BSCS categorised biological literacy in increasing levels of competence:

- Nominal, with recognition but little explanation,
- Functional, consisting of memorisation and little understanding,
- Structural, the ability to provide appropriate explanations of concepts and
- multi-dimensional, the ability to apply and integrate understanding to problems.

These categories of competence show similarity with the taxonomies described by Piaget (1960) and Biggs and Collis (1982), as well as a possible expert/novice continuum and can be compared with data from the participating teachers.

2.5.1 A history of content and curriculum organisation in biology

In 1959 the formation of the new Biological Sciences Curriculum Study in the USA was announced (Biological Sciences Curriculum Study, 1959). The aim was to create a new curriculum in biological sciences, with broad foundations at all levels from primary to university with an initial focus on secondary school. Part of the development was to identify effective biology teachers and examine what successful practices they had in common. Similarly, this current study selected experienced biology teachers and sought to identify practices and ideas in-common which could have formed teachers' interpretational frameworks.

Following the renewal and development of biology in the form of *BSCS* in the USA, *The Web of Life* (Australian Academy of Science, 1981a) was developed in Australia. The first edition in 1967 was adapted from the *Biological Science Curriculum Study Guide* (*BSCS*) Green Version (Morgan, 1967), with similar organisation to the *BSCS* in the content area of biology and accompanying inquiry, nature of science and instructional models. It was a comprehensive course incorporating a textbook, teachers' guides, laboratory manuals and some audio-visual materials. The organisation was across 80 ideas, based on single propositions and incorporated biological material engendering a *narrative of enquiry*, exercises designed to develop specific concepts and their integration into the pattern for the whole course (Morgan, 1967). Lucas (1980) emphasised that the *BSCS* philosophical basis and methods of instruction were needed in its implementation for successful practice. In research on *The Web of Life* implementation and practice, Dowd and Dekkers (1980) found significant differences between teachers' and students' priorities in the objectives and that classroom inquiry practices were limited, despite many teachers believing their inquiry orientation was high. These early studies focused on teacher understanding and perception of practice in the implementation of biology curriculum.

Later revisions of *The Web of Life* in 1973 and 1981 incorporated contemporary understandings of the learning process, changes in biology knowledge and a greater emphasis on the Australian context. All of the Western Australian biology teachers participating in the current study used *The Web of Life* as their biology textbooks for the first years of their teaching careers. *The Web of Life* had a virtual monopoly in Australian senior school biology curriculum for about 20 years and its materials were used for university entrance courses, examinations and curriculum syllabuses (Lucas, 1980). In addition to *The Web of Life*, Western Australia was the only state that had a separate Human Biology course simultaneously (Lucas, 1980). *The Web of Life* was not revised or re-printed but the Australian Academy of Sciences produced *Biology: The common threads* (Australian Academy of Science, 1990) instead. Consequently, *The Web of Life* was replaced by teachers in that decade with a range of other texts.

The Australian *Web of Life* (Australian Academy of Science, 1981b) described three levels of learning used throughout the book, each of which was referred to as a *Level of treatment*. These were

> Level 1 work involves the student in making firsthand observations and thinking about those observations in a very concrete way. Level 2 involves reasoning from observations to generalisations and carrying out related reasoning processes. Level 3 work involves the student in reasoning with ideas alone, at an abstract level. (p. 15)

This description appeared to be a combination of Bloom (1956) and Piaget (1960) in origin. In the book there is a caution to teachers confirming that a "level indicated suggests the type of thinking likely to be involved in a certain activity" (p. 15) and warned to not categorise a student into a level.

The main aspects of discussion in the introduction of the 1981 *Web of Life Teachers Guide* (Australian Academy of Science, 1981b) were not the biology content but the general aims to help students develop particular cognitive abilities such as scientific understanding in biology and application to problems, the nature and limitations of science and respect for evidence, rationality and honesty.

The content in the third edition of the *Australian Web of Life* (Australian Academy of Science, 1981a) was organised into a Year 11 and Year 12 course, the Year 12 course examinable in the Tertiary Entrance Exam (TEE) which was a Western Australian final year examination. In the Year 11 course, *The Living World* topics of classification, adaptations and environment, reproduction, nutrition, populations, the web of life and human impact suggested an immersion of students into the breadth and issues of biology. In the Year 12 course *The Functioning Organism*, the topics of cells, function and structure in organisms in their environment, integration and regulation, cells, heredity, selection and evolution and human species suggested more complexity and relationship building in biology. There were organisational charts showing that knowledge in some sections was based on one or two previous sections. It seemed that individual organisms were not discussed in isolation but they were related to their cells, their environment and adaptations for survival. The content as discussed by Shulman (1986) - cellular level, organism level and ecosystem level along with a survival focus - were continually related within the groupings of knowledge in Year 11 and Year 12.

From the 1990s in Western Australia, the TEE biology curriculum course was divided into five modules over the two senior school years of biology study: Module 0 *Introduction to Scientific Method,* Module 1 *The Cell,* Module 2 *The Organism,* Module 3 *The Species* and Module 4 *Ecosystems* (Walster, 1997). The organisation of biology by 1997 was more similar to that operating in the *BSCS* up to the late 1980s, when Shulman (1986) commented on it. There was not the *BSCS* re-focus indicated by Carlsen (1999) of evolutionary theory to provide *the* conceptual organiser for biological literacy in the Western Australian senior school curriculum. The experienced Western Australian teachers participating in this study taught this revised curriculum in the 1990s and early 2000s, retaining the levels of biological organisation of earlier *BSCS* and *The Australian Web of Life*. There was considerable stability in the course for many years.

The most recent Western Australian *Biological Sciences Senior School Syllabus* (SCSA, 2009) had three Outcomes - Investigating and Communicating in Biology, Biological Systems, and Biological Change. Four themes were developed in structuring the course content. These were *Ecosystems, biodiversity and sustainability*, *The functioning organism*, *Continuity of species* and *Working as a biologist* each of these contributing to achievement of the Outcomes. This was the curriculum with which the biology teachers were working at the time of the study.

Other countries developed a biology curriculum in slightly different ways. The Oxford Cambridge and Royal Society of Arts (OCR) AS/A Level General Certificate of Education (GCE) Biology course in the United Kingdom (OCR, 2013) had a structural arrangement of Cells, Exchange and Transport, Molecules, Biodiversity, Food and Health, Communication, Homeostasis and Energy and Control, Genomes and Environment. The A level biology examinations would be equivalent to the Western Australian TEE examination, although the students are in general, one year older. The Republic of Ireland Department of Education and Skills Leaving Certificate Biology Syllabus (Department of Education and Skills, 2013) consisted of three units: *Biology – The Study of Life* (method, characteristics of life, nutrition, ecology, ecosystem), *The Cell* (structure, metabolism, continuity, diversity, genetics) and *The Organism* (diversity, organisation and vascular structure, transport and nutrition, breathing and excretion, reproduction and growth). The Republic of Ireland system would have been used by the Irish teacher in the study and the course used appeared to be closely related to the main three levels of cells, organism and ecosystems that appeared in most biology curricula for the last 50 years.

2.5.2 Developing a three-dimensional framework in biology

Three-dimensional organisational frameworks in biology have been developed. Tsui and Treagust (2013) proposed a cube model for examining learning across the representations of biological knowledge. This model consisted of a three dimensional cube framework consisting of six unifying themes for the biology domain (*Evolution*, *Homeostasis*, *Energy, matter and organisation*, *Continuity*, *Development and Ecology* drawn from the Biological Sciences Curriculum Study (2006), four translation levels in Biology (*Macro*, *Micro*, *Sub-micro* and *Symbolic*) and seven modes of increasing abstraction (*Worldly objects / actions*, *Photos / animations*, *Natural drawings*, *Maps / diagrams*, *Graphs / tables, Equations, Linguistic input and output).* The seven modes of increasing abstraction were proposed by Pozzer and Roth (2003). This cube framework was selected from the literature as it directly compared the unifying themes in biology, the levels of visibility of concepts within biology and the modes of abstraction of representations, areas that are possibly aligned with teacher thinking or development of frameworks in biology. In *Developing biological literacy*, the *BSCS* teachers' guide (Biological Sciences Curriculum Study, 1993), three different cubes had been developed, one for biology as a scientific discipline (pp. 109-110), one for advising about teaching and learning in biology (pp. 54-55) and a third about biology education (card inserts representing one cube are found in Appendix 1).

So far the discussion has described several ways of viewing biological knowledge, those being levels of understanding from cellular/biochemical (microscopic/symbolic) to ecosystem (macroscopic) levels, another being in terms of biology topics, a third way being concrete or abstract and finally looking at complexities in interactions and multidirectional causality in biology. The results and assertions from teachers in the current study are compared with the biological models and organisational frameworks described, to find how well the orientation and findings align with these frameworks.

During the teacher interviews a probing question was asked to ascertain if there was a focus or preference for the use of visual representations by teachers and students in understanding biology. Treagust and Tsui (2013) specifically drew out visual representations as being a common recurring theme amongst the studies in their edited book. Gilbert, Reiner, and Nakhleh (2008) showed that visual models were important in science education. Gilbert (2008) wrote about visualisation as making meaning of both external representations (in forms available to others, for example pictures, diagrams, tables) and internal representations (individual mental representations or images). Eilam (2013) drew attention to the need for extensive use of visualisation to connect with characteristics of the biology domain, such as in representing stages of processes, temporal development and different sectional views of organisms.

2.5.3 Qualitative differences in biology

Two aspects of qualitative differences in biology may be relevant to discuss as part of this study. Domain areas in biology may be qualitatively different from each other and account for differences in teachers' ideas about their own frameworks for organising biology. Student frameworks in organising biology may also exhibit qualitative differences.

An aspect of qualitative difference noted in this study is in the domain area of biology. Schonborn and Bogeholz (2013) described a hierarchical model of types of biological knowledge being developed in courses at secondary high schools in Germany. The expert teachers in their study exhibited differences in interpretation and views about the relationships being studied in the courses, generally mostly agreeing, but with some reservations. Among the many interesting discussions that emerged the authors commented that, "The differences between the three biological domains are: ecology is a describing [descriptive] biological area; genetics is more abstract and with a lot of chemical aspects; and evolution is extremely analytical. The way of thinking differs a lot [between these three domains]" (p. 121). The quote was an insightful comment about qualitative difference between biology domains that indicated another way of viewing biology.

A qualitative difference in the way students organise biology in their cognitive schemas has been suggested by Lopez, Atran, Coley, and Medin (1997), who found that different cultures promoted different biology schemas. Taxonomic schemas, where animals were classified using their characteristics, were common among American college students, whereas Itzaj Maya students from Guatemala were found to develop schema predominantly on ecological relationships. While each group understood the importance of the alternative organisation, Lopez et al. (1997) suggested that the dominant organisational schema was valued by the culture in which it operated.

The studies by Treagust and Tsui (2013) and Schonborn and Bogeholz (2013) were informative on a number of levels to the current study, including their use of experienced biology teachers. The influence of frameworks on the biology teachers in the current study and whether teachers take account of qualitative differences within biology domains in their questions become significant. Through the data analysis, comment related to this area of research emerged.

2.6 Assessment Frameworks

The context chosen for the research question was assessment, with the opportunities it created to explore biology teachers' interpretational frameworks when discussing student achievement. In developing understandings of assessment, the researcher reviewed the relevant literature about assessment and possible assessment frameworks.

There are many definitions of assessment. Assessment is referred to by Sadler (2005, pp. 1-2) as the "process of forming a judgment about the quality and extent of student achievement or performance, and therefore by inference, a judgment about the learning that has taken place". Pellegrino et al. (2001) suggested that:

> an assessment result is an estimate, based on samples of knowledge and performance from the much larger universe of everything a person knows and can do.
>
> One must therefore draw inferences about what students know and can do on the basis of what one sees them say, do, or make in a handful of situations. What a student knows and what one observes a student doing are not the same thing. The two can only be connected through a chain of inference, which involves reasoning from what one knows and observes to form explanations, conclusions or predictions. (p. 42)

Pellegrino et al. (2001) also described assessment in terms of three elements: the achievement or cognition assessed, the tasks, observations or questions used in evidence collection, and the analysis methods and interpretation of the evidence on student achievement. Pellegrino (2012, p. 63) defined assessment as "a rigorous and carefully structured process of reasoning from evidence that should be driven by theories and data on student cognition and learning”. Similarly Tomlinson and Moon (2013, p. 18) defined classroom assessment as “the process of collecting, synthesising, and interpreting information in a classroom for the purpose of aiding a teacher’s decision making”. This last definition explicitly combined purpose with the description of assessment, whereas in many other definitions of assessment, the purpose was implicit.

Definitions for the purpose of assessment were highlighted by Sadler (1989), who viewed assessment as providing information on the current state of the learner, and by Wiggins (1998, p. 7) who wrote that assessment should “educate and improve student performance, not merely audit it”. Pellegrino (2012, p. 82) commented that teachers and others need to understand “how students represent knowledge and develop competence in a domain” in making informed decisions about steps in students’ learning. Pellegrino et al. (2001, p. 27) stated that “assessments provide *snapshots* of achievement at particular points in time”, but thought it more valuable that assessments allow tracking or progressions of students’ understanding over time. Pellegrino (2012, p. 80) described diverse purposes for assessment, contrasting those for internal classroom assessment and external tests, norm and criterion-referenced assessments, and formative and summative assessments. In comparing the different and dichotomous examples, Pellegrino commented that the purpose of an assessment constrained its use but explained that this was not always evident in practice.

Masters (2014) presented a different view in defining assessment as having a single purpose. “The fundamental purpose of assessment is to establish and understand where learners are in an aspect of their learning at the time of assessment” (p. 1). He described assessment as having different levels and degrees of detail and different uses and considered that establishing the student learning through assessment contributed to a continuing decision-making process. He asserted that a “formative/summative distinction” (p. 3) was less essential. Masters commented that feedback was an important function of assessment in “building students’ self-efficacy as learners” (p. 3) building on the realisation that effort and success are connected. A number of definitions of the purpose for assessment have been provided through the research literature and are similar in focusing on the student’s learning in a particular area at a particular time.

Pellegrino (2012) stated that the “different levels and functions of assessment can have varying degrees of match with theoretical stances about the nature of knowing and learning” (p. 81). Assessment, by its nature and in understanding that it is based on people making inferences and judgments in an environment of uncertainty, is at best an estimate and is constrained by its intended purposes. Assessment is a complex area used extensively in all levels of school systems and by teachers in their everyday professional lives. In this study, data were gathered and analysed related to teachers’ theories, understandings, practices and expectations in the assessment area and teachers’ possible interpretational frameworks in the context of assessment.

2.6.1 Validity and reliability

Historically and in many contemporary studies, assessment was viewed in terms of validity and reliability and considered to be quantitative. Although certainty is based on a series of quantitative assumptions and inferences by the teacher about students and data collected, the place of validity and reliability in qualitative research is not so obvious. Consequently, the definitions of validity and reliability in the literature and how they apply to qualitative investigations are relevant in this qualitative study.

Definitions of validity were provided by Minichiello et al. (1990, p. 208) as “the extent to which an assessment gives the correct answer, or a finding is interpreted in correct ways” and by Pellegrino et al. (2001, p. 39) as “the degree to which evidence and theory support the interpretations of assessment scores”. Messick (1989, p. 13/14) defined validity as “an integrated evaluative judgment of the degree to which empirical evidence and theoretical rationales support the adequacy and appropriateness of inferences and actions based on test scores or other modes of assessment”. Wiliam (2003, p. 79) commented “that the definition of validity is that a test is valid to the extent that it tests what it purports to assess.” He also referred to “validity argument. Specifically, in validating an assessment one needs to make an argument that the conclusions that will be drawn from the results are warranted, and also that other conclusions are less warranted.” Wiliam’s (2003) discussion of validity provided a general working notion that is applied within this study.

A definition of reliability provided by Pellegrino et al. (2001, p. 39) was “Reliability denotes the consistency of an assessment’s results when the assessment procedure is repeated on a population of individuals or groups". Minichiello et al. (1990, p. 208) claimed that "Reliability is the extent to which a measurement procedure yields the same answer." Mislevy (1996, p. 386) defined reliability as "the correlation between parallel forms in a specified population of examinees". Definitions of reliability using quantitative data (Minichiello et al., 1990; Mislevy, 1996; Pellegrino et al., 2001) were difficult to apply to the research aspects of this study, given the qualitative foundations of the study and associated probable lack of repeatability, the differing contexts and the selected methodology. However, both validity and reliability are frequently priorities for tests in schools, which are the focus of analysis and discussion in this study.

In further explicating the difficulties with the idea and definition of reliability, the researcher found that Broadfoot and Black (2004, p. 15) observed problems with reliability in that the reliability of assessment data for student performances remained disturbingly low. They commented "how alarmingly large are the chances of students being wrongly graded" and "that tests which are nationally important and can determine life chances of children do not satisfy the standards for testing of the professional test community." Broadfoot and Black (2004) provided research data and analysis of a possible crisis in the application of validity and reliability standards to formal state educational assessments in at least some education jurisdictions. They described significant educational misjudgments occurring through testing that could have a negative impact on students' lives. Cresswell (1997) commented on predictive validity coefficients of lower than 0.6 from different countries for selection into higher education, indicating the weak predictive power of national examinations on future performance. He pointed out that as candidates took only one examination in a domain, there were no significant data sets that could provide correlational measures of concurrent validity. He also referred to the claims of content validity by examination boards, which he discussed as being based on *professional judgments* and acceptance by teachers and therefore interpretive. Cresswell (1997) argued that misunderstanding the complex nature of assessment and its interpretational and inferential base could result in poor decisions about students.

Validity and reliability may be seen as constructs of assessment. A discussion of validity and reliability in relation to the selection of Methods for this research investigation is in the Methodology, Chapter 3.

2.6.2 Assessment paradigms, interpretations, inferences and judgments

An understanding of the frames in which theory on assessment has been constructed, understood and used can help in determining where the current study is situated. Two paradigms are briefly described and the theory on which they are founded is outlined. Classical test theory and the associated behavioural psychological paradigm, according to Mislevy (1996), had an emphasis on the expectation that students would answer test questions in specific ways, domains and contexts and the focus of instruction was to change student behavior to be more coherent or competent in the future. However, the behavioural paradigm has lost its domination within assessment research (Mislevy, 1996). Contemporary research has adopted a cognitive and developmental psychological paradigm for education assessment, which included a focus on the nature of learning and on people's learning and using knowledge and skills. Mislevy (1996) summarised the main ideas from the cognitive psychology paradigm as: (1) People interpret experience and solve problems by mapping them to internal models, (2) these internal models must be constructed, (3) constructed models result in situated knowledge that is gradually extended and de-contexualised to interpret other structurally similar situations. This summary provided confirmation of the focus of this study and the likelihood that rich descriptions and complexity of experiences, environments and decisions will emerge from this current study of the teachers' interpretational frameworks.

Within the cognitive psychology paradigm, a chain of evidence has more links and uncertainty (Mislevy, 1996) which require understanding of how competence and learning developed in the targeted knowledge area. Mislevy (1994) defined reasoning from evidence as "the process of collecting evidence to support the types of inference" (p. 391). Pellegrino et al. (2001) commented about uncertainty and reasoning:

> Assessment users always reason in the presence of uncertainty; as a result, the information produced by an assessment is typically incomplete, inconclusive, and amenable to more than one explanation. An assessment is a tool designed to observe students' behaviour and produce data that can be used to draw reasonable inferences about what students know. (p. 42)

Rumelhart (1980) stated that the reasoning people did was tied to particular areas of knowledge and that once the situation, the concepts and their conditions for use were "understood" (p. 55), then problems could be solved. Rumelhart (1980) emphasised that most reasoning did not involve using general reasoning skills. To the idea of "theory about inference under uncertainty", Mislevy (1996, p. 391) added "theory about the nature and acquisition of competence in the domain" for developing conjectures and interpreting evidence. Mislevy suggested that the change in paradigm and the further redefining of the cognitive psychology paradigm changed the research focus on assessment purposes of comparing students along a gradient or continuum for comparisons, to that of determining evidence of students' development of ideas and progress and what they needed to learn or achieve next. Inferences or series of inferences, assumptions, searching for reasoning in the targeted domain and awareness of purposes that assessors, in this situation biology teachers, were applying to their understanding of students' thinking from an examination of their work, were critical to this study.

The connection between these discussions so far and interpretational frameworks that are the focus of this body of research and the current investigation was highlighted by Pellegrino et al. (2001):

> The first question in the assessment reasoning process is *evidence about what?* Data do not provide their own meaning; their value as evidence can arise only through some interpretational framework. … These data become evidence only with respect to conjectures about how students acquire knowledge and skill. (p. 43)

Schum (1987) stated "A datum becomes evidence in a particular inference when its relevance to this inference has been established" (p. 20).

Judgment-making

In the preceding sections it has been shown that research suggests interpretational frameworks in an assessment context derive from but also influence how people operate. Interpretational frameworks impact on how people make their *chain of inferences* and understand how successful achievement in a subject is acquired and demonstrated. These frameworks are central features in understanding how teachers make judgments related to the quality of the students' work.

Assessors apply their interpretational frameworks to judge assessment responses and appear to analyse the data within the context of its development, domain and application. This is an important notion under investigation, where the assessors are the biology teachers and the researcher in this study is looking at the details of their inferences and decisions in order to make assertions about their interpretational frameworks.

Referring to teacher judgments Brady and Kennedy (2001, p. 53) commented that "making judgments is at the heart of assessment". Sadler (1998) described the types of knowledge that teachers brought to assessment situations, including their application and command of knowledge, curriculum and standards, their critical, empathic attitude to teaching and student learning, skills in testing and eliciting student response, their expertise in making judgments, providing feedback and recognition of past students' efforts. Many of these types of knowledge have been explicated within the body of research literature cited in this study. These ideas may also be described as a combination of an expert/novice framework and Pedagogical Content Knowledge (PCK) for assessment.

The Biology teachers in the study referred to their decision-making processes and judgments in their interviews. The research area of teachers' judgment-making during the marking process has been identified by Crisp (2013) as an under-researched area of mostly hidden and complex processes used by assessors to evaluate students' work against marking criteria. Elander and Hardman (2002) analysed expert judgments in marking psychology papers and identified aspects, which influenced marks, including "addressing the question, covering the area, understanding" (p. 303). Cresswell (1997) found that the process by which assessors judged student work consisted of immediate evaluations with revisions during their reading of the answers. He commented that criteria may be altered as a result of the nature of the answer being evaluated and said "awarders' judgments of candidates' work are inadequate, by themselves, as a basis for maintaining comparable standards in successive examinations on the same syllabus" (p. 2). Einhorn (2000) identified tasks in experts' judgment-making including identifying, measuring and integrating cues. He also referred to the multi-dimensional aspects of the task. Grainger, Purnell, and Kipf (2008) found that even though markers had similar knowledge and identified similar aspects in the student scripts, they may evaluate the same script differently. Dennis, Newstead, and Wright (1996) found that influences specific to the supervisor could account for significant variance in students' psychology project marks. It was suggested that factors affecting marking accuracy include question difficulty, constraints of the candidates' response and mark scheme flexibility (Bramley, 2008; Raikes & Massey, 2007; Suto & Nadas, 2008; Suto, Nadas, & Bell, 2011). Suto et al. (2011) called for an integrated approach in assessing factors affecting marking accuracy.

Looking at other aspects of teachers' judgment-making, Laming (2004) proposed that comparisons, either direct or remembered, are involved in judging students' work. Crisp (2013) found that although physical education teachers always or usually undertook comparisons between students, science teachers only sometimes or occasionally compared students and she suggested the difference was that science teachers mainly focused on marking criteria. She also found that most teachers looked initially for points of content when viewing an answer and thought that specific features of an answer would affect marks. She suggested the teachers used a combination of two strategies: actively searching for, and evaluating features in, an assessment and that these resulted in a back and forth process seeking particular evidence in an answer.

Crisp found that 35% of responding participants in her study were influenced by features of an answer that were not described in a marking key. She described comments by several teachers of trying to form holistic impressions or trying to "hold the whole answer in my head drawing on every aspect of it" (p. 137). As a result of her research, Crisp suggested that teachers hold internalised standards, which are probably essential to their judgment-making.

Suto and Greatorex (2008) undertook detailed work in analysing strategies within psychological theories of human judgment, particularly "*dual-processing theories of judgment"* (p. 213) as they investigated teachers' cognitive strategies when using a marking key to mark examinations. *Dual-processing theory* consisted of System 1: quick, intuitive, automatic, associative thought processes and System 2: slow, rule-governed, controlled, effortful, reflective and self-aware cognitive operations (Kahneman & Frederick, 2002). Suto and Greatorex (2008) proposed in their findings a framework of five marking strategies which included "*matching"*, "*scanning"*, "*evaluating"*, "*scrutinising"* and "*no response"* (p. 220). *Matching, scanning* and *no response* were categorised as System 1 cognitive operations, while *evaluating* and *scrutinising* were categorised as System 2 cognitive operations. Teachers' comments within the current study can be compared with these marking strategies. Particularly relevant was the strategy of *Evaluating,* which was used when the teacher viewed the response holistically, identifying meaning in a number of ways. Interim judgments were often a feature of this process. Also relevant was *Scrutinising,* which focused on reconstructing the student's line of reasoning or what the student was trying to say. This strategy entailed uncertainty and multiple re-reads before a teacher made a judgment. Marking speed decreased significantly with *evaluating* and *scrutinising*.

The current study has analysed and compared biology teachers' marking keys, marking decisions and judgments on a common Test Question and Student Answer in Chapter 5. The teachers made their own individual marking keys and did not have access to a pre-made key or the collaborative activities involved in finalising a common marking key and this created a difference with studies such as Suto and Greatorex (2008). Another difference to other cited studies, related to teachers' judgments of assessments, was the lack in this study of a stated a priori paradigm or theory to test against. It was instead an emergent and iterative study. The teachers in the current study were involved in a conceptualisation stage prior to the starting point of participants in the other studies cited here and were not given the benefit in this study of collaboration and an agreed marking key. This was in line with the goal of this study to identify interpretational frameworks of individual biology teachers in an assessment context. Therefore the researcher in this study has not entirely embraced the application of the cognitive strategies suggested by Suto and Greatorex (2008) within the *dual-processing theories of judgment* framework but analysed the teachers' marking decisions in relation to those cognitive strategies.

A notion that is useful in this section is *dynamic decision making*. Dynamic decision making has been defined by Gonzales, Lerch, and Lebiere (2003) as "multiple, interdependent and real-time decisions, occurring in an environment that changes independently and as a function of a sequence of actions" (p. 591). Additionally, Brehmer (1992) and Edwards (1962) described dynamic decision making as goal oriented and consequential in terms of earlier decisions reached. Gonzales et al. (2003) commented that correct decisions needed to be in the correct order and made at the correct time and that dynamic decisions therefore were decisions in context and time. Brehmer (1992) noted the need for the environment to determine when decisions were needed and that this introduced an aspect of stress. These definitions and characteristics of dynamic decision making capture the type of activity that teachers are involved in every day and especially in assessment processes. The aspects of real-time, experience, sequential actions resulting in consequential results, complex (considered as multiple and interdependent), having a goal and inducing an element of stress could be considered hallmarks of assessment processes undertaken by teachers.

Cognitive load theory

An awareness of cognitive load theory in an assessment context has provided insights into teachers' frameworks, relevant to the current study. Sweller (1994) suggested that a learner's short-term memory was limited in capacity and duration and that it could "store and process no more than a few discrete items at any given time" (p. 299). The amount of schema acquisition and the amount of automatic thinking and processing found in more expert understanding of knowledge areas would be a factor in test performance. Other factors that affected test outcomes, according to Sweller, were inappropriate amounts of information in questions, responding to a novel problem where students are unable to use previously acquired schemas to generate solutions and the need for a processing capacity greater than the student's limits. In an assessment context, particularly those assessments that have high stake outcomes with important consequences for the participants, extraneous cognitive overload may be a negative factor in tests. Do the teachers demonstrate understanding of cognitive load theory within their frameworks of assessment in biology?

Assessment transactions between teachers and students

A comparison of the interpretational frameworks of individual teachers is a key area of research that was undertaken in this study. Genishi (1997) commented that there needs to be a fundamental shift in ways of looking at the person – both the assessor and the person being assessed. He argued that both are capable of actively constructing their own theories of the world and their unique interpretations of situations. He contended that assessment became an entirely personal transaction between teacher and students. Key areas of focus of this study include: teachers' interpretations as assessors, transactions and negotiations involved in assessment, and the teachers' own interpretational frameworks related to biology, assessment and student achievement.

In terms of the assessment transactions and negotiations between student and teacher that may have direct application to this study Brady and Kennedy (2001, pp. 1-2) commented that "assessment and reporting at one level might simply be private transactions between teachers and students, yet … they are also public processes that require professional expertise on the part of teachers and that are open to scrutiny and questioning." Blackmore (1988) made the distinction between *educational* and *instrumental* purposes for assessment. Brady and Kennedy (2001, p. 4) commented that "it seems that external stakeholders are overwhelmingly instrumental in their approach to assessment. Teachers, it appears, stand in a special relationship to assessment. In one sense they might be seen as the guardians of the educational function of assessment" Brady and Kennedy (2001) went on to note that "the criteria for these judgments are not always explicit and they are often not consistent, but we make them nevertheless" (p. 2). A part of this study that explored Brady and Kennedy's ideas on explicit criteria was the analysis of judgments of a common Test Question and Student Answer by expert teachers and curriculum officers. How teachers respond to and negotiate the dichotomous nature of assessment, for private or public transactions, is expected to emerge from many aspects of this investigation.

These comments from the research vindicate the choice of this study to largely focus on the teachers' interpretations of their students' achievements, not on external measures applied to the classroom or the interpretation of external assessors. The experienced biology teachers, some of whom were also external assessors, were also compared through their analysis of a common Test Question and Student Answer in order to check comparability and triangulate data. Other experienced biology teachers also commented on the Test Question and Student Answer and proved a wider comparative analysis.

A different line of thinking that is applied to the teachers in the study, was that of Pellegrino et al. (2001, p. 43) who suggested that "What one believes about the nature of learning will affect the kinds of assessment data sought and the chain of inferences drawn." They also said that "teachers interpret ... evidence in light of everything else they know about their students and the conditions of instruction". The current study examined views that the teachers in this study hold about the nature of assessment and expectations and views they hold about their students.

Complex decisions about the selection of the amount and what evidence, how evidence is collected and the varied interpretations and analysis of the evidence drawn would be part of teachers' interpretational frameworks in assessing students. These complex ideas and processes form part of teachers' lived professional experiences and knowledge.

2.7 Pedagogical Content Knowledge and Expert/Novice Perspectives

2.7.1 Pedagogical Content Knowledge (PCK) lens

PCK emerged as a possible lens through which to examine teachers' interpretational frameworks in a biology assessment context. In addition to the interpretational frameworks held by biology teachers, Shulman (1986) asserted that the way the knowledge was used was also important. So for example, a teacher may recognise in which circumstances to use particular frameworks of knowledge, the justification for particular subject matter and why some ideas are central to a discipline while other ideas are more peripheral.

Shulman (1986, p. 9) had an encompassing view, termed *Pedagogical Content Knowledge* (PCK), which he defined as "subject matter knowledge for teaching". In this term he included teachers' representations (and choosing from alternative representations) of subject knowledge to students, the use of analogies and explanations and understanding alternative conceptions along with instructional conditions necessary to overcome initial conceptions. PCK includes categories of knowledge that are applied synergistically, as dynamic, as content-based and as transforming other knowledge, according to Abell (2008). Magnusson, Krajcik, and Borko (1999) conceptualised PCK as having five components:

> (a) orientations toward science teaching, (b) knowledge and beliefs about science curriculum, (c) knowledge and beliefs about students' understanding of specific science topics, (d) knowledge and beliefs about assessment in science, and (e) knowledge and beliefs about instructional strategies for teaching science. (p. 97)

In their model, Magnusson et al. (1999) defined (a) orientations to science teaching as central, linked with a double-ended arrow to each of the other components (b) to (e). They described assessment within PCK using two areas. These areas were knowledge of the dimensions of science that can be assessed effectively and types of assessment, for example written tests, laboratory examinations and performance-based assessments. The

Magnusson et al. model was one of the few found in the research on PCK with some detail of teachers' PCK understanding of assessment and therefore valuable in reference to this study.

Assessment as separate or included within PCK

The question could be asked of whether assessment should be included in PCK or as a separate PCK entity. In applying a nature of science context to PCK, van Dijk (2014) commented that nature of science aspects are dependent on scientific content and should emerge in the teaching of that content. Van Dijk commented that PCK for scientific literacy depended on "understanding of scientific knowledge within the context of inquiry in which it was developed" (p. 408). Similarly to the decision by van Dijk that nature of science could not exist separately from scientific literacy or from PCK, in this study assessment could be considered as a context or focus in PCK rather than a separate area.

Expert/novice in PCK

The teachers in this study are very experienced, and could be considered expert teachers. In describing expert teachers' orientation to PCK, Abell (2007) identified their orientation to their theoretical framework, their expertise in better content structures, evidence of more correct answers and that they chunk information in problem solving and come up with more solutions and in fewer steps. Procedural and declarative knowledge were more common in novice teachers. Hauslein, Good, and Cummins (1992) stated that as teachers gain more experience they re-structure their thinking about biology. Kapyla, Heikkinen, and Asunta (2009), comparing primary teachers with secondary, biology, pre-service teachers, found that teaching orientation was related to training. They said the primary group practised the student-centred learning highlighted in their training, while the biology student teachers were more content-oriented but exhibited both student- and teacher-centred approaches in line with their training and the academic knowledge in their subject. The researchers suggested that another reason for the student-centred approach by the primary group was the possible concealment of their weaker content knowledge. They also found that secondary biology student teachers could recognise conceptual difficulties that students may have, whereas the primary student teachers did not realise that students had content misconceptions. This research provided more understanding of the complex area of expert/novice in relation to PCK.

Assessment influenced by teachers' dispositions

In a discussion of assessment within PCK, Duffee and Aikenhead (1992) concluded that teachers' decisions on how and what to assess were consistent with their beliefs about teaching and learning. Several studies attempted to understand science teachers' actions and found that biology teachers used different criteria in their marking, resulting in a considerable variation of allocated marks (Schonborn & Bogeholz, 2009). Kokkotas, Vlachos, and Koulaidis (1998) and Sanders (1993) found that pre-service secondary biology teachers' marks for student answers were based on a range of ideas, such as perceptions of difficulty and wanting to encourage students. Morrison and Lederman (2003) found that science teachers recognised that science students' prior knowledge was important. Falk (2012) found in his study on teachers' formative assessment of elementary physics that knowledge of curriculum and knowledge of instructional strategies were the most commonly used components of PCK. Kamen (1996) found that an early childhood teacher could change her practice in assessment when her views changed from hands-on to minds-on in science teaching and Briscoe (1993) commented that a change in assessment practice is influenced by the teacher's knowledge about teaching, learning and the nature of education.

PCK in biology

Berry et al. (2008) reported on an interview with Lee Shulman in 2007. In an extensive transcript of the interview, Shulman referred to Carlsen's findings of differences in teaching biology topics depending on ways that teachers differentiated and understood different topics. Shulman also referred to his interactions with researchers who described the centrality and complexity of evolutionary theory in biology and commented that the pedagogy of biology was an example of PCK because:

> you've got to deeply understand what it is that makes evolutionary theory and evolutionary analysis of the world, whether you think ecologically or cellularly, what makes it difficult, and then what the variety of misunderstandings students might have, with the resilience of their misunderstandings. (p. 1276)

Shulman also posited “a teacher who does not both understand and have a real affection for a subject will never be able to teach it well” (p. 1276).

These ideas are investigated in this study, where teacher frameworks of knowledge in a specific science area, biology, are being drawn out and developed and where PCK fits within this framework. The study did not set out to identify PCK as a theoretical framework and did not ask specific questions about PCK. Frameworks of knowledge are anticipated in teacher’ explanations, of biology, experiences in identifying purposes, selection of and expectations from specific assessment questions and explanations of why teachers judged an assessment in a particular way. Also pertinent are why the teachers favoured particular representations of knowledge, the knowledge that was selected to answer particular questions, depth of content and expected assessment strategies to be used by students. These ideas had a natural affinity to possible PCK applications in the assessment context.

Assessment PCK

PCK that is adapted to students undertaking tests or examinations may be thought of as knowledge-based, that is, applied to students’ biological explanations demonstrating their content understanding, or Pedagogy–based, that is, applied to examination strategy. The researcher examined the idea of knowledge and pedagogy used in assessments being analysed separately and in detail. At the same time, the researcher investigated whether particular content or strategies helped in achieving higher ratings from teachers.

PCK has been suggested as important in all aspects of teaching and also in assessment. Teachers may be calling on these understandings and skills to enable them to make judgments about student achievements. Within the literature, assessment is infrequently mentioned within the PCK corpus. Abell (2007, p. 1132), in discussing the need for PCK for science assessment, called for more studies “to better understand what teachers know about assessment, and how they design, enact and score assessments in their science classes.” Berry et al. (2008) posed the problem of teachers’ low expectations of descriptions of PCK research knowledge, because they were fully occupied in other focus areas arising from teaching.

The application of Shulman's ideas about the structure of biology and the application of a PCK model to assessment may be used to develop fruitful insights and to form a perspective for the study. The study aimed to add to the PCK body of knowledge or at least considerations of PCK ideas in the assessment context, in a similar way to the call from Abell (2007). Capturing the attention of teachers, which was posed as problematic by Berry et al. (2008), may need a PCK community response.

In relation to methodology, Abell (2008) suggested that if the PCK lens is applied to research, then the research tools such as research questions, overall design, data collection and analysis should be aligned to the theoretical framework. As this study examined teachers' interpretational frameworks, the methods chosen were to enable these frameworks to be explicated. It became clear early in the analysis that PCK could offer a lens for examination of the data so it was applied from that point with the pedagogical and professional-experience repertoires (PaP-eR) method (Mulhall et al., 2003) as used in analysing teacher comments by the researcher. This method is described in detail in Chapter 3.

2.7.2 Expert/novice lens

In preparing for the current research, it became apparent that teachers held many views about their students. Their particular views about their students' levels of expertise became evident when undertaking the study. In a similar way to PCK, discussions of expertise were considered useful in understanding if an expert/novice lens is appropriate for this study. Pellegrino et al. (2001) stated that:

> It is in the context of classroom assessment that theories of cognition and learning can be particularly helpful by providing a picture of intermediary states of student understanding on the pathway from novice to competent performer in a subject domain. (p. 8)

This proposition led to a possible framework within which the research could be situated. The teachers selected for the study were all experienced teachers. Do the expert teachers give clues in their responses to student answers that indicate that they view students and students' biology knowledge in a particular way or on a continuum from novice to expert? Specific questions relating to these aspects were not part of the interview, but teachers' views on this idea did arise.

Studies on experts can show what the results of successful learning looks like. Sweller (1994), in discussing cognitive load theory, defined experts as having "the ability to store huge numbers of schemas may be a primary intelligence" (p298) and that "experts are better able to remember problem configurations because their schemas permit them to see the configuration as a single entity" (p. 298) rather than as a collection of individual elements. Reviewing studies on novice/expert, Bransford et al. (2000) defined experts' knowledge and processing, including "experts *chunk* various elements of a configuration that are related by an underlying function or strategy" (p. 32). They suggested that expert knowledge involved the "development of organised conceptual structures, or schemas, that guide how problems are represented and understood" (p. 33), that "knowledge is organised around core concepts or *big ideas* that guide their thinking about domains" (p. 36), and that experts had "deep understanding of how to formulate reasoned interpretations" (p. 42). Bransford et al. (2000) also stated that experts "are good at retrieving the knowledge that is relevant to a particular task", that is *conditionalised* knowledge (p. 43), and that they notice different stimuli and have different ways to think, remember and reason. Mislevy (1996) confirmed the greater command of concepts and connections by experts and particularly emphasised their "ways of viewing phenomena and representing and approaching problems" (p. 389). Sadler (1998) pointed out that teachers' development of assessments could be an example of "creative and integrative activity of a high order" (p. 83). It is apparent that experts are considered to have particular abilities and experiences that influence their recognition, interpretation and organisation of information and experiences and they think, reason and *chunk* into and use effective schemas. McClelland (1995) put forward the view that perception is "an extremely knowledge-rich cognitive skill, which evolved through development and through experience in a domain" (p. 141) and related this in terms of expert and less expert, "When we understand how experience can be encoded so as to let us really see the implications of things, we will be a lot closer to understanding thinking." (p. 141)

These principles about experts proposed by Sweller (1994), Bransford et al. (2000) and McClelland (1995) are directly applicable to teachers who are experts in making judgments and to students who may be moving from novice to expert in their understanding of the learning area and the ways they demonstrate their knowledge as they understand and interpret the requirements of the assessments. This study recognised that the teachers participating in the study had established expertise in the teaching, learning and assessing of senior high school biology.

2.8 Concluding Comments

The research of the literature was conducted in order to find research pertinent to the aim: *to investigate the interpretational frameworks used by biology teachers in assessing students' understandings in biology*, and the six research questions.

This study is the intersection of the research literature related to general educational frameworks, particularly cognitive frameworks, student developmental frameworks and frameworks for assessment and biology. As well, added to this intersection lenses have been applied in this study, those of PCK and expert/novice understanding. Within the emergent and iterative approach taken in this study, drawing on research literature as needed was a logical process.

Definitions of interpretational frameworks and relevant terms were initially introduced early in this chapter. As teachers have been exposed to and building organisational, cognitive and strategic frameworks during their professional life, informative areas have been investigated for this study and relevant literature cited. One key area explored was general organising frameworks and theory development in education. Definitions and examples of these were discussed in this chapter, including teaching, learning and assessment frameworks, conceptual models, theory and schema. These education frameworks, theories and models are relevant to the development of teachers' own frameworks. Also shaping teachers' theory and practice are frameworks describing student learning, including developmental stages and models, taxonomies and multiple frameworks and cognitive strategies.

Frameworks for teaching biology are critical for understanding the expectations, judgments and organisational structuring of biology teachers' interpretational frameworks. These included multi-level, evolution, causal, inquiry, qualitative and cultural perspectives and approaches or a combination of these. Also models of learning biology or understanding, teaching and assessing the biology curriculum were important considerations in analysing teachers' frameworks.

In order to understand teachers' frameworks in the context of assessment, a review of relevant theory, practices and frameworks for assessment was conducted. An outline of the cognitive psychology paradigm provided substance for the discussion of assessment. Research on teachers' decision- and judgment-making was outlined. Cognitive load theory was outlined and the idea that assessment is a personal transaction between teachers and students explored. All of these areas of research provided assistance in understanding teachers' comments and nuances in the assessment context.

One lens for viewing the data from the study was PCK and was used in the analyses of the research of this study and to provide a way of understanding teachers' knowledge, rationales, strategies and actions. Components of PCK, expert/novice orientations to PCK, PCK in the biology domain and assessment PCK have been discussed in order to apply to research understandings. A second lens for viewing the data from the study was expert/novice research, which could be applied, with the experienced teachers viewed as experts and their students who may be considered on a continuum of expert/novice in their achievements. The expert/novice research in the literature showed the intersection with PCK, conceptual and organisational schemas and effective teachers' frameworks. These lenses were factored into planning and undertaking the analyses and in developing insights into the aim of the study and the research questions.

In this current study, frameworks and ways of thinking, whether similar or novel and different, were investigated. Opportunities were developed for reflections of the strategies and methodologies selected by the teachers in their preparation of students for learning and assessment, their assessment practices and their rationales or theories influencing their judgments. Finding a congruence between the experienced teachers' interpretational frameworks and particular areas of research in the literature would suggest research success in influencing teachers' practices and theories.

Chapter 3

Research Methodology and Methods

3.1 Introduction

The methodology and methods for the study were chosen in order to reveal the teachers' underlying knowledge, assumptions, preferences and ways of thinking in their judgments of student achievement. The methods were selected with the intention of allowing the teachers' voices to be strongly heard throughout the study. The study was not constructed to support or disprove a pre-conceived theory, but to communicate meaning-perspectives and allow theory building, frameworks and interpretations to emerge. This approach was taken in order to provide illumination and insights and to provide cogent findings. Lessons learned during early stages of the study were applied in later stages, including making sense of the data.

Chapter 3 begins by explicitly outlining the research orientation in Section 3.2, demonstrating that the research methodology and orientation of the study were appropriate to address the aim and research questions. The discussion of selected epistemology, theoretical perspective, methodology and methods presents a comprehensive hierarchical framework of the increasing levels of detail involved in the study.

An account of the data sources is outlined in Section 3.3, including selection and description of the participating teachers and an outline of the origin and reporting of student work samples and responses. In Section 3.4, as a check that the research questions were targeted and purposeful, the researcher discussed the research questions with an experienced biology teacher, who also later participated in the study. A detailed description of the data collected from the biology teachers and a discussion of methods appropriate to this process is presented in Section 3.5. Within this study, a distinction is made between methods selected for data collection (Section 3.5) and methods selected for data analysis (Section 3.6).

In Section 3.6 the methods used for the data analysis are outlined. An interpretive commentary device (PaP-eR) was used to find and make concise the meaning within teacher interviews and to examine the potent gems arising from the data (Mulhall et al., 2003). This method was illustrated by using the device with one teacher's interview. A discussion of the methods including cases and applying theory-generating research in describing each teacher's framework and theories follows. Assertions were used to explicate the themes from the research (Erickson, 1986), and assertions were developed and presented.

Plausibility and confidence are discussed in Section 3.7. In Section 3.8 the consideration of and application of ethics to the study are outlined. Concluding comments about the selection and application of the methodology appropriate to and used in the study are presented in Section 3.9.

3.2 Research Orientation

3.2.1 Research aim

The aim constructed for the study was *to investigate the interpretational frameworks used by biology teachers in assessing students' understandings in biology*.

3.2.2 Research questions

Six research questions were developed:

1. What are the views and perceptions of each teacher regarding assessment in senior school biology?
2. What are the influences on teachers' assessments and judgments of student achievement in senior school biology?
3. In what ways are different teachers consistent in their judgments of student achievement in biology?
4. What strategies do teachers use in assessing senior school biology?
5. What do teachers consider are their own and their students' frameworks for biology?
6. What are the commonalities and differences among the interpretational frameworks used by teachers in assessing senior school biology?

These research questions are addressed in Chapters 4, 5, 6 and 7.

3.2.3 Theoretical stance

Critical to the choice of research orientation, methodology and methods was the aim of the research and the epistemological synchronisation between the research topic, aim and contexts and the selected methodology. There was recognition of a trade-off between depth and breadth in the study, that is, between fidelity and bandwidth. Pellegrino et al. (2001, p. 222) stated that "A high-fidelity, narrow-bandwidth test provides accurate information about a small number of focused questions, whereas a low-fidelity, broad bandwidth test provides noisier information for a larger number of less focused questions." These comments were made about testing but are also relevant to trade-offs in qualitative research. The researcher chose to apply a *high-fidelity, narrow bandwidth* study of six teachers.

In constructing the study, the researcher reflected on the best epistemology and research orientation in order to answer the research questions. Erickson (1986, p. 119) referred to different theories and methods including qualitative, case study, ethnography and phenomenology that applied to research on teaching, as a family of interpretive approaches. Erickson (1986) referred to the German social philosopher Wilhelm Dilthey (1833-1911) as the most significant advocate of the necessary distinction between natural sciences and human sciences, and went on to comment that Dilthey argued "the methods of the human sciences should be hermeneutical, or interpretive, with the aim of discovering and communicating the meaning-perspectives of the people studied" (p. 123). The researcher was cognisant of these views in undertaking the selection of the elements of the research orientation for this study. Hitchcock and Hughes (1995) suggested a hierarchy of methodological consideration. A clear interconnected hierarchy for research was proposed by Crotty (1998, p. 3) with his four questions:

- What epistemology informs this theoretical perspective?
- What theoretical perspective lies behind the methodology in question?
- What methodology governs our choice and use of methods?
- What methods do we propose to use?

The theoretical stance chosen for this study, emanating from Crotty's questions, is presented in Table 3.1.

Table 3.1 Theoretical stance for this study (adapted from Crotty, 1998, p. 5)

Crotty's hierarchy of elements for the research process	***Specific theoretical stance taken in this study***
Epistemology	Constructionism
Theoretical perspective	Interpretivism
Methodology	Phenomenology
Methods	Interviews, case studies, PaP-eR analysis, assertions

Epistemology – Constructionism

Epistemology is defined as the theory of knowledge embedded in the theoretical perspective and therefore in the methodology (Crotty, 1998). St.Pierre (2011, p. 615) defined epistemology as "the branch of philosophy concerned with what counts as knowledge and how knowledge claims are justified as true." The nature, basis, scope and possibilities of knowledge are encompassed in the epistemology (Hamlyn, 1995). St.Pierre (2011, p. 615) also defined ontology: "the branch of metaphysics concerned with what exists (what *is*) with being and reality and how entities are organised". Crotty and St Pierre contended that postmodern theories blurred epistemology and ontology differences.

Constructionism was chosen as the epistemology most relevant to this study as it posits that "meaning comes into existence in and out of our engagement with the realities in our world" and that meaning is constructed (Crotty, 1998, p. 8). Crotty (1998) also commented:

> all knowledge, and therefore all meaningful reality as such, is contingent upon human practices being constructed in and out of interaction between human beings and their world, and developed and transmitted within an essentially social context. (p. 42)

Charmaz (2000) described the constructivist approach as intermediate between positivist and postmodern research. She favoured meanings made by participants. Bryman (2001) defined constructionism as an ontological position, which he said was often interchanged with constructivism. He suggested that people produced and revised meanings and social phenomena through interaction. Crotty (1998, p. 58), however, distinguished between constructionism, which he defined as the "social dimension of meaning" or "collective generation [and transmission] of meaning" as fundamental, and constructivism, defined as the "meaning making activity of the individual mind". Cresswell and Miller (2000, p. 125) stated that "constructivists believe in pluralistic, interpretive, open-ended and contextualised perspectives towards reality." Guba and Lincoln (1989, p. 44) posited that epistemologically, "the constructivist paradigm suggests … that the findings of a study exist …because there is an interaction between observer and observed that literally creates what emerges from that inquiry". Constructivism was described by Guba (1990, p. 27) as based on local, specific and personal social and experiential realities in the form of "multiple mental constructions".

This epistemology was selected to match the purpose of this research study, which was to make meaning of biology teachers' interpretations and ways of knowing in a biology assessment context and to determine what interpretational frameworks the teachers had developed in that context. Further, if interpretational frameworks were identified, then were there commonalities between these teachers' frameworks? In this study, a constructivist epistemology could be used to describe the former, that is meaning making of individual teachers, and a constructionism epistemology would describe the latter research regarding the generalisable understandings that emerge.

Theoretical perspective – Interpretivism

The theoretical perspective of a study is the philosophical stance informing the methodology, providing the context for the process and grounding its logic and criteria (Crotty, 1998). Interpretivism, derived from a constructionism epistemology and chosen for this study, is a way of looking at knowledge and experiences, deriving meanings and making sense of them. The interpretivist approach was considered the best-fit theoretical perspective because it "looks for culturally derived and historically situated interpretations of the social life-world" (Crotty, 1998, p. 67) as distinct from a critical inquiry, feminist or postmodernist focus. Bryman (2001) identified interpretivism in opposition to positivism and stated that it was based on a strategy that differentiates between objects of study and the people and on interpretation of the meaning of social action. Cresswell (2012) defined interpretation within research as making sense of the research and the formation of a larger meaning in regard to the phenomena by the researcher. He stated that "qualitative research is interpretive research" (p. 259). Erickson (1986, p. 119) used interpretive research to describe a "family of approaches to participant observational research". He explained, in particular, that interpretive approach focused on “the nature (and content) of the meaning-perspectives of teacher and learner to the educational process”. Hence, the methodology for this study was situated within an interpretivist theoretical perspective (Crotty, 1998). The study sought teachers’ perspectives, ways of knowing and interpreting biology assessments arising from their commentary and judgment of student work.

Methodology – Phenomenology

The researcher constructed and selected a methodology for the study that enabled the priorities described in the research questions to be explored by directly addressing the participants’ experiences of the ideas, thinking frameworks and worldviews involved in biology assessment. Methodology is defined as “the strategy, plan of action, process or design lying behind the choice and use of particular methods and linking the choice and use of methods to the desired outcomes” (Crotty, 1998, p. 3).

Phenomenology was useful in framing this study. Preissle (2011, p. 689) described how phenomenology was constructed from a philosophical base by Husserl (1893-1917) as a foundation for sciences which later became an alternative to positivist theory. Despite Husserl’s foundations, scientific study was entrenched for many more decades in positivist theory. Patton (1990, p. 69) described phenomenological inquiry as focusing on the question “What is the structure and essence of experience of this phenomenon for these people?” Marton and Booth (1997, p. 115) considered that “individuals are seen as the bearers of different ways of experiencing a phenomenon” (p 115). They described phenomenology as concerned with having the objects of research, the phenomenon and essence as its only defining attributes. Marton and Booth (1997, p. 117) commented that phenomenology was aimed at “clarifying their experiential foundations”. Welman and Kruger (1999) stated “phenomenologists are concerned with understanding social and psychological phenomena from the perspectives of people involved” (p. 189).

Crotty (1998) described phenomenology:

> Phenomenology suggests that, if we lay aside, as best we can, the prevailing understandings of those phenomena and revisit our immediate experience of them, possibilities for new meaning emerge for us or we witness at least an authentication and enhancement of former meaning (p. 78).

Crotty (1998) emphasised the current meaning of phenomenology for researchers as "studying experience from the 'point of view' or 'perspective' of the subject" and 'phenomenon' is spoken of as 'experience', "or presented as an essence distilled from everyday accounts of experience, a total picture synthesised from partial accounts" (p. 83).

For this study both the individual perspectives of the participants and the commonalities of their experiences are explored. The researcher focused on the experience of biology assessment for the experienced biology teachers. In considering the purpose of the research, the epistemological synchronisation between the research questions and the interpretivist theoretical perspective, and an approach that emphasised interpretation and personal perspective of biology assessment by teachers, phenomenology was selected as the appropriate methodology. The teachers in this study could be equated to bearers of different ways of experiencing assessment, and the researcher developed understandings of those phenomena and the teachers' immediate experience of them.

Methods – interviews, document and PaP-eR analysis, theory building, cases, assertions.

Several methods were used for the current study, consistent with the research questions and the aim of the research. Methods are the techniques or procedures used to gather and analyse data related to some research question or hypothesis (Crotty, 1998).

Particular methods postulated by Erickson (1986) were chosen as compatible with the current research intentions and content. Having a family of research methods was useful in realising meaning-perspectives of and making comparisons between the teachers. Using a variety of methods also enabled plausibility and confidence in the findings and conclusions. Methods are described in two categories, methods used for collection of data and methods used for analysis of data. These are discussed further in this chapter.

The family of methods used to collect data appropriate to the research questions and consistent with the methodology were deep interviews (Minichiello et al., 1990) using an interview schedule (Patton, 1990), participants' marking keys for a common Test Question and Test Answer, and teacher comments about their students' work.

The family of methods used to analyse the data were empirical assertions, analytical narratives, quotes from interviews, interpretive commentary framing particular and general descriptions, theoretical discussion, reporting on the natural history of inquiry in the study (Erickson, 1986), Pedagogical and Professional-experience Repertoires (PaP-eR) commentary (Mulhall et al., 2003) and case studies (Lincoln & Guba, 1985; Merriam, 1998). These methods are explicated in the sections below, particularly in Section 3.5 Data Collection and Section 3.6 Data Analysis.

3.3 Data Sources

Data were collected from six experienced biology teachers from Perth city schools, a Western Australia country school and a school from Ireland, with male and female teachers. Data consisted of interviews and teacher-selected samples of student work within their classes in the biology learning area. The teachers' schools were from a range of socio-economic areas and were two Perth metropolitan Government high schools and four non-Government high schools consisting of three Catholic (Perth, WA country and Ireland) and one Anglican high school (Perth).

The researcher sought to identify interpretational frameworks used by experienced teachers in an assessment context. A group of biology teachers, who had many years of successful experience in teaching and assessment and were prominent as leaders with professional practice of other teachers in biology education, were hand-picked. Purposive and targeted sampling as discussed by Cohen, Manion, and Morrison (2000), where the sample has been selected for a specific purpose, was utilised. Attending to these ideas, five Western Australian teachers were approached and volunteered to participate in interviews, and another four selected who participated in the marking activity of the common Test Question and Student Answer. A teacher from Ireland was selected for interview through a recommendation from a prominent university science educator in Ireland.

The six teachers chosen for interview each had a minimum of 25 years of classroom teaching experience in the biology area. The choice to select these teachers for the current study was based on recognition of expertise, membership of committees the education system the teachers belonged to, indicators of interest and the teachers' insights into student learning during professional conversations. The selection of an experienced teacher from Ireland was serendipitous and based on her experience as a biology teacher rather than her country.

Data were in the form of 60 minute interviews with teachers (interview schedule in Appendix 2), their selected questions and selected students’ marked work samples to these questions, and these teachers’ judgments of a common Test Question and Student Answer (Table 3.3). Wendy and Philip (from the two Perth metropolitan Government high schools) did not have a self-selected question or a cohort of student work samples to discuss so most of their comments were in terms of the common Test Question and Student Answer. The questions selected by the teachers and the Test Question selected by the researcher were those that measured more than propositional knowledge, but that measured application of biological knowledge. Generally questions used in the study originated from summative tests but the nature of the questions and answers were the focus in this study rather than consideration of a summative or formative purpose. Interviews were audio-taped. Full transcriptions from taped interviews to written format were prepared for all interviews. A total of six teacher interviews were audio taped and transcribed.

Various informational materials gathered from the teachers included transcripts of the interviews with the researcher, tests and marked student work samples. These teachers and some of their students’ comments and judgments on a common Test Question and Student Answer were collected. The experience and involvement of the interviewed teachers - Howard, Collette, Anthea, Michelle, Wendy and Philip are shown in Table 3.2.

In the interviews the teachers’ views of learning, their preferred learning styles, assessment styles, their discussion of each assessment, whether the students’ answers aligned with the expected answer, their views on the capability of the students and their reflections on how and what they used (e.g. mental schemas, concept knowledge) to interpret each assessment, were discussed. The teachers who participated in the interview selected specific questions and student work samples from their class, which was used in their discussions. The selection was predominantly from students who had written substantial answers in their tests and examination.

Teacher interviews partially relied on a particular assessment to be discussed that a selected group of students in their class had completed. Selection of the test or examination assessment for each interview was carried out by the teacher being interviewed.

Table 3.2 Experience and involvement of interviewed teachers

Teacher	**Experience**	**Involvement**
Howard	Perth, biology teacher and HoD, 30 years experience, Catholic private school, TEE marker.	Interview, marked student work samples, judgment on common Test Question and Student Answer. Four students were interviewed (not included in this study).
Collette	Perth, biology teacher and HoD, 31 years, Anglican private school, TEE marker, Examinations writer.	Interview, marked student work samples, judgment on common Test Question and Student Answer. Four students were interviewed (not included in this study).
Anthea	Country Western Australia, biology teacher and HoD, 25 years, Catholic private school, was curriculum officer, TEE marker.	Interview, marked student work samples, judgment on common Test Question and Student Answer. Four students were interviewed (not included in this study).
Michelle	Ireland, biology teacher and HoD, 26 years, Catholic private school.	Interview, marked student work samples, judgment on common Test Question and Student Answer. Six students were interviewed (not included in this study).
Wendy	Perth, biology teacher, 30 years, State school. TEE marker.	Interview, judgment on common Test Question and Student Answer.
Philip	Perth biology teacher and HoD, 35 years, State school TEE marker, examinations writer.	Interview, judgment on common Test Question and Student Answer.

Note: abbreviations - Head of Department (HoD), Tertiary Entrance Exam (TEE)

Longer answer questions were generally given preference by the teacher in order to maximise the discussion on the demonstration of a student’s complexity of ideas in their answers and possible patterns of thinking. Students had answered the questions chosen by the teacher in previous days, had received their assessments with a mark, and had received feedback in class on the test questions. Appendix 3 contains teacher-selected examination and test questions, their students' answers and teachers' marking of these answers.

3.4 A Discussion on Research Questions with an Experienced Biology Teacher

A discussion was undertaken, based on the proposed interview schedule for the study using a selection of questions about assessment and ways of thinking. One open-ended question from the school's biology, end of semester test (which became the Test Question used in the study) and a student's answer from the school cohort that year to that question (which became the Student Answer used in the study) provided as discussion focus points. The teacher interviewed for the review of questions, Philip, was an experienced biology teacher with 35 years teaching experience and was Head of Biology in a large high school. He constructed his own expected answer and marking key for the common Test Question. An interview was carried out with Philip about what ideas or theoretical framework he was using when constructing this marking key and the reason for his allocation of marks. Some probing was undertaken related to the Western Australian curriculum and Science Progress Maps (Curriculum Council of Western Australia, 2005), used at that time. Philip was included as one of the six expert teachers who participated in the study. The full results of the interview and his marking key can be found in Appendix 3.

Discussions indicated that Philip had clear understandings of the questions. He constructed a marking scheme related to the emphasis expressed within the Test Question. During the interview, Philip answered substantially in terms of biological content knowledge. However, his use of a concept map as an answer key instead of, for example, a list of points, appeared to be significant in the way he thought and organised his ideas. It was evidence of the sort of relational and conceptual framework Philip used. When shown the Science Progress Maps (Curriculum Council of Western Australia, 2005), Philip thought it might be useful for less- experienced teachers, but that it was too general to be much help in the assessments that he and the researcher were discussing. The Science Progress Maps question was retained in the interview schedule until after the interview with Collette, at which time radical curriculum review by the Western Australian Curriculum Council changed curriculum direction in regard to these Maps. As a result, the question was removed for further interviews although Howard raised similar ideas in his interview.

Philip’s comments on the scheduled questions reinforced productive directions proposed by the study. For example, he commented about the range of responses he thought students would give to the Test Question and on the amount of expertise held by students. This discussion warranted an expert/novice focus (Bransford et al., 2000) for this study. He referred to many issues that may have affected student responses, such as time, newness of knowledge and syllabus requirements indicating that he was aware of competing priorities and decisions he was making. Philip was using his depth of knowledge of the subject area and experience of his students in assessment and in making judgments of their achievement. Philip’s views linked very closely to the understanding of Shulman’s Pedagogical Content Knowledge as applied by an experienced teacher to assessment. Philip’s comments re-confirmed PCK within an assessment context as a proposed lens for this study.

The discussion occurred early in the conceptualisation of the research and enabled refinement of the interview questions and of ideas concerning interpretational frameworks. The discussion with Philip and initial PaP-eR analysis (Mulhall et al., 2003) of his interview is presented in Appendix 3. The interview with Philip provided valuable perspectives and insights and is included in the current study’s methods (Figure 3.6), in the results chapter on teacher cases and frameworks and chapters on the discussion of assertions.

3.5 Data Collection

Several information sources were used in order to increase confidence in the study. In essence, a triangulation of data sources was enabled through collection of data from teacher interviews, analysis of answers from marked test papers from the selected teacher’s classes and specific comments about students’ work by their teachers. Other student data collected consisted of responses to assessment items and 18 students from four teachers - Collette, Anthea, Howard and Michelle - were interviewed about their tests. The data from student interviews may be used in a separate study and are not included in the body of this thesis.

The teacher interview schedule consisted of 16 questions. Teachers had the questions in front of them at the interview and could refer to them during the discussion. The teacher interview schedule is located in Appendix 2. The interviews took about 30 minutes and were tape-recorded. The Test Question, Student Answer and other questions that the teachers discussed in interviews are shown in Table 3.3 and Table 3.4. The other questions selected by teachers were a range of short answer or written questions covering specific areas of biology that their students were studying at the time of the interviews. The biology topic covered by the questions for the interview was considered less important than the propensity of the question for promoting expansive comments from the teachers. It was also considered important that, as professionals, the teacher should choose the most appropriate relevant question or questions for discussion.

Table 3.3 Test Question and Student Answer.

Test Question
38. (Written Question) 10 marks Describe a series of four (4) processes that occur in a plant cell and how they are related to enable the cell to work efficiently. (Marks will be allocated for the relationships between the processes and how they benefit the cell, not just for the names of the processes).

Student Answer

DNA Replication

Before mitosis is able to be completed, the DNA located in the nucleus of the cell must replicate, this is necessary as the two daughter cells must have the same number of chromosomes as the parent cell and if the DNA didn't replicate, then the daughter cell would only have half the required number of chromosomes.

Mitosis

Consists of the stages interphase, prophase, metaphase, anaphase, and telophase. During this process the cell replicates and divides by forming a spindle and separating the replicated DNA chromosomes to either end of the cell, the membranes then enclosed each daughter cell and two new cells, identical to the first parent cell are formed. Mitosis is necessary for growth and repair in an organism.

Photosynthesis

Plants create their own nutrients through photosynthesis, i.e. they are autotrophs. By capturing light energy through chloroplasts photosynthesis uses carbon dioxide and water to create glucose and oxygen, glucose and oxygen being the raw products/materials of respiration and the raw products/materials of photosynthesis being carbon dioxide and water. Photosynthesis is necessary in creating these products that are required for respiration.

Respiration

Respiration comes in two forms, aerobic and anaerobic, both producing energy that is used by the cell, aerobic requiring oxygen and producing 36-38 molecules of ATP from 1 glucose molecule in the mitochondria and anaerobic not requiring oxygen and producing carbon dioxide and alcohol in the cytoplasm. Respiration is necessary as a process within a plant cell as it creates ATP which is required for several of the cells activity and produces an instant source of energy that is located on the third phosphate bond. ATP is also required predominantly for protein synthesis, where mRNA is released into the cytoplasm and connects to a ribosome and consequently proteins are made.

Table 3.4 Questions selected by teachers for discussion in interview.

Anthea

Question 32d (Short answer, 4 marks)

A cell biologist obtained the following images when examining a cell with an electron microscope. (This is followed by two micrograph images, image A with arrow pointing to the grana of a chloroplast and image B pointing to the internal structure of a mitochondrion.)

Describe and explain the effect of a slow increase in temperature on the metabolism of these cells.

The teacher's answer to 32d was

"A slow temperature rise will increase metabolism (1)

Because according to kinetic theory particles move more quickly (1)

As temperature increases metabolism will peak then fall (1)

As enzymes become denatured (1)."

Question 36a (Essay, 10 marks)

Describe the structure and importance of enzymes to the body. Include in your answer an explanation of the factors which affect enzyme activity.

The teacher's answer was:

- "Enzymes are organic catalysts, i.e. some enzymes are protein in nature and can speed up a chemical reaction.
- Enzymes are specific to the reaction they can catalyse
- Each enzyme has a particular shape
- On the surface of the enzyme is the active site onto which another molecule, the substrate can fit
- Lock (substrate) and key (enzyme) mechanism
- The enzyme will hold the substrate which the chemical reaction occurs
- The changed molecule, the product is released, leaving the enzyme unchanged and able to catalyse more reactions. (6 marks for 6 points)

Factors which affect enzyme activity:

- Temperature-high temperatures will permanently denature enzymes while low temperatures will temporarily inactivate them
- Enzymes are sensitive to changes in pH – they work best at an optimum pH
- Their activity is affected by the concentration of both reactants and products. Increase in concentration leads to increase in activity until other factors become limiting
- Heavy metals and inhibitors can restrict their functioning. (maximum 4 marks)"

Howard

Question 32c (Short answer, 3 marks)

Describe three (3) ways organisms may GAIN or LOSE heat.

The teacher's answer was:

- radiation
- conduction
- evaporation

Question 39c (Essay, 10 marks)

A polar bear is a large thickly furred mammal, which inhabits arctic environments in Canada, Alaska and Russia. Polar bears used to be kept in Perth Zoo, but a few years ago the zoo decided not to replace the polar bears after they died.

Describe the problems that an arctic mammal like the polar bear would experience in a warm climate like Perth's and explain the biological reasons for those problems.

Collette

Year 11 Question (Short answer, 7 marks)

What is classification? (1 mark)

Why is classification an important life skill? (2 marks)

Give one example of how classification is or can be used in your daily life. (1 mark)

What is a classification key? (1 mark)

If someone makes an error while using the key, what did they probably do wrong? (2 marks)

Year 12 Question (Short answer, 12 marks)

An experiment was conducted in which the digestion of polypeptides by trypsin was investigated. Six *test tubes were placed in the water bath that was set at 35°C. Each test tube contained 5mL of peptide solution and 1mL of trypsin solution. The pH of the test tubes was altered as indicated below. The reaction was tested for the percentage breakdown of polypeptide into amino acid at the end of 30 minutes.*

pH of test tube	***% breakdown of peptide***
6	*32*
7	*65*
8	*100*
9	*95*
10	*35*
11	*20*

Plot a graph of % breakdown of peptide against the pH. (4 marks)
Write a hypothesis that was possibly being tested in this experiment. (1 mark)
Name the independent and dependent variables. (2 marks)
Name two factors that should have been kept constant in conducting the experiment. (2 marks)
Explain why it is important to keep each of these constant. (2 marks)
From this data what is the optimum pH for the activity of the enzyme trypsin. (1 mark)

Michelle

11b vi
In aerobic respiration, the product of the first stage moves to the mitochondrion. Outline subsequent events in the total breakdown of this product. (5 marks)

The methods used for data collection were deep interviews (Minichiello et al., 1990) using an interview schedule (Patton, 1990), analysis of participants' marking keys for a common Test Question and Student Answer and analysis of teacher-selected and marked test questions. The deep interviews used a semi-structured questionnaire to collect data on teacher judgments and interpretations (Appendix 2). A "funnelling" (Minichiello et al., 1990, p. 116) strategy was used, where interviews started with broad, general questions and then, as specific issues emerged from the interviews, guiding questions were developed by the interviewer to explore those issues further. An interview schedule consisting of open-ended questions was devised and used to gather insights and build rich understandings from the teachers in the sample and enable qualitative analysis to be undertaken (Patton, 1990).

In exploring the methods for collection of rich data and the interpretations that people attach to their situation, in this case the context of assessment and classroom tests, the researcher became aware of an interesting parallel between interviews and in-school test construction and responses. In the construction of the interview, the researcher encoded questions with purposes, knowledge about responses and perceptions of response presumptions in mind. Each teacher participant decoded the question. After interpreting, considering the question and framing a response, the teacher encoded their answer defined by their dimensions. The researcher then decoded the answer provided by the interviewee. The coding and decoding process between interviewers and respondents forms a part of the symbolic interaction theory in social research (Foddy, 1993). Symbolic interaction posits that "social actors in any social situation are constantly negotiating a shared definition of the situation" (Foddy, 1993, p. 20). Blumer (1969) listed key ideas of a symbolic interactionist approach, including that responses are made to the interpretation of acts rather than to the acts themselves. Further, Blumer argued that these interactions occur in established social situations, where participants often form common understandings, as well as in new ones. Foddy (1993, p. 20) commented that there had been little research into "respondents take-the-role of the researcher" when constructing their answers. In examining the process of encoding and decoding that he hypothesised, Foddy explained in several tables (pp. 22, 26, 39, 53, 77), which have been combined by the researcher in illustrating the different activities that take place within a coding, decoding framework.

I Interviewer		II Respondent
Encodes question. The need to clearly specify the information that is required. The assumption that respondents have the required information. The assumption that respondents can access this information.	→	Decodes question. Contextual clues that influence respondents' interpretations. ↓
IV Interviewer		**III Respondent**
Decodes answer. Taking into account own presumptions / knowledge about the respondent and perceptions of the respondent's presumptions / knowledge about self (ie. the interviewer).	←	Encodes answer. The kind of answer given is defined by the dimensions of the response framework that is employed. Taking into account own purposes and presumptions about the interviewer.

Figure 3.1 A coding and decoding framework (adapted from Foddy, 1993).

A framework of encoding a question by the interviewer, decoding the question by the respondent, encoding an answer to the question as interpreted by the respondent and decoding the answer by the interviewer is illustrated in Figure 3.1 as steps in interpretation occurring for each research question. If *Teacher* replaced *Interviewer* and *Student* replaced *Respondent*, the framework illustrated above could be postulated as being applicable to the classroom assessment context. That is, construction of tests by teachers who encode questions, students respond to the tests by decoding the question and then encoding an answer, then teachers mark or make judgments of the answers by decoding or interpreting the student responses. Teachers and students who have an awareness that interpretations may differ, that is encoding and decoding mistakes may be made, could engage in a negotiation after class-based tests.

Coding and decoding responses in both research and classroom contexts is an area where mistakes in interpretation and therefore in meaning are possible. In education, mistakes in coding or decoding responses affect judgments and could lead to erroneous answers from students or attribution of flawed marks or comments from teachers. There may be a significant chance of errors of this nature occurring in the confined temporal environment of tests and marking. During the study, evidence of teachers' awareness of this issue and strategies that helped ameliorate this potential problem was sought. In research, inaccurate interpretation of participant responses could lead to unreliable results and propositions. Within the study, checking during the interview with further questions and comparative analysis of answers for consistency of thinking and explanations through each interview was undertaken.

3.6 Data Analysis

A logical first step in making sense of the interviews and other data was to construct researcher's commentaries and notes when reading each interview. A method to begin initial analysis and reporting on the documentary materials collected in the current study was the Pedagogical and Professional-experience Repertoires (PaP-eR) commentary device (Mulhall et al., 2003). This process enabled the researcher to decode the responses of the teachers and highlight any links to research in order to build understandings about teachers' interpretations, perspectives and thinking.

Following the initial examination of the PaP-eR analysed data from the interviews, marked answers from questions selected by teachers were analysed by the researcher. The teacher's judgment of students' work was informative in developing a picture of the teacher's pattern or framework of thinking.

Using these analyses, teacher participants' views and interpretational frameworks were predicated through case methods (Lincoln & Guba, 1985; Merriam, 1998; Yin, 1994) and assertions were developed (Erickson, 1986). The aim of these actions was to identify teachers' lived experience, to make meaning, and compare teachers' experiences with those of other teachers. The development of assertions could be viewed as developing a cross-case analysis and this process enabled identification of commonalities and differences and of themes or patterns. Extended descriptions, quotes and commentary were used to illustrate aspects of the cases and each assertion theme.

3.6.1 PaP-eR method

The PaP-eR commentary method devised by Mulhall et al. (2003) was used to provide a way of meaning-making and to provide an "evidentiary warrant" (Erickson, 1986, p. 146). The PaP-eR method provided a way to capture participant insights and researcher interpretations. This technique formed the basis of an interpretive commentary by the researcher of the teachers' practices and teachers' responses to the interview. A similar commentary device was illustrated in the *Making Progress* series of documents for teachers from the Curriculum Council of Western Australia (2001). Both the PaP-eR technique and commentary device helped the researcher in conceptualising the task of decoding or interpreting the responses.

The PaP-eR format is an explicit representation attempting to capture teachers' reasoned decision-making in the teaching context (Mulhall et al., 2003). The PaP-eR could also be utilised as a narrative account of a teachers' PCK for a particular aspect of science teaching or assessing. This description is a form of evidence demonstrating that teachers are using PCK. The method is used to illuminate aspects of teachers' accounts of practice. Each PaP-eR "unpacks the teacher's thinking around an element of PCK for that content and was based on … comments made by teachers during the interviews" (Mulhall et al., 2003, About PaP-eRs, para. 1). Further, the PaP-eR uses "call-out boxes to highlight the interpretive frames we have used in its construction" (Mulhall et al., 2003, About PaP-eRs, para. 2). The teacher's voice or reflections in the interview are captured in narrative text. The "voice of the call-out boxes is that of the researchers elaborating" (Mulhall et al., 2003, About PaP-eRs, para. 2), illustrating and interpreting the teacher's narrative in terms of PCK. PaP-eRs are explained as offering "one way of capturing the holistic nature and complexity of PCK… PaP-eRs have the capacity to represent a *narrative whole* and function to explain in a text what one knows in action as a teacher" (Mulhall et al., 2003, About PaP-eR, para. 3).

In the current study ways of capturing insights, revealing commonality and difference and analysing the teacher's reflections and explanations, as well as enabling researcher interpretation in an analytical structure or framework, led to the common-sense approach of the PaP-eR format. It also enabled a comparison of teacher comments with PCK research. An interview of Philip (P) with the researcher (R) illustrating a PaP-eR format is shown in Figure 3.2 with more details in Appendix 3. The PaP-eR format, as illustrated in Figure 3.2, consists of the interview narrative with two formats shown alongside on the right hand side. The first format in plain narrative highlights noteworthy points and inferences made by the researcher from the text of the interview. The boxed narratives are the big ideas drawn from the narrative highlights that can be used to formulate coherent responses to the research questions.

3.6.2 Cases

Teacher cases were constructed following and using the initial PaP-eR format to analyse and discuss teachers' reflections and explanation of ideas, with an aim to identify teachers' interpretational frameworks and their personal and professional ideas in the context of biology assessment. Case studies have been defined by various researchers as a specific instance that is frequently designed to illustrate a more general principle. Lincoln and Guba (1985) described a case as a unit that must meet two criteria. A case should be "heuristic - that is, the unit should reveal information relevant to the study and stimulate the reader to think beyond the particular bit of information" (p. 345). Secondly the unit should be:

> the smallest piece of information about something that can stand by itself, that is, it must be interpretable in the absence of any additional information other than a broad understanding of the context in which the inquiry is carried out. (p. 345)

P I would have set out with a marking key to do this. I see you had a bit of a marking key. You didn't indicate on that marking key where marks were allocated.

R What would you have done?

P I would have started off with something like this flow diagram… (I was shown his diagrammatic representation of an answer with mark allocation explained in two sentences at the base)…link up whatever these particular processes were, like photosynthesis is linked to respiration, it (photosynthesis) produces glucose which is needed in respiration and getting ATP for active processes, cytoplasmic streaming and so on. Cell division tends to reduce the size of the cell and therefore maintains a higher surface area to volume ratio which impacts on other process, such as making photosynthesis more efficient, enabling the uptake of carbon dioxide and water more efficiently. With a flow diagram I would try to relate all these processes.

And that's what I would be talking to them about when going back over the exam - showing how they can relate all of these, because they are interrelated.

In marking this you have to appreciate that a lot of people could not develop something like this until they have years of contact with the subject. For a good student they would need to be able to explain each of the processes that they talked about. I think they need to mention photosynthesis, discussion of the equation would be required and they would get one mark, and similarly for cell division, active transport, cytoplasmic streaming, respiration. Each of these together could add to a total of 4 marks, that's without showing any interrelationship, then the students a bit stronger than that would go on to show some links. Most of them are able to link photosynthesis and respiration. They will say that because we teach them photosynthesis and respiration are almost opposite reactions that therefore without photosynthesis you can't have respiration, without respiration you can't have photosynthesis, because that produces the carbon dioxide which inevitably gets back to the photosynthesis. So that would get the medium type student 6-8 marks or 6 marks is probably the maximum they would get. Then the better students would say respiration is related to all these other processes by ATP so they would be discussing how ATP is used in cell division, not in detail, but just saying ATP breaks down to ADP releasing energy which makes cell division possible, because cell division requires movement of tiny molecules and organelles and the like and active transport is an energy requiring process so all those things have to show that ATP breaks down to produce the energy needed for these endothermic type reactions so they are getting marks for relating ATP to those sort of things, so possibly 9 marks.

Then to get a full 10 marks they would have to explain how all of these processes make up the whole organism - without one you can't have the other.

P=Philip, R=Researcher.

Analysis

Philip constructed an answer model in the form of a flow diagram/concept map and had a clear concise representation of the concepts and the relationships between them.

He is using his content knowledge to describe his expectations and a good answer. He used a visual representation to construct a marking key. His thinking is complex and relational in the biology context.

He makes plans about the concepts and issues within the question that he will raise with the students after the exam.

He plans for feedback and learning experiences as a result of assessment.

He identifies an Expert/novice situation.

He identifies the parts of the answer (which he allocates marks).

Then he describes the relationships the students generally make between the concepts and identifies a mark that he would give them.

He uses his experiences of students, teaching and assessing to predict answers that students would give. This is linked to PCK.

He identifies ranges of answers that increasingly more expert students would give.

He recognises complex responses in that the answers both require more microscopic knowledge, more parts to each concept and the beginnings of integration of chemistry concepts within the biology field.

He identifies a multi-level approach to biology.

Figure 3.2 Interview with Biology teacher using PaP-eR (Mulhall et al., 2003) format. (Philip and the researcher's interview is displayed on the left hand side of the page. The researcher's commentary is displayed on the right hand side.)

According to Yin (1994, p. 193), a case study is an "intensive, holistic description and analysis of a single, bounded unit." Flyvberg (2011, p. 314) outlined the strengths of case studies as having "depth, high conceptual validity, understanding of context and process, understanding of what causes a phenomena, linking causes and outcomes and fostering new hypotheses and new research questions".

A separate group of ideas about cases have been expounded by Wallace and Louden (2000, p. 87) who paraphrased Shulman in describing characteristics of cases as a narrative "specific to the setting and locally situated; and that it reveals the human condition". Studies focusing on related cases at different sites have been described by Merriam (1998) as cross-case studies. Yin (1994) suggested conducting and reporting individual cases separately at first, then drawing cross-case comparisons. In this study, the main participants in the research are six teachers. Cases that were constructed from all teachers in this group are described in Chapter 4 with a focus on revealing their interpretational frameworks and implied theories related to learning and assessment of students in biology. Cross-case comparisons were essential in developing the assertions that were developed in Chapters 6, 7 and 8.

3.6.3 Theory building

A major goal of this study is to identify teachers' interpretational frameworks in a context of biology assessment. Theory building is an approach that has been used in developing the cases and assertions. In order to generate theory, insights and findings, and to appropriately answer the research questions, descriptive texts, initial comparisons and partial interpretations were analysed and synthesised. Merriam (1998, p. 178) described analysing the data as a "complex process that involves moving back and forth between concrete bits of data and abstract concepts, between inductive and deductive reasoning, between description and interpretation." She also said:

> These meanings and insights constitute the findings of a study. Findings can be in the form of organised descriptive accounts, themes, or categories that cut across the data, or in the form of models and theories that explain the data. (p. 178)

Theorizing is defined by LeCompte and Preissle (1993, p. 239) as "the cognitive process of discovering or manipulating abstract categories and the relationships between those categories". Miles and Huberman (1994, p. 261) described developing theory as moving up “from the empirical trenches to a more conceptual overview of the landscape. We’re no longer just dealing with observables, but also with unobservables, and are connecting the two with successive layers of inferential glue.” As well as the researcher building theory for the purpose of the study, teachers build theory in the subject, in their practice and in their analysis of their students and their students’ assessment responses. The teachers’ explanations and interpretational frameworks are developed, proposed and presented in the case studies in Chapter 4.

3.6.4 Assertions

After a first stage of interpretation of the six teachers’ comments using a PaP-eR commentary method, assertions were developed and used to organise the information further and provide more clarity in terms of the research questions. Assertions are viewed as synonymous with categories, as described by Merriam (1998). She stated that categories are “concepts indicated by the data (and not the data itself)” (p. 179) and that these properties “have a life apart from the evidence that gave rise to them” (p. 179). Merriam wrote that constructing categories is largely intuitive, but is also “systematic and informed by the study’s purpose, the investigator’s orientation and knowledge, and the meanings made explicit by the participants themselves” (p. 179). Similarly, Erickson (1986, p. 147) explained that “the researcher is looking for key linkages among various items of data. A *key linkage* is key in that is of central significance for the major assertions the researcher wants to make.”

The categories and processes referred to by Merriam (1998) and the key linkages described by Erickson (1986) were considered in the analysis of information in constructing robust assertions. Analogous instances of the same phenomena were linked through pattern discovery. Assertions were generated largely by an inductive process from the interview data and written responses, the initial PaP-eR analysis, comments on students’ test material and on the Test Question and Student Answer, seeking and describing confirming and disconfirming evidence. The aim of the researcher was to develop clarity of meaning for each assertion and provide the “evidentiary warrant” for the assertions (Erickson, 1986, p. 146). Instances of interview data that provided clarity and evidence for assertions are quoted in interpretive commentaries that appear in the analytic narrative of the results and discussions chapters.

As well as seeking confirming evidence, the researcher searched for disconfirming evidence as an essential part of the analysis related to assertions. The discrepant cases were useful in illuminating locally distinctive subtleties (Erickson, 1986) and provided authentic reality within the situation and phenomenon for this research.

The researcher considered the nine main elements or methods for a research report as detailed by Erickson (1986). Those elements were empirical assertions, analytical narrative vignettes, quotes from notes, quotes from interviews, synoptic data reports, interpretive commentary framing particular and general descriptions, theoretical discussion and reports of the natural history of inquiry. The elements used in this study were empirical assertions, analytical narratives, quotes from interviews, interpretive commentary framing particular and general descriptions and theoretical discussion. Interpretive commentary was illustrated by analytic narratives within the study, which were intended to give clarity, provide evidence and help identify the patterns within the assertions. Interpretive connections were made across descriptions, quotes and other narratives.

3.6.5 Structuring the study: An iterative process

An iterative process was used for the study involving analysis and making sense of data, checking with teachers and modifying the proposed research framework. The process of data analysis and the interpretation of the data was undertaken as an iterative and emergent approach, where meaning would emerge through the data collection process and then from the data in the style of grounded theory. Grounded theory was first proposed by Glaser and Strauss (1967) and described by Denzin and Lincoln (1994) as an interpretive method. Maxwell (2005) defined grounded theory as "theory that is inductively developed during a study…and in constant interaction with the data from that study" (p. 42). The theory arises from and is grounded in the data collected.

The researcher used methods for data analysis already described in the study in order to reveal the structure and essence of the phenomena, that is, the assessment, interpretations, experience, assumptions, understanding, theories and views held by the biology teachers and consequently, their interpretational frameworks in an assessment context. Figure 1.1 illustrates the frameworks from research literature in the review in Chapter 2, which led to understanding aspects of the phenomena.

3.6.6 Structuring the study: Identifying teacher statements from the interviews

The researcher examined the transcripts of teacher interviews, which had each undergone an initial PaP-eR commentary analysis in order to investigate ways to analyse the data and develop categories. Categories were determined and were constructed into a list. Twenty-eight categories were developed from the researcher's interrogation and conceptualisation of the interview data. The categories are contained in Figure 3.3 and additional relevant notes are contained in Figure 3.4.

3.6.7 Structuring the study: Development of assertions

The researcher re-examined the data to ensure that all ideas were captured. Discussion with the supervisor of this thesis was iterative about the statements of teachers' work fitting under an umbrella of teacher assertions. A grounded practice (Glaser & Strauss, 1967) of structuring frameworks inductively developed from this body of information was used resulting in six major assertions under three headings.

Making judgments of student achievement

The first assertion was developed from statements 1, 2, 3, 5, 6, 7, 9, 10, 14, 16, 19, 21, 22, 26, 27.

1. These biology teachers' assessment judgments are dependent on their expectations of and interpretations of the students' biological explanations to questions.

The second assertion was developed from the statements 6, 8, 12, 14, 16, 20, 24, 28.

2. These biology teachers award marks using a dynamic process consistent with their rationale and guided by a marking key.

Teachers' strategies for assessment

The third assertion was developed from statements 11, 12, 13, 14, 15, 23, 25.

3. These biology teachers design the most appropriate assessment strategies for their purposes and to meet internalised or external frameworks.

Researcher’s statements drawn from teachers’ interviews
When assessing students, experienced biology teachers:

1. Expect a clear representation of the biological concepts asked in the question.
2. Accept multiple representations and / or the students to choose the most appropriate representation in order to answer the question.
3. Within a comprehensive biology assessment, look for evidence of a multi-level understanding of the biological concepts as in Shulman’s (1986) three ways to organise biological knowledge.
4. Plan for learning experiences as a result of assessment based on, for example, feedback, re-teaching, student reflection, frequency, recency, re-visiting, practice.
5. Identify expert/novice approaches in assessment problems or questions and in ranges of answers.
6. Identify the priorities, critical student answers and allocate marks accordingly.
7. Segment the question and make judgments on answers to each segment.
8. Can predict answers students generally give from teachers past experiences and allocate marks according to that expectation.
9. Recognise and judge from patterns of student responses.
10. Demonstrate flexibility of marking not only on complexity, but on answers that provide more than is necessary.
11. Are aware of external factors affecting student performance and try to control these factors or take them into account.
12. Understand the idiosyncrasies in different question types and what is required in answering them.
13. Are aware of need for processing time.
14. Demonstrate flexibility in their own use of different assessment frameworks in judging answers.
15. Design best assessment strategies for a particular purpose, such as open-ended, application questions for teasing out student understanding.
16. Look for clues indicating student understanding.
17. Can relate steps in thinking about biology in more complex ways.
18. Acknowledge the place of discussion and student talk about biology as good predictors of exam success.
19. Recognise different styles that students use to express their understanding.
20. Use their own content knowledge to select the best response from possible answers and attributes a score (for level of detail, specific content, connections between ideas)
21. Make inferences about students’ understanding (in the way students express answers and terminology, in the links made between ideas, in the proper explanation of a process, 4. in understanding how it fits together, 5. correctness).
22. Make judgments based on their usual cohort of students - teacher expectations.
23. Consider that different students need different amounts of time to lock in the knowledge and to answer questions.
24. Look for shifts in student responses, from describing a process to having a more holistic view.
25. Set different question types related to their purpose (multiple choice questions for basic content, calculations, interpretation and application questions, short answer and extended questions for demonstrating knowledge, links, depth, lateral and vertical expansion).
26. Recognise the importance of not letting their relationships with students influence teachers’ judgments.
27. recognise that making judgments is a dynamic process (depends on the variations in answers and the teachers’ flexibility is accommodating a variety of student interpretations).
28. Make judgments partially in terms of an external framework (Bloom’s taxonomy (Bloom, 1956), state or national requirements and question style such as open ended compared with closed).

Figure 3.3 Researchers’ statements drawn from teachers’ interview data

Teachers' ideas about biology content understanding

a) Content continuum or discrete groups of steps?

b) Concepts interrelating in dynamic ways (teachers think that students don't know how to do this)

c) Belief that students reach a level of understanding and for some, cannot go beyond that – a blockage or an attitude.

d) Each process or step needs to be understood before the whole process can be understood

Teachers' general perceptions

e) Students tell teachers they need clear responses and specificity in knowledge in feedback, not generalised statements

f) Students are more receptive to learning when they have done a test and failed to receive marks for their answer

g) Teachers have a big picture understanding, relate macroscopic to microscopic (and biochemical), specifics at the organisms level, niche and interrelationships. Then shifts – changes & what happens. Relates, hierarchy, cross-links, changes in these, complexity.

h) When given new information, students step though processes starting with concrete thinking then move to interpretation, analysis and evaluation.

i) Students who are abstract thinkers internalise quickly, relate the concrete information quickly to their mental picture, and understand what is happening

j) Teachers have good visual models in biology

k) Students use many techniques to help them learn (boxing information, colour, visuals, use props or equipment to show important ideas, models, stickers, sounds out words, lists).

l) Assessment can provide the teachers and students with feedback on information to improve learning

Figure 3.4 Teachers' ideas, perceptions and statements drawn from interview data.

Teachers' strategies for assessment, continued.

The fourth assertion was developed from statements and ideas 4, 18, e, f, l.

4. These biology teachers recognise the importance of feedback about assessments to student learning.

Frameworks for biology thinking

The fifth assertion was developed from the statements and ideas 17, 24, a, b, g, j.

5. These biology teachers have a big picture, three-dimensional understanding of biology and prefer visual models.

The sixth assertion was developed from statements and ideas 24, c, d, h, i, k.

6. These biology teachers consider that students differ from each other in their thinking, with most being linear thinkers who progress through shifts in learning.

The assertions developed from categorising the data are discussed in detail in Chapters 6, 7 and 8. Table 3.5 shows the distributions of assertions within the chapters. Evidence from teacher interviews and from their analysis of student assessments is presented in these chapters to support the proposed assertions. The presentation of evidence is strongly focused on teachers' voices in the form of their statements, quotes and interpretations from commentaries. The assertions are grouped under three categories, *Making judgments of student achievement*, *Teachers' strategies for assessment* and *Frameworks for biology thinking* and these headings will be the focus of each of Chapters 5, 6 and 7.

3.7 Trustworthiness and Plausibility in the Study

3.7.1 Plausibility, validity and trustworthiness

The aim of this thesis is to persuade with adequate evidence that claims by the researcher of particular patterns of generalisation are reasonable and trustworthy. Campbell (1978) referred to this as plausibility, which is an appropriate aim of this research. Accounting for patterns found across rare and frequent events would provide the best case for validity and this was undertaken by using assertions (Erickson, 1986). By definition, the strongest assertions would have most connections and supporting evidence, while rare events may provide important insights within the study. The study included a search for disconfirming evidence (Erickson, 1986). This search provided alterative perspectives (Cresswell & Miller, 2000) and gave credence to confirming evidence, which outweighed the alternative evidence.

Table 3.5 Categories and assertions developed through cross-case analysis and contributing to teachers' interpretational frameworks.

Categories and Research Questions	Assertions	Statements and ideas
Making judgments of student achievement Chapter 5 Addresses Research Questions 2 and 3.	1. These biology teachers' assessment judgments are dependent on their expectations of and interpretations of the students' biological explanations to questions.	1, 2, 3, 5, 6, 7, 9, 10, 14, 16, 19, 21, 22, 26, 27.
	2. These biology teachers award marks using a dynamic process consistent with their rationale and guided by a marking key.	6, 8, 12, 14, 16, 20, 24, 28
Teachers' strategies for assessment Chapter 6 Addresses Research Question 4.	3. These biology teachers design the most appropriate assessment strategies for their purposes and to meet internalised or external frameworks.	11, 12, 13, 14, 15, 23, 25
	4. These biology teachers recognise the importance of feedback about assessments to student learning.	4, 18, e, f, l
Frameworks for biology thinking Chapter 7 Addresses Research Question 5.	5. These biology teachers have a big picture, three-dimensional understanding of biology and prefer visual models.	17, 24, a, b, g, j
	6. These biology teachers consider that students differ from each other in their thinking, with most being linear thinkers who progress through shifts in learning.	24, c, d, h, i, k

Lincoln and Guba (1985) suggested validity be abandoned in research other than in the positivist paradigm, and replaced by trustworthiness. Roth (2007) indicated that trustworthiness meant having trustworthy data and also questions worthy of investigation and interest beyond the individual's classroom.

The researcher used rich, thick descriptions from the data to ensure participant voices, assumptions and frameworks emerged strongly, in order to demonstrate credibility and trustworthiness in this study. Multiple and diverse sites were used for the study in seeking patterns in and answers to the research questions. The researcher also used PaP-eR methods, cases and assertions to identify, describe and account for individual views as well as patterns in the data and used and demonstrated a coherent flow of research-based, emergent theory building practices, resulting in authentic conclusions and findings.

The researcher's background, professional practice, relevant ideologies and assumptions have been described in the Introduction to the thesis (Chapter1). Self-disclosure of researcher's professional beliefs and biases is seen as important. Cohen et al. (2000, p. 121) stated that minimising the amount of bias, such as accounting for "the attitudes, opinions, and expectations of the interviewer" assists in reaching greater validity. Merriam (1998) suggested conditions for ensuring reliability of results, including making the investigator's position clear, explaining the assumptions and theories, using triangulation and providing an audit trail.

Triangulation was used in the design of the study and effected, with interviews, teacher-selected student scripts and a separate Test Question / Student Answer exercise being used. Denzin (1971) identified triangulation as forcing the investigator to use multiple data sources and methods. Eisner (1979, p. 215) suggested "*structural corroboration* is a process of gathering data or information and using it to establish links that eventually create a whole". Multiple data sources and methods were used to provide corroborating evidence in assisting the development of categories as proposed by Cresswell and Miller (2000).

3.7.2 Generalisibility

Generalisations have been identified by Donmoyer (1990) as working hypotheses, by Cronbach (1975) as concrete universals, by Stake (1978) as naturalistic generalisation and by Wilson (1979) and Walker (1980) as user or reader generalisability. However, generalisability of any type is difficult in studies of this kind, where there were relatively small numbers of participants involved in the sampling. Therefore generalising findings to a larger population may be inappropriate. Generalisability may be more appropriately applied with a larger numbers of participants or multiple sites (Lincoln, 1995).

Nevertheless, strategies to enhance generalisability such as rich, thick descriptions, typicality or modal category (describing how typical the events or individuals are compared to others) and multi-site designs (thus maximising diversity), were used in the study and were described by Merriam (1998) as important to consider. Thick descriptions in evidence in the study aimed to provide richness and "deep, dense, detailed accounts" (Denzin, 1989, p. 83) and enable others to determine the credibility and applicability of the research.

3.8 Ethical Issues

The researcher was responsible for the ethical conduct and decisions related to the study, in addition to following ethical guidelines and regulations demanded by a university as discussed by Merriam (1998). All respondents were volunteers. The teacher participants were experienced teachers and were aware of the nature of the study and that they had the right to withdraw at any time. Written permission was gained from students, students' parents and schools before student data such as responses to tests and examinations was collected. Schools and individuals have not been named and pseudonyms used for individuals. Information sheets and permission forms are included in Appendix 4. All data collected remain confidential and anonymous and have been stored in a secure environment for a period of seven years.

3.9 Concluding Comments

For the design and conduct of this study, an appropriate research orientation to address the research questions was developed. Methodology and methods were selected that were critical in the collection of relevant data and analysis processes in order for plausible and trustworthy conclusions and theories to be constructed. This study is an interpretive study with data, analyses and findings expected to emerge from an exploration of experienced biology teachers' views, expectations and understanding in order to answer the research questions.

The research questions were designed to explicate teachers' interpretational frameworks in biology and assessment contexts. The research questions required understanding aspects of and the intersection of many frameworks used by biology teachers, including biology domain knowledge and education, assessment and student learning frameworks. Expert/novice and PCK perspectives were investigated. Critical to the choice of research design was the alignment of the purpose of the research, the topic, the context and the methodology.

Reflection on various background and historical research guided the researcher's thinking on, selection of and use of methodology and methods. Different theories and methods that applied to research on teaching, referred to as a family of interpretive approaches, was illuminated by the research of Erickson (1986) and a particular design was devised for the study.

The idea of a research design based on a family of interpretive approaches was solidified into a framework for selecting and ordering the elements of the study. A hierarchical framework of increasing detail, consisting of epistemology, theoretical perspective, research methodology and methods, was applied to the study (Crotty, 1998). In aligning the research questions and the complexity of education areas with elements of the research design framework, the researcher selected constructionism as the epistemology, interpretivism as the theoretical perspective, phenomenology as the methodology, and PaP-eR analysis, interviews, cases and assertions as the methods.

The current study set out to make meaning of experienced teachers' perspectives and interpretations in terms of the research questions, to hear and acknowledge teacher voices and to use appropriate methodology to discover patterns in teachers' interpretational frameworks and views in the context of biology assessment. Using a family of methods enabled plausibility and confidence in the findings and the conclusions.

An interesting comparison emerged, through explicating the methodology and the interpretations, in terms of coding and decoding communications between people. Coding and decoding forms a part of the symbolic interaction theory in social research (Foddy, 1993). Interview contexts were therefore able to be directly compared with classroom assessment contexts. From this perspective the teacher participants in the study undertook extensive coding and decoding processes in constructing, answering, interpreting and analysing questions and answers in research. In the same way it could be proposed that teachers and students undertake coding and decoding operations as part of the interpretations that occur in classrooms when assessment is undertaken and when assessment discussions between teacher and student take place.

Through the use of the PaP-eR technique, commentaries and interpretations were developed from the interview data and then cases were written and patterns identified leading to categories being constructed. This led to the development of teacher cases and assertions to order and make sense of the data, as well as to enable conclusions to be written.

In the results and discussion chapters, teachers' interpretational frameworks and theories are developed from the data and explained. Teacher cases are developed in Chapter 4. The teachers are introduced. The cases elucidate each teacher's understanding, views, expectations and practices illustrating their interpretational frameworks through individual, partial and temporal descriptions of their professional lives. Analysis in Chapter 4 addresses Research Question 1. *What are the views and perceptions of each teacher regarding assessment in senior school biology?*

In Chapters 5, 6 and 7 confirming or alternative evidence from the data is presented in substantiating the assertions proposed for the study. The assertions are indicative of a cross-case analysis and as such naturally follow the elucidation of the teacher cases. Particular research questions are addressed in each chapter. Analyses and evidence are presented in Chapter 5 for Research Questions 2. *What are the influences on teachers' assessments and judgments of student achievement in senior school biology?* and 3. *In what ways are different teachers consistent in their judgments of student achievement in biology?* In Chapter 6, discussion of evidence addresses Research Question 4. *What strategies do teachers use in assessing senior school biology?* Chapter 7 addresses Research Question 5. *What do teachers consider are their own and their students' frameworks for organising biology?*

Research Question 6. *What are the commonalities and differences among the interpretational frameworks used by teachers in assessing senior school biology?* is addressed as part of the results and discussions in Chapters 5, 6 and 7. In Chapter 8 findings and conclusions are presented on the aim of the study and the research questions.

Chapter 4

Revealing Individual Teacher's Interpretational Frameworks about Assessment

4.1 Introduction

Six experienced biology teachers were interviewed for this study. Teachers have their own particular views as a result of their experiences, context and knowledge. Examining these teachers' ideas and views revealed useful information about the aim, *to investigate the interpretational frameworks used by biology teachers in assessing students' understandings in biology* and provided insights into their decisions and practice. The elucidation of the teachers' ideas and views by presentation of data and discussion in Chapter 4 contributed understanding related to Research Question 1. *What are the views and perceptions of each teacher regarding assessment in senior school biology?* Table 4.1 is an adaptation of Table 1.1 and is the first of a series of tables through the thesis results and discussions introducing the location and response to each research question.

Table 4.1 Research question in results and discussion chapter 4.

Research Questions	Assertions	Chapter
1. *What are the views and perceptions of each teacher regarding assessment in senior school biology?*	No assertions. Individual teacher cases are built.	Chapter 4 Individual teacher's interpretational frameworks

Chapter 4 is the first of the results and discussion chapters and introduces and frames selected comments and ideas of each interviewed teacher within a cohesive individual case. As was indicated in Chapter 3 the teachers' voices are strongly represented. In addressing the aim and Research Question 1, the teachers' responses are described and presented in individual cases and not in the same order as the interview schedule. The descriptions of these teachers' ideas, views and theories represent a snapshot at a moment in time and provide a partial view of their interpretational frameworks. The resultant story of each teacher in drawing a model or map of their world and capturing their related insights and concepts about the phenomena - their interpretational frameworks - met the criteria for theory as defined by LeCompte and Preissle (1993) and Strauss (1995) .

The teachers' interpretational frameworks in biology education in the context of assessment were drawn from the data and analysed as described in Chapter 3. Within Chapter 4 the quotes from the interviews, analyses and theoretical discussion are presented as individual cases of each interviewed teacher (Lincoln & Guba, 1985) and directly provide understandings related to Research question 1. Each case, the data naturally divided into three sections, which were *Assessment*, *Students*, *Himself/Herself*. The discussion of each teacher case is presented as a section: Howard (Section 4.2), Collette (Section 4.3), Anthea (Section 4.4), Michelle (Section 4.5), Wendy (Section 4.6) and Philip (Section 4.7). Concluding comments (Section 4.8) follow.

4.2 Howard

Howard was a male teacher with 30 years experience in teaching biology. The school in which he was teaching was a private metropolitan Catholic school. He was a prominent member of Catholic Education Office professional development events, a TEE marker and at various times was on committees for the Western Australian Curriculum Council. In his two interviews, one on the common Test Question and Student Answer, the other about his selected question and the students' answers to it, he talked through issues and ideas as part of developing a particular view. He valued interaction and reflection as ways of bringing forward his ideas. He had views and insights about assessment, students and his own approach and thinking.

4.2.1 Assessment

In his interviews, Howard addressed selected student responses to two questions and in both he used simultaneous, multiple ideas in his assessment of student responses. Howard moved seamlessly between descriptions of the students' explanations of content, his judgments, expectations and comments about that explicit content, as well as comments on the inferences that he made about what the students may have been saying.

Critique on a Test Question and Student Answer

Howard made several comments about the common Student Answer (Table 3.3). These comments highlighted his multiple focus, including these responses: "The student is relating and looking at benefits, but in the last answer really is going off on a tangent", "I would have expected the student to talk a bit about DNA, talk about mitosis" and "The student is saying that respiration is necessary as a process within a plant cell as it requires, creates the ATP for cell activity" (Howard's interview responses, Appendix 3). This discussion was transcribed in the space of three short, linked paragraphs. In these paragraphs, Howard showed that he was attending to multiple aspects of a question simultaneously, that is, the actual student explanations, what was unsaid but apparently implicit and his judgment on those. This process was similar to *evaluating* proposed by Suto and Greatorex (2008).

Howard's conversation in his interview moved fluently between the multiple aspects in questions and what he would do in class to prepare his students for these type of question. "I show the kids how to approach a question. I try to make them realise that it is not an English-style essay, so they have to give the points."

Howard has shown two dimensions to his roles as a teacher. Firstly, Howard was aware of the teaching and learning needed in particular questions, thus attending to content delivered, content expected from student answers in examinations and pedagogical approaches to a question. Secondly, Howard demonstrated roles as an assessor, his explanations and expectations of the depth of content and relational aspects of answers, his identification of an irrelevant direction taken in an answer and his review of the pertinent points of the answer. His roles as a teacher were integrated with his roles in assessing student answers. In his role in providing judgments, he demonstrated an ability to separate teaching from assessing.

Critique on a self-selected test question and student answers

During his interview Howard selected question *Question 39c (Essay, 10 marks)* and discussed his students' answers to this question:

> *A polar bear is a large thickly furred mammal, which inhabits arctic environments in Canada, Alaska and Russia. Polar bears used to be kept in Perth Zoo, but a few years ago the zoo decided not to replace the polar bears after they died.*
> *Describe the problems that an arctic mammal like the polar bear would experience in a warm climate like Perth's and explain the biological reasons for those problems*

Howard concentrated on analysing the scientific ideas and biological reasoning he expected in an answer, therefore attending to content knowledge. He discussed questions that enabled understanding to be demonstrated and that promoted higher-level answers. Howard described his expectations of a good biological answer and a critique of the students' answers was exemplified in his list of expected content points "Endothermy to be understood. Surface area to volume ratio, control of water retention. How adaptations to the cold are not useful in the heat and why. Biological reasoning, problems with insulation, enzymes." Crisp (2013) showed that most teachers looked for points of content and that science teachers particularly were focused on content criteria.

Howard critiqued problematic areas for students. He ascribed marks and rationale, which provided him with a reminder and focus on strategic and process problems that students often experienced. He commented about appropriateness of answers, where students may have gone wrong and the issues of students not reading the whole question and therefore giving incomplete answers. For example, in his statement, "the question says describe a series of four processes that occur in a plant cell, so the kids will read that and then just start describing the four processes", Howard outlined a problem regarding an inadequate reading of a question by students and as a result of hurrying, missing a vital component of the question that required relationships between the processes also to be described. He particularly emphasised issues of writing too much "gobbledy gook", of providing meaningless answers and wasting valuable examination time. Howard understood that technical or strategic knowledge of assessment was needed by students as well as good conceptual explanations in an answer.

Systemic problems or compromises in marking, leading to pragmatic responses, were highlighted by Howard with his contention, "I think the problem with giving marks is that you are rating, you are looking for the answers that are on that answer key, you are not looking at how much they understand". Howard highlighted that marking was rating students and therefore comparing a student answer with an expected standard answer. Howard inferred that a repertoire of practice in undertaking marking includes adhering to pre-determined answer keys and looking for points or particular answers. An example of his response about what he would include in his marking key for this selected question was "the actual problems faced and a biological reason for each. So, five problems and five reasons". He believed tests and examinations did not allow demonstration of a "whole concept" or of students' proper understanding and that they stifled "creativity". It is proposed by the researcher that examinations and tests may be seen by teachers such as Howard as a staccato, inflexible, imperfect method of assessing students' knowledge of a subject.

Alignment with current curriculum systems and examination environments was a critical consideration in constructing assessment and Howard referred to their importance in his pragmatic comment about a single question "It covers about five of the objectives in Module 2 in some way." He made comments about a system of levelling student responses that was being implemented in Kindergarten to Year 10 at the time of his interview. In that levelling system an assessor should be looking for understanding of concepts rather than a pre-determined answer, reflected in Howard's statement "inherent in the free flow of showing understanding rather than the stricture of 'Oh no!' you have to show marks". He would have preferred to look for complexity in an answer rather than a list of points. He commented about the Biology syllabus and the TEE (in Definitions and terminology, Section 1.6) as defining his work. He compared student answers with what would be expected in the TEE and the type of marking expected in the TEE, "I know what the answer key in a TEE paper would have been looking for". Howard showed familiarity with State curriculum and State assessment and these were fundamental in guiding the construction and style of his tests, examinations and marking.

Checking marking responses with other experienced teachers is often a feature of common examinations or tests and Howard described an adaptation of this: the benefit of co-marking with students. He stated "I will have a dialogue about that answer [with students]" and "we talk about it afterwards or I re-mark so they are the second marker". These comments led on to his thinking regarding the effectiveness of feedback and its importance to students. The comments demonstrated that Howard was prepared to negotiate, although he also understood that there was little flexibility because marking and ratings were implemented within a system providing a ranked order of students.

Essentially, Howard thought of the assessment process and interpretation of answers as developing pieces that the teacher or assessor relates together in a "jigsaw" of student understanding. Howard indicated the level of difficulty in this process as being significant but achievable within certain contexts, for example, "if you are fresh". Howard considered that teachers were pragmatic in their use of time, therefore that they had to read answers quickly and make quick judgments based on the points or clues in the answers, which reduced their capacity to use reflection and the active processing needed to put together a jigsaw impression of a student's achievement.

4.2.2 Students

Teachers, including Howard, mentioned that technical or strategic approaches to tests and examinations were critical for students to understand. Howard made comments about students obtaining or losing marks through strategic decisions. In relation to the test, he indicated that students reduce their marks: by waffling, not reading the question properly, not relating the answer to the question, "not planning and then repeating", incorrect answers, jumping points, jumbling points, "not clear … and [lacking] ordered thinking". Howard commented that students often rush their reading of questions, either not reading a question fully before answering or not going back to the question to check that they have covered all necessary ideas. In relation to the examination environment, he commented on distractions to students, suggesting that "quiet is their distraction". This referred to the general practice of students listening to music while studying at home.

Howard commented that students were inexperienced thinkers and that their learning began with small details and an emphasis on getting those details correct. He believed that students thought in two dimensions, but given the right questions and examples, could think in three dimensions "Their thinking is very two-dimensional and slowly becoming 3D". He correlated higher levels of thinking with processes of relating, comparing and contrasting and using models.

4.2.3 Himself

Teachers' impressions of their own thinking and ideas are major aspects of interpretational frameworks. Howard said he looked at everything in a three-dimensional way, at relationships and multiple effects, at the detail involved in processes and how those relate to other processes. He commented that what appeared to be linear ideas, for example equations, could be thought about in non-linear ways. He summarised this as "just looking at the whole". He thought his role as a teacher was "to break that down for the kids, because the kids can't do that". He also used the words "relational, transitional, dynamic" about his thinking. He stated that his thinking took place in words, places and visually but not in pictures.

Howard commented that, like other teachers, he was generally a little flexible, for example in "TEE marking I would say that the majority of people are pretty flexible because you get a range". He stated that this is why TEE marking had two markers and a negotiation/reconciliation component built in to allow for variations in interpretations and marks between markers. He commented that in biology, as a result of the TEE marking being computerised, problems would be introduced into the system, because there would be a lack of capacity to pick up and reflect on different answers and comparative interpretations.

A dynamic process used in marking was evident in many of the teachers' responses. Howard commented that he treated the marking process as dynamic, going back to re-read earlier papers to get a feel for the standard of the class or group and re-marking if necessary, as demonstrated in his statement - "when I start reading through the answers, that [the marking] changes and then I have to go back and re-mark some of the papers from the beginning". He reflected on his perspective as a teacher, with his expectations of student answers compared with his reflections from the students' angle, "I read the question from a teacher's perspective" and then "I'm thinking which angle are they coming from". Howard demonstrated multiple perspectives and critical analysis of the different pathways that students used in answering a question. The processes that he used were influential in his marking, demonstrating dynamic practices in assessment.

Understanding students and their achievement was a common discussion point among the teachers. Howard stated, "you get to know your kids and their mental processes intuitively". Teachers know their students, their "mental processes" and what they are capable of achieving. An assessor marking unknown students' work was at a disadvantage because the marker had to guess at what the student was writing without the benefit of knowing the child. Howard said he saw a flaw in his own argument, because students' answers should be written for an unknown audience, similar to in the scientific field. He thought that teachers would recognise pre-prepared student answers as they might "not hit the target", so causing a disconnection between the answer and the question. Howard concluded his interview by emphasising the need to be open-minded in assessing and in trying to "rearrange the students' answers in your own mind".

4.3 Collette

Collette was a female teacher and Head of Department with 31 years experience teaching biology. The school in which she was teaching was a high-performing private metropolitan girls school. She led professional development seminars for other biology teachers, was an experienced TEE Biology marker, and for lengthy periods of time was on committees for the Western Australian Curriculum Council. In her interview, she demonstrated that she had strong views on teaching and students. She had ideas and insights about assessment and students.

4.3.1 Assessment

Critique of the common Test Question and Student Answer

A strong focus on rigorous biological content knowledge was notable within the interview with Collette. Collette's responses to many interview questions were concentrated on the biological ideas. For example, in critiquing the common Test Question, *38. (Written Question) 10 marks.*

> *Describe a series of four (4) processes that occur in a plant cell and how they are related to enable the cell to work efficiently. (Marks will be allocated for the relationships between the processes and how they benefit the cell, not just for the names of the processes)*

Collette expected to see a focus on photosynthesis "what I would be expecting them to tell me about is the light and dark reaction and tell me where it is happening in the chloroplast, about the stroma and thykaloids and where it is happening – that is what I would expect from my top student."

Collette spent a lot of time explaining her expectations of the biological content and a TEE standard of work. In her interview about the common Test Question and Student Answer, Collette specified particular levels of biological detail she expected. She chose the concepts she regarded as essential in an explanation and prioritised particular processes for which she awarded more marks. In this regard she was the only one among the six teachers interviewed who prioritised particular processes.

> What I would be expecting a student to do – I would have three [processes] that are essential for all students to have and they are photosynthesis, respiration and movement of substances. They would need

> to have those three and then after that they have a number they can choose from.

After viewing the common Student Answer, Collette critiqued that it was general, confused in some places, not the level of detail she would expect and thought that it consisted of part answers. She used biological evidence to highlight the student's lack of understanding, for example "she has not really talked about glucose and glucose molecules in what happens; that we extract the energy out of that to produce ATP" and "her DNA replication description is very poor with not a really good understanding of DNA replication". Collette reflected that she was 'a bit hard' with the mark she gave the Student Answer but that she expected an end of year TEE standard of answer, "I would be giving her 3 out 10". The mark awarded by Collette was the lowest of the marks given by teachers for the common Student Answer. Her rationale was that her assessment was based on an assumption that the sample was from the end of Year 12 and from a student of the calibre of those whom she taught.

In this study, teachers, including Collette, modelled multiple roles and showed that they switched roles depending on the context. Collette's explanations of biological details often switched between a teacher's view, an assessor's view of explanations and the position of a student undertaking the explanation, including reasoning and questioning out loud. An example of being in a teacher role talking about assessment was when Collette related the cellular and microscopic structures, functions and links required in the Test Question to a macroscopic effect: "You have to understand how those processes inter-relate. It is the crux of what is happening in the body, whether it is a plant or animal or even a microscopic animal." Collette used a teacher role in this example and in other examples, would use an assessor's or student's role. In this particular example, Collette's comments were indicative of Shulman's (1986) proposals in biology, which postulated that biology teaching attended to microscopic/biochemical to macroscopic organism and ecosystem understanding.

Referring to question types, Collette said she liked multiple-choice questions for assessment of basic content and for calculations. She commented about tests being too hard if they contained too many interpretation questions,

> a fault of mine I put too much interpretation and make them too hard. Because I think if they can interpret and apply to a different situation then they do actually understand what you have taught them.

She considered that short answer questions allowed glimpses of understanding and extended answers allowed students to show links between aspects of their knowledge. The priority shown by Collette was for different types of questions to provide opportunities for students to demonstrate different types of thinking.

4.3.2 Students

In commenting on her views and theories on her students' abilities, behaviour and learning, Collette commented that different students would respond differently to the timing of tests, depending on how quickly or how much practice they need to "lock in" the information. She said that most students could take the full year to process the information needed to answer more open-ended questions such as the one given as the common Test Question. She observed, however, that some of her very able students would learn the biological information and be able to answer these sorts of questions soon after learning the ideas in class without needing much or any processing time. Collette differentiated students on the basis of their ability and speed in processing information.

In engendering communication between the teacher and students, Collette commented that examination and test questions were "information-giving between her and the kids". She said questions helped her and the students to realise the students' understandings, what they needed to do to improve performance and move on and to also give her feedback on the effectiveness of her teaching. Thus a two-way feedback process was evident.

When discussing feedback, Collette mentioned specific issues. She spoke in detail about feedback, referring to the necessity of giving feedback soon after the test, giving group feedback and individual feedback and being precise about improvements, for example "Feedback to a student is important, but it is how you give it to them. Frequency is very important" and "you sit down with them and say Right! These are the specific things that you have to do". Collette described feedback in what might be called a role-play of her interactions with students:

> I would be telling the student: You haven't actually given me the level of detail that is required of a full answer – you have given me parts of an answer and a general description of what photosynthesis is, and a general description of what respiration is.

Collette commented that students needed specific facts and parts of knowledge they had omitted in order to construct a full answer and they were more open to learning after a test, as mentioned in her interview, “They would be probably more receptive. You have probably said it in class six times, but they’re more receptive of you when they have something back that they haven’t achieved too well on”.

One issue in assessment emerging from the data, and mentioned by Collette, was the idea of grading or comparative positioning of students as a result of tests. Collette remarked about students’ understanding of where they fit in particular cohorts, so whether they are “floundering” or doing well. This information would be accompanied by the expectation of what they needed to achieve. Collette commented about different expectations and assistance with students who had external problems at school or home or had other impediments to their learning. Collette listed benefits resulting after assessment. In summary, they included increased student receptiveness to learning, higher awareness of the relevant content area and specific revision needed, comparative success and motivation toward continued improvement, targeted assistance with students and opportunities for more sustained and meaningful discussions and interactions between her and the students.

When discussing student learning, Collette observed that students made shifts starting from just describing a process to achieving a full understanding, “I still think kids go through those processes”. Collette elaborated her views through identification of distinctive stages in student thinking. Other interviewed teachers also raised the idea of shifts in thinking. Collette commented that students move through stages of thinking starting with concrete thinking “they start off concrete and you have to give them examples” and that when given appropriate examples, can move to “interpret and analyse it and then evaluate it”. She stated that abstract thinkers undertook an internalisation process very quickly, that some students seemed very slow to pick up new concepts and a few students were unable to think analytically, “she got it straight away but the others took ages” and “the abstract thinker, I think that they internalise it very quickly”. She also discussed students’ lateral and vertical expansion of thinking resulting from extended questions. Collette had explained her views on ways that students shift in the processing of ideas then explained a type of assessment that would enable demonstration of their resultant thinking. Collette also expressed her view that “good” students are better at these questions because they are more capable of “interpretation and application”.

Collette's views described in the interview whilst discussing assessment, related concrete and abstract thinking, which could be seen to have a Piagetian origin (Piaget, 1960), types of thinking such as describing, interpreting, analysing and evaluating, which are levels in Bloom's model (Bloom, 1956) and ideas involved in processing and internalising ideas in student thinking. Collette's comments and views demonstrated the wide field of understanding and application of different models of learning, thinking and knowledge construction that Collette held and used in the context of assessment.

Biology teachers have expressed preferences for visual models in making sense of biology (Eilam, 2013; Gilbert et al., 2008; Treagust & Tsui, 2013) and Collette suggested that her biology students were visual thinkers, "you can almost see them mentally picturing what is happening". She gave a further example:

> I gave them a pile of butchers' paper, coloured pens, and black pens, and I said "I want you to provide me with a chart showing things on corals". We had done something on corals. "Give me an explosion chart". We put them up around the class and they were all completely different. There were some that were completely black, black pen in boxes, and others with colour all over. I used it [explosion charts] as a learning tool for the kids. I said, just have a look around the room and it will show you that you are all different in how you learn. Some of you will have to have colour to remember the major point and the minor point, others of you will have put it in boxes, others of you, I said "the girls over here have actually pinched some beakers" and had put some beakers on their piece of paper to show the corals on an explosion chart.

In her teaching, Collette gave students opportunities to undertake concrete experiences and found students responded differently. She used the differences as a teaching opportunity, raising students' awareness of other ways of representing knowledge in the topic.

4.3.3 Herself

During much of the interview, Collette concentrated on explanations of detailed biological information, provided evidence and justification for her decisions. Her expectations of student responses mirrored this.

Collette, thinking about biology, regarded biology as a series of problems that living things had to solve and that this problem solving view was useful for students in their learning and understanding in biology. For example, in imagining her conversation with a student, she stated:

> What I would be expecting to write in your answer is that you can tell me why that needed to happen first of all? Why do I need to take in light energy and go through this process of photosynthesis? So what is the problem? What problem do we have as living things that need to do that? Explain that we cannot use light energy in its form. That we have to convert it and store it as glucose in the first place. So talk to them about the why.

Collette also commented that to teach biology,

> Take the big picture, take the macroscopic and start to show them some of the microscopic, and… what is happening at the biochemical level. Then you have to build that back again.

Collette thought that biology needed a big picture view moving back and forth between micro- and macroscopic details from cellular equations to ecosystem calculations for example, in a hierarchical structure. But at the same time she had another complementary view in biology of niche and interrelationships "two sorts of things happening at the same time. You are talking about a single organism but then you are also talking about the relationships between organisms." She added another perspective that changes in biochemical and hierarchical structures, individuals, niches and ecosystems were additional aspect of biology. She summarised biology as being a hierarchical structure, with copious cross-links and changes and the dynamism of the systems at all levels happening at the same time. Collette demonstrated her view that biology was complex.

In relation to the question of whether teachers preferred visual models in biology, Collette said she formed mental visualisations of processes and structures, "I form pictures" and thought that students did as well. In teaching, she actively presented visualisations and models to the students and gave evidence of the same task resulting in a variety of different products of students' visualisations. Collette commented that students who did not think visually, thought in words, language, by talking or immersing in sound.

4.4 Anthea

Anthea was a female teacher and Head of Department with 25 years experience in teaching biology. The school in which she was teaching was a private country Catholic school. She had been a curriculum officer for a major school education system and led professional development events, was a regular attender and presenter at the annual conference of the Science Teachers Association of Western Australia and at various times was on committees for the Western Australian Curriculum Council. In her interview, she demonstrated that she had reasoned views and theories on teaching, students and assessment.

4.4.1 Assessment

Critique on a self-selected test question and student answers

When Anthea was asked in her interview about selected questions from an exam she had constructed, her responses were concentrated on detailed biological concepts. For example she described an expected answer to *Question 36a (Essay, 10 marks)* in Appendix 3:

> *Describe the structure and importance of enzymes to the body. Include in your answer an explanation of the factors which affect enzyme activity.*

as demonstrated in her comments:

> I expected them to state what an enzyme was, comment about how specific they are, so looking at the lock and key model. And, looking at active sites, the factors that affect enzyme activity… like the temperature effect as it increases with activity, the concept of denaturing or inactivation, giving an example of the sort of pH that most enzymes work in and concentrations of reactants and products. Also anything that might inhibit enzyme action - the activity of enzymes like heavy metals and other inhibitors.

Anthea made several complex points in her answer key based on expectations of comprehensive biological content knowledge.

In constructing tests, Anthea had thought about the main concepts she wanted the students to explain and devised appropriate questions to ascertain those. A question about enzymes was selected by Anthea as she identified enzymes as a central concept in biology, “important”, “a big part of the syllabus” and “it can be transferred to a lot of other concepts”. Anthea demonstrated a purposeful selection of content and creation of a question to meet a number of requirements. In discussing questions, Anthea moved between the roles of teacher, who was concerned with covering content in the syllabus and the substantial amount of student effort that had been directed to this concept area, and assessor, where she considered the choice or construction of appropriate questions suited to the topic and syllabus.

In discussing preparation of students for assessments, Anthea had definite ideas, some of which could be referred to as pedagogical or strategic preparation for assessment, together described as the mechanics of answering a question. These included strategies illustrated in her comments: “When I teach the kids how to answer questions I tell them to underline the key words, we go through what describe, explain mean” and the strategy of using labelled diagrams in their answers where appropriate. She also encouraged students “to try and in their heads break it down into a mark allocation, so if this is worth 10 marks they would know that they need at least ten important points”. A key area of conversation in the interview with Anthea was strategic approaches to questions and tests.

Anthea appreciated that students could misinterpret questions and miss vital clues that would have led to the concepts required for discussion or explanation. “Sometimes when you read their answers you can actually see how or why they misinterpreted it”. Anthea not only realised that the student misinterpreted the question but her experience was evident when she recognised the origin of the mistake.

Anthea gave a critique of question types. She commented that the students were more comfortable and could demonstrate their achievement best with short answer questions. These are consistent with Anthea’s preference to break questions down to what the students can handle. She saw a gradation of questions as important in order to structure student thinking, starting with recall and moving to more analytical questions.

> I would think the short answer questions are the best, because they break down a concept into smaller bits and generally you start off with easy recall questions, “What is this idea? What is this relating to?” and then you can work into it more in depth, more analytical type questions.

Multiple choice were problematic, Anthea pointed out, with alternatives that could be interpreted as correct in some cases and also the problem of students guessing the correct answer rather than it being a test of their understanding. She commented that extended answers were difficult for students who had trouble expressing themselves on paper, but essentially, they really can show a student’s knowledge. “I think that big picture is long answer, definitely, so they can really, really show what they know”. Anthea related the question type to the capacity to demonstrate "big picture" thinking, which is a different idea to complexity, strategies or content knowledge.

4.4.2 Students

In considering the thinking that students used, Anthea thought that a few students had a big picture understanding and were able to make links. She said that other students did not have this understanding and were more likely to pigeon-hole information and give three or four separate facts to an answer without linking them or without a diagram that may have been useful.

> It depends on the student, it really does. Students like Ken would have a big picture and he would be able to link it all together. Whereas others would not, would pigeon-hole different aspects of it and not make those links.

In relation to preferences and student limitations, Anthea commented that students had a range of learning styles, which affected their achievement. She described how she helped various students. In describing one male student, she said

> I think he struggles in terms of literacy and I think that all the words completely bombard him, so I think that it would be worthwhile for him to have, and I have tried to encourage, a glossary list and actually putting pictures with words.

Anthea viewed students who achieved A or B grades as liking structure, listening, seeing notes, doing case studies and diagrams and applying biology ideas to other contexts, then making their own notes, graphs and links. She liked students to use labelled diagrams, for example in her interview she modelled her advice to students "if you really can't think of the words then draw the pictures and as you are drawing them, the labelling might come to you".

> We do a lot of modelling. So for example with meiosis and mitosis we basically drew a great big cell, we had pipe cleaners and we modelled the whole process. I find that good for me when I am learning things, to actually try and model something. I also really like doing case studies and relating your knowledge or your interpretation of data back to an actual situation.

She commented that to accommodate other students who struggle or do not concentrate in class, she role plays, breaks down questions into components, practises interpretation, labelling diagrams and applying knowledge to real situations, demonstrated by her comment above.

4.4.3 Herself

Anthea described her enjoyment of biology teaching and referred to aspects like labelling diagrams, tables, analysing data, practical work and structuring the information logically.

> I like diagrams and data that allow me to analyse what's going on. I like to be able to have a labelled diagram and then describe or say what the functions are and to tabulate things. I like everything nicely structured and neat.

She enjoyed case studies, interpreting real situations and getting the students to model structures. She used her preferences and experiences to add to her teaching repertoire.

4.5 Michelle

Michelle was a female teacher and Head of Department with 26 years experience in teaching biology. The school in which she taught was a private Catholic school in the Republic of Ireland. She contributed to and led professional development events, was a regular attender and presenter at the local science educators' conferences and at various times was on committees for the science education association and the local university. In her interview, she demonstrated her views and theories about biology, students and assessment.

4.5.1 Assessment

Critiquing the common Test Question in relation to test strategies

When looking at a question, Michelle's first reactions were to examine the wording of the question, consider the biological content she thought necessary to answer the question and comment on the allocation of marks. Michelle thought that the coverage and structure of the question was important. For example, in looking at the common Test Question, in Section 4.3.1, she stated:

> I would look at the marking scheme first of all and see how much detail is required. Then the word 'describe'. I would tell them that 'describe' would involve writing something. Then I'd look at the four processes - they would have to have four processes, no point them writing down three. And then looking at the plant cell, then the word related. So when I was planning the answer I started looking at the four processes, then made sure that they were connected to a plant cell.

In discussing ways students could focus on a question, Michelle highlighted the use of tools, such as mind maps, equations and arrows showing relationships, for example, “a balanced chemical equation” and “to have arrows coming out from that [apart from the arrow in the reaction] to show how they where connected”.

Michelle considered the number of marks allocated to a question in determining the level of detail needed in the answer and therefore her judgment on the piece of work. She had a pragmatic view of marking in looking for a number of points, descriptions or relationships. She would not give extra marks for more than was asked for in the question “they would not gain any extra marks because it was a tight marking scheme and if they are giving extra stuff, it will not be marked”.

Michelle expected that students, on reading a question would look at a marking scheme to assess the level of detail - “when the students see ten marks, they know how much detail to give”, examine words in the question such as describe, decide numbers of concepts and relationships needed and then “that students work efficiently”. Working efficiently may mean attending to time allocation and writing concise, appropriate biological detail.

Examination techniques were a strong focus for Michelle. She discussed the importance of the students understanding examination techniques, and she provided the researcher with a copy of a sheet that she gave students, which can be found in Appendix 5. This sheet included allocation and accurate timing of questions, use of pencil and eraser, leaving a line between paragraphs in case extra points need to be added later, breaking questions into parts, “underlining technique”, doing the minimum number of questions that will be marked, supply targeted answers appropriate to the question and write clear and distinct points. Michelle gave the students practice in using these techniques and thought they were an essential preparation for tests.

4.5.2 Students

Michelle indicated that students had a tendency to read a question quickly, pick the main aspect and “plough” into answering it instead of taking their time in analysing questions. Michelle spoke about regular assessment: “Every single day they are questioned in class. They always get homework.” She was very thorough in marking and providing positive feedback “I believe in having positive comments and so it is very important to encourage students”. To support them in remembering the material covered in class and homework, Michelle engaged students by “continuously revising”. She viewed the students’ mental models in terms of biological content and concepts and thought they learned best through, “I would say, sequence diagrams, bullet points, short summaries”.

4.5.3 Herself

Michelle represented her thinking with a mind map and linking ideas and processes with arrows. She also described her thinking about questions using detailed biological concepts as well as describing techniques that enhanced the ability to write appropriate, thorough, concise answers in the allocated time. Her emphasis on test strategies in answering questions and in detailed explanations of biological content, closely aligned with PCK as applied to assessment.

Michelle’s marking was mostly pragmatic in alignment with a pre-set marking key but she showed that quality of student answers, in a cohort or whether it was a for class mark or for a final mark, could affect her decisions under certain circumstances. This was exemplified from her interview about student answers to Michelle’s selected test question, *Question 11b vi*

> *In aerobic respiration, the product of the first stage moves to the mitochondrion. Outline subsequent events in the total breakdown of this product.*

In this example the answer involved a pathway including glycolysis and the Krebs Cycle with products, reactants, identification of enzyme activity and number of ATPs generated. This is illustrated in the work samples of Students 15 and 16 in Appendix 3. Some students unexpectedly added another pathway, the electron/hydrogen carrier system, which then raised the standard. Work samples that showed the extra pathway were from Students13, 14, 17 and 18 in Appendix 3. Michelle stated “I would have probably given this a 5 [pointing at a student answer without the extra pathway] and then docked a mark because she did not put the electron carrier system.” In response to the researcher’s question “But would you take marks off for that?” Michelle stated, “[Yes] if I was being real nit picky, but if it was a lead up to an exam they would not have had marks deducted, they would have all got full marks.” Students who would normally expect 5 marks out of 5 in this class test, were deducted a mark if the carrier system was not shown. Previously, Michelle had said that she would not give extra marks for more information, so this case highlighted the need for complexity, context and meeting competing priorities in making judgments.

In response to a question about types of test or examination questions, Michelle replied that she did not like multiple choice questions because she said they did not test the students well, selecting the right answer could be by chance and “I feel a student could be just part looking and answer the right one, it does not really test them”. She preferred many “snappy, short questions” and diagrams, which tackled many parts of chapters, with long questions used less often.

One reason for using questions from tests was that the students could practise authentic questions - “I wanted to give them a question from the papers and so they could see and answer it after doing the material”. Michelle was referring to papers from previous Irish examinations. Another of her reasons for using tests was that it gave students an assessment of their learning after they had completed a topic, that is, whether they had “learned the theory”.

Michelle’s approach to biology was to start with ecosystems and the interconnections within that area and, when the students understand, then move on to another area of biology, looking for overlapping knowledge. “I would stay in the one area, complete that one area and make sure they know it and then move on to another area, but as we are building on it, refer back continuously.” She described the other major areas as organisms and cells and metabolism, similarly to Shulman’s (1986) organisation of biology as “a science of molecules”, “a science of ecological systems” or “a science of biological organisms”.

4.6 Wendy

Wendy was a female teacher with 30 years experience in teaching biology. The school in which she was teaching was a Perth metropolitan government senior high school. She developed student-focused materials for her general science senior school classes, which she shared with other teachers, was an experienced TEE Biology marker, and for lengthy periods of time was on committees for the Western Australian Curriculum Council. In her interview, she demonstrated her views on teaching, assessment and students.

4.6.1 Assessment

Critique of the common Test Question and Student Answer

In describing answers to the common Test Question, (see Section 4.3.1), Wendy started by outlining the areas she would select for an appropriate answer, then provided a detailed explanation of the biological content of the answer. Her examination of the question was as follows:

> I looked at the question and I thought the important part of the question was that it was a series of thought processes. So the word series seemed important to me and that it had some logical follow on. That it occurred in a plant cell and that it related to how it could work efficiently.

Wendy used the word "series", which was not used in the Test Question, so it was Wendy's construct for organising the question. Her explanation of the Test Question was demonstrated in these excerpts from her biologically comprehensive interview answer.

> I would have started with transport and talked about passive and active transport and the different types and I would have related that to energy and the different cell structures. Another one is the chemical reaction. I probably would have described a cell membrane, photosynthesis and respiration and emphasised the energy, the inputs, the outputs, chemicals, energy production, aerobic and anaerobic respiration, mitochondria, cell structure and the ADP/ATP relationship and that the energy is stored there [in ATP]. Then photosynthesis, the energy output with the equation relating the chemicals again, glucose, oxygen and water. And lastly enzymes, because you need enzymes for all those chemical reactions. Then lock and key and a little bit about temperature and pH probably. I would have related it that way.

When faced with the Student Answer (see Section 4.3.1) that did not agree with her ideas - "it did not fit with what I naturally thought" and "it was still a valid answer to the question" - Wendy took the different concepts into account in her assessment of the answer, as long as it was focused on the question and was an acceptable alternative. She tried to "find the positive things that I can give a mark for, rather than finding the negative thing", so she was unlikely to take marks off for a problematic answer. Depending on the question, she may not have given marks for extra information and commented that it was not a good examination strategy, unless it was relevant to go into detail. She said, "I would not expect the student to tell me everything that they have learnt in a whole biology course".

Wendy was pragmatic in marking as she would look for points to mark: "They are writing for four marks I would want to know four things". She would be open to other valid answers not in the scope of her marking key but would be less interested in inferring or guessing at what the student was trying to say, "as long as it would not take me years to figure out exactly what they are doing". She also mentioned the need for the students' answers to be clear enough for a busy teacher to identify their ideas and understanding quickly.

Wendy preferred questions that enabled students to demonstrate their understanding, and saw value in having a mix of question types because "it is such a wide field to get them to tell you what you want them to tell you".

4.6.2 Students

Wendy thought that students' thinking was mostly linear and that many of their responses were recall, "I don't think it shows connections, I think it shows recall". She spoke about uni-dimensional and single ideas as being common in student answers - "it is linear".

With regard to students' strategic planning, for example in planning time for completion of test papers, Wendy commented on a particular student and made a generalisation about many students, "perhaps she was struggling for time as a lot of students do at the end of the paper when they get to the essay section. You know they try to get as much information down as fast as possible and also sometimes they glean things from the multiple choice [questions]". In addition to time planning, Wendy made suggestions about students using previous questions in the test to assist later answers, an effective strategy if there is overlap in content.

Wendy said that few students had a passion for biology and that their feeling emerged through their writing. She was the only teacher who spoke about students having a passion for the subject of biology.

4.6.3 Herself

Views about biology organisation and ways of understanding biology figured prominently in Wendy's thinking. Wendy commented that her thinking was structured by problem solving. She believed biology was based on problem solving, "biology is a problem solving thing as far I can see". Because organisms were so different "but there are exceptions and differences all the time", she said that information regarding an organism needed to be processed, ideas adapted and connections drawn from previous similar experiences in order to fit and relate the information and explanations.

When probed about her thinking structures, Wendy's initial reaction was to speak about her information-giving to the students, "because I always feel that I have got to give them a lot of information, then they can mull it all through and then get the right answer back from all that". On further probing, she considered she had interconnections at all levels of thinking about biology and spoke about the wonder of biology - "you have got look at it at all levels because it is all interrelated".

4.7 Philip

Philip was a male teacher and experienced Head of Department with 35 years experience in teaching biology. The school in which he was teaching was a government high school in Perth and he commented on the proposed questions for this current study. He was a Biology TEE marker and wrote books on biology. In his interview, he demonstrated that he had valuable insights into teaching and learning biology. He had views and theories about students and assessment.

4.7.1 Assessment

Critique of the common Test Question and Student Answer

To commence the interview, Philip was shown the Test Question and Student Answer and asked for his comments. Philip responded to the Test Question, (see Section 4.3.1), by examining the biological content and extent of the answer, ascribing marks as he spoke.

> I think students need to mention photosynthesis, discussion of the equation would be required and they would get one mark, and similarly for cell division, active transport, cytoplasmic streaming, respiration. Each of these together could add to a total of 4 marks.

He predicted a range of answers that students could give. He stated that he would not give extra marks for more complex answers unless the question suggested those ideas, "A wonderful essay on photosynthesis, indicating the light and dark stage, and all those sort of things would not necessarily get them any more marks". He considered that the students had a responsibility to read questions properly and that teacher judgment was needed. Philip identified the best assessment strategies for his purpose, for example, creative open–ended questions or application questions for teasing out student understanding. He said there was a place for multiple-choice questions.

Philip took account of other factors affecting student performance of assessments. He considered that students could perform better on tests and examinations if they had time to mentally process the material, therefore achieving a more realistic, better score a few weeks after they had encountered the information in class. “You might also take into account just how much exposure they have had to the whole area and you might mark it harder if they have had more time to digest the material they have been given.”

Philip planned which aspects of questions and issues to discuss in feedback with students. He recognised the importance of student reflection and accurate teacher feedback in student learning. He was mindful that different question types had different time constraints in considering feedback in class, for example that multiple choice required a lot of reading and thinking and that it was more important to go over the written questions.

> It is important to go through the written questions particularly. You do not have time to go over all the multiple-choice questions. This test had a lot of longer multiple-choice questions with long preambles, which involves a lot of reading and thinking and sometimes in class you do not have time to go over every one of those multiple-choice.

Philip understood that after a set time, whether or not all students had fully understood the topic, it was necessary to move onto another topic.

> It is time constraints, which are necessary, because you have got a course and a course structure and you need to move on. Some students are probably not going to be at this stage and it is no point keeping them and trying to press on with the same thing.

This quote demonstrated the complexity of teachers’ work, where there are compromises and competing priorities.

4.7.2 Students

Philip identified a progression to more expert student knowledge. Philip was experienced with how students responded to assessment. He commented that some students were not going to be ready to move on to another topic and may never understand a particular area of biology, but that it was important for the sake of the other students and to also allow the less capable students a chance at a new topic.

> You immerse them in the area, do experiments and discuss all of these things with them but there comes a point where the weaker students are not really going to understand the concepts and detail to the depth that the brighter kids do.

Philip commented that every student is not going to be at a high level and that some students will not progress from a certain level of thinking.

Philip explained his thinking that there could be either discrete groups or a continuum of student biological understanding or levels of thinking in a class, “I don’t know whether it is a continuum or whether we are getting two or three discrete groups of people” and offered biological examples to demonstrate the different levels of thinking required. He described concepts interrelating in dynamic ways and thought that his students did not understand dynamic aspects. He thought that some students who reached a certain level of understanding and did not proceed any further, what he described as a “block”. He said, “some students are prepared to learn those and others, I suspect, reach a stage where they don’t understand and decide not to proceed any further”.

Philip thought that some students were lateral thinkers and were capable of higher levels than they were achieving in tests, so there was an onus on teachers to enable them to demonstrate these qualities with particular questions, “you give them obviously open-ended questions, or tease out (understanding), so we gave them a scenario” and “open questions are great because they are interesting and see how creative people can get”.

4.7.3 Himself

Using extensive and inter-connected biology content knowledge, Philip described focused answers he expected from students. His responses were concise and clear, using diagrammatic representations, “I would have started off with something like this flow diagram”. His marking key to the common Test Question was one of only two teachers that represented the answer in a concept diagram. He stated in his interview “In marking this you appreciate that a lot of people could not develop something like this until they have years of contact with the subject.” He alluded to a skill demonstrated by expert teachers.

Philip thought that a teacher needed to be very assured with their understanding in biology, “you need to be very confident about the answer yourself if you are going to engage in a discussion with them [the students]”. He stated that he would support students as far as they could go. He felt that he had a good understanding of what his students would achieve just by talking to them, although written tests were important for detailed assessments of students.

4.8 Concluding Comments

In these cases the six biology teachers revealed their views and theoretical perspectives about assessment in biology, which gave insights into each teacher’s individual interpretational frameworks. All of the teachers spoke about the detailed biological ideas involved in the various questions under consideration and their students’ and their own understanding of these. Chapter 4 addressed Research Question 1 as described in Table 4.1.

At some points during their interviews, Howard, Collette and Anthea switched from an assessor role to a teacher role and back again, sometimes acting out what would occur in class, also demonstrating that they understood student perspectives. In developing an interpretational framework in biology assessment, teachers commented on their thinking and views about student learning, practices, capabilities and achievement in assessments. All of the teachers interviewed discussed aspects of the knowledge, purposes and strategic nuances in designing, interpreting and answering test questions, these being interrelated and integrated in teachers’ assessment practices and in the assessment context. All six of these teachers considered the understanding of biology, assessment and students as forming an important part of their effectiveness and in formulating their theories of practice.

During the interviews, teachers’ views and theoretical perspectives were identified. These were similar to each other in many ways with a diversity in emphases. So this Chapter 4 discussion developed a window with a partial view of each teacher’s views, understanding and experiences. These are summarised below.

Howard demonstrated the importance of attending simultaneously to multiple aspects of a question and answer. He viewed biology as multidimensional rather than the two-dimensional way that he thought was typical for many students. Howard operated in both a teacher role and assessor role when discussing tests. He tried to view answers from his (teacher's) perspective and a student's perspective. He considered marking as a dynamic process, re-reading, re-marking and returning to earlier scripts as a result of assessing later ones. Added to his feedback and negotiation with students after tests, this entire assessing process used by Howard could be viewed as a feedback loop.

Howard thought that test responses should be treated as jigsaws of clues, inferences and a "free flow" of answers that could be put together to enable an assessment of a student's work. He was pragmatic about the difficulty in achieving this and discussed time, curriculum and examinations, which led to a marking style relating to points of content, rather than building up a whole response. He considered that tests did not allow demonstration of complete concepts.

Collette provided explanations of the detailed biological underpinnings of answers and her expectations of priorities and a particular standard of answer. She viewed answers as glimpses into students' understandings and test question feedback as an opportunity for information sharing between her and the students. She stated that precision feedback to students was very important. She considered that students moved through stages from concrete to abstract thinking, from descriptions to interpretation and analysis, and that more able students internalised information more rapidly. Her ideas encompassed aspects from Piaget's stages of cognitive development (Piaget, 1960) and Bloom's levels of thinking (Bloom, 1956).

Collette viewed biology as a series of problems that living things had to solve and that using this perspective involved students in better learning and understanding of biology. Also, she considered that a big picture was needed in biology, moving vertically between biochemical, microscopic and macroscopic as well as horizontally through the ideas of niches, individual organisms and relationships simultaneously with change at all levels. She showed aspects of Shulman's postulates in biology (Shulman, 1986) which also encompassed these levels of content in biology.

Anthea selected questions that were central to biology, were important to the curriculum and covered a number of biology concepts. She had definite ideas, which could be considered pedagogical or strategic, about preparation of students for tests, in addition to their content preparation. Anthea was concerned about the students' misinterpretation of test questions.

Anthea thought that a few students had a big picture understanding in biology, but most were likely to pigeon-hole information. In discussing her view on biology, she commented on her enjoyment of biology and those aspects that she enjoyed, mostly biological representations and logical structuring of information.

Michelle expected students to approach a test question using techniques or strategies to help them understand the question, consider the time restraints and the allocated marks, and provide coverage and structure of content in the answer. Incorporating content knowledge and the use of specific strategies for assessment could be considered a PCK view of assessment.

Michelle viewed students' thinking in biology in terms of biological content, describing biology moving between ecosystem and biochemical understanding. She represented her thinking in terms of a mind map and described her thinking using detailed biology concepts and strategies to enhance students' ability to improve on their answers. She thought tests gave her and the students an assessment of whether they had learned the "theory" in biology.

Wendy outlined detailed areas in biology she may expect in a student answer, but was flexible in accepting alternative, viable answers. Her marking was positive, looking for correct points, rather than taking marks off for incorrect responses. She preferred clear responses and would not be spending time trying to infer what a student was trying to say.

Wendy thought student thinking was mostly linear and used single ideas. She thought that few students had a passion for biology. She suggested her thinking in biology was based on problem solving, as was biology, and that ideas needed to be processed and thinking adapted. She indicated interconnections at all levels of thinking in biology and spoke about the wonder of biology.

Philip identified a range of student answers, the appropriate complexity that he would expect from a question and marks for the biological content. He suggested that students had a responsibility to answer a question properly and not have expectations that teachers would guess at their answers or give extra marks for unnecessary answers. He commented on feedback as an important part of assessment.

Philip considered that students' thinking and understanding in biology could form discrete groups or a continuum and that some students understanding did not progress after reaching a certain level of understanding or a "block". He demonstrated a multi-dimensional understanding of biology and used concepts maps to illustrate this. He thought that written tests gave accurate assessments of student understanding, but also felt that he had a good understanding of his students by talking with them.

Within Chapter 4, data, analysis and development of six teacher cases contributed proposed answers to Research Question 1. *What are the views and perceptions of each teacher regarding assessment in senior school biology?* The results and discussion presented a map of each teacher's insights, experiences and concepts. These biology teachers' individual views, perceptions and insights about assessment demonstrated parts of their *interpretational frameworks used in assessing students' understandings in biology*. They demonstrated wide-ranging, coherent and complex perspectives on assessment, their students and themselves. Once a picture of each participating teacher's framework had been built and described in this chapter, comparisons could be formulated. Comparisons between the interviewed teachers are presented in Chapters 5, 6 and 7, where analyses have drawn out six assertions within three major categories.

Chapter 5

Making Judgments of Student Achievement

5.1 Introduction

Assertions were constructed on teacher judgments of their students' assessments and are based on the interpretation of teachers' responses in their interviews, their own assessment of their self-selected test questions and students' work samples from tests, and their comments on and marking of a common Test Question and Student Answer. A grounded practice (Glaser & Strauss, 1967) of inductively developing and structuring reality from this body of information has been used, as discussed in Chapter 3, and six major assertions were identified from this endeavour. The emergence of assertions was based on ideas proposed by Erickson (1986), and looked for confirming and disconfirming evidence. Case methodology was used in Chapter 4 to draw out the interpretational framework of each teacher and in Chapters 5, 6 and 7 cross-case comparisons, suggested by Yin (1994) where the commonalities and differences between the teacher participants were identified, draw out the fundamental essence from the teachers' data. The cross-case comparisons are presented in the form of assertions.

Table 5.1 Research Questions in results and discussion for Chapter 5.

Research Questions	Assertions	Chapter
2. *What are the influences on teachers' assessments and judgments of student achievement in senior school biology? and* 3. *In what ways are different teachers consistent in their judgments of student achievement in biology?*	1. These biology teachers' assessment judgments are dependent on their expectations of and interpretations of the students' biological explanations to questions. 2. These biology teachers award marks using a dynamic process consistent with their rationale and guided by a marking key.	Chapter 5 Making judgments about assessing
6. *What are the commonalities and differences among the interpretational frameworks used by teachers in assessing senior school biology?*	Data compared from Assertions 1 and 2.	Chapters 5, 6 and 7

Analyses and evidence are presented in Chapter 5 for Research Questions 2, 3 and 6 as shown in Table 5.1. The results and discussions of Chapters 6 and 7 also addressed Research Question 6.

The two assertions, 1 and 2, viewed together as *Making judgments of student achievement* emerged from the data. These attend to assessment inferences, decisions, including dynamic decision making (Gonzales et al., 2003) and judgments, add to understanding of biology teachers' interpretational frameworks in the assessment context and address Research Questions 2, 3 and 6. Factors affecting teacher judgments have been explored and a discussion undertaken of the different perceptions and preferences of the teachers with regard to the first and second assertions.

Section 5.2 explores Assertion 1: *These teachers' assessment judgments are dependent on their expectations of and interpretations of the students' biological explanations to questions.* Section 5.2.1 is an examination of six teachers' interpretations of particular, self-selected questions and a Test Question selected by the researcher. An examination follows in Section 5.2.2, of each teacher's general and detailed account of expected student explanations of biological answers and their comments on student responses to those particular questions. Teachers approached discussion of questions and answers with general observations regarding what they were looking for and then progressed to describe the detailed biology content that matched the particular question. The teachers discussed situations where there was flexibility and those where they were uncompromising. Section 5.2.3 concludes with the teachers' discussion of their interpretations of answers.

Section 5.2 addresses Assertion 2: *These teachers award marks using a dynamic process consistent with their rationale and guided by a marking key*. Section 5.3.1 explores teachers' rationales, marking keys and the reasons why they attributed particular marks to student assessments. The Test Question and Student Answer provide the areas of focus for this section. The teachers involved in this part of the study were asked to construct a marking key for the Test Question, mark the Student Answer and discuss or write a rationale or reasons for the allocation of marks. In Section 5.3.2 comparisons are undertaken of the teachers' rationales, marking keys and marks. Section 5.3.3 is a case study of Howard.

In this chapter, teacher commentaries and evidence related to the development of their rationales and marking keys and to their making conceptual and numerical judgments are examined. In Section 5.4 a summary of teachers' reactions and explanations related to Assertions 1 and 2 and in addressing Research Questions 2, 3 and 6 concludes the chapter.

5.2 Assertion 1 *These teachers' assessment judgments are dependent on their expectations of and interpretations of the students' biological explanations to questions.*

All of the teachers interviewed provided strong evidence and support for this assertion. They discussed their expectations for particular biological explanations in student answers. The answers were in response to test or examination questions that the teachers themselves selected. Wendy and Philip did not have a cohort of students to discuss so most of their comments were in terms of the common Test Question and Student Answer. Teachers' self-selected test questions are found in Table 3.4 and the common Test Question and Student Answer in Table 3.3.

When discussing a question all of the teachers spoke in detail about the area of biology in each question and provided specific explanations of content. These explanations generally described a comprehensive, ideal, senior school level answer. When the teachers considered what they hoped to see in the test answers from their students the teacher conversations became pragmatic and their answers more concise. The teachers' responses showed awareness of differences in interpretation of the question, their interpretation of the students' answers and what could be expected and achievable, within a framework of some internalised standards. When discussing test questions and student work samples teachers highlighted the aspects of explanations they were expecting and reflected on those that failed to result in a sufficient or targeted answer. There was evidence that the teachers used a range of processes and thinking related to expectations and explanations in biology arising from their interpretation of a question, before making their judgments. The evidence to support Assertion 1 and resulting statements and interpretations by the researcher are outlined.

5.2.1 Interpretation of examination questions

Different interpretations start with consideration of each question. Understanding this, teachers demonstrated their experience, expectations and reactions to questions and resultant answers (the students' and their own). Howard, Anthea and Wendy specifically discussed interpretations of questions in their interviews.

Anthea commented on "the misinterpretations of the question". Anthea's first reaction to looking at the student answers, was intrigue about their lack of understanding of specific non-biological words in the question and them failing to look closely at key words. When asked about her students' responses to her self-selected test question,

> *A cell biologist obtained the following images when examining a cell with an electron microscope.* (Two micrograph images showing A. chloroplast and B. mitochondrion.) *Describe and explain the effect of a slow increase in temperature on the metabolism of these cells* (Table 3.4, question 36d),

Anthea commented about students' misinterpretation of "describe" and "explain" and the need for identifying key words. For example, she said "we made a point of going through and looking at those sorts of descriptive words that make it a very specific rather than a general question." In relation to key words, she commented "the key word is *slow increase*. This word *metabolism* was also a key word. Some kids did not think about chemical reactions, they specifically thought respiration."

Question 36d was leading the students in a particular direction and some of them did not pick this up, but answered with a related but non-targeted answer. Anthea later said "you do realise perhaps that you [the teacher] could have asked it in a different way. On the other hand… I feel that this was straightforward and very clear". Anthea was surprised about how the students could have misread or misinterpreted this question.

Howard identified different ways that his chosen question

> *A polar bear is a large thickly furred mammal, which inhabits arctic environments in Canada, Alaska and Russia. Polar bears used to be kept in Perth Zoo, but a few years ago the zoo decided not to replace the polar bears after they died. Describe the problems that an arctic mammal like the polar bear would experience in a warm climate like Perth's and explain the biological reasons for those problems* (Table 3.4, question 39c),

was interpreted by his students, differently from his expected answer, which was "maintaining constant temperature and availability of the various methods to control this". Howard had this particular idea in mind but could see other ways of answering the question. Howard acknowledged that students may look at a number of relevant facts other than the particular set that he chose in constructing and answering the question.

Howard commented on the general focus of the common Test Question, "describing the four processes, the relationship between the processes and benefits to the cell" which he perceived gave the students guidance and direction for their answer. Howard considered that the students may describe only the processes.

> I can see the word describe. The students are going to start describing four processes and kids being kids read the first part and think *oh! I can do that.* Then they write it down and they forget to go back to the question and find out what the question is really asking.

Howard identified a perceived problem in the question and in students' responses to the question, that some students would not read the question in totality. Or that students would immerse themselves in the descriptions of processes and not re-read the question and therefore not write about the relationships requested in the second half of the question.

Teachers viewed keywords or phrases in questions as providing clues on how to answer questions. Wendy had noted a keyword in the common Test Question and emphasised that it highlighted a clue to answering the question by describing "a *plant* cell and that it related to how it could work efficiently." Anthea commented that words such as metabolism and "slow increase in temperature" in her self-selected question had provided clues in what or how to answer the question.

Howard summarised his view on interpretation of questions when he indicated his expectations of questions. These expectations included that direction should generally be given in the question for the biology needed in the answer, the extent or boundaries of the biology and the level of complexity Howard considered these should be available from proper reading of a good question.

5.2.2 Expectations of clear student explanations of biological concepts asked in a question

All of the teachers discussed their expectations of the direction and content and, in many cases, structure of the student answers to biology questions. Discussions are related to teachers' self-selected test questions (Table 3.4) and the common Test Question and Student Answer (Table 3.3).

When discussing an answer that Anthea would expect from a student, she spoke about the general biological information she would be expecting, then specific biological concepts and facts. Anthea, in reference to her chosen question, an essay question

> *Describe the structure and importance of enzymes to the body. Include in your answer an explanation of the factors which affect enzyme activity (10 marks,* Table 3.4, 36a),

explained about general requirements she expected in an answer, such as for a definition and description, and then an example of specificity and detail of the major model required.

Anthea proceeded to explain the sort of details in biology she would be expecting from a student's answer.

> The factors that affect enzyme activity, things like the temperature, and then the concept of denaturing or inactivation. The students need to include the effect of pH and perhaps even giving an example of the sort of pH that most enzymes work in. Or maybe in the stomach, that it is quite different and is one that has to work in an acidic environment. Concentrations of reactants and products are needed. And also anything that might inhibit the activity of enzymes like heavy metals and other inhibitors, although I was not expecting that most students would actually come up with heavy metals. It was the other three that I was mainly looking for.

Anthea was very specific about some of the content and concepts she expected to find in a student answer and indicated areas where she would be looking for details, although she qualified the last part of her answer. She suggested an answer that may not be expected and would have awarded a mark if it had been used instead of another more obvious answer.

Michelle was asked: "What did you expect in an answer?" in respect to the test question she had selected for interview,

> *11b vi In aerobic respiration, the product of the first stage moves to the mitochondrion. Outline subsequent events in the total breakdown of this product (5 marks,* Table 3.4, 11b vi).

She initially gave a very general reply: “To be able to answer it at an even sort of level and to be able to answer it correctly, showing that the students had learnt the theory”. Then later she responded in more biological detail. “They would have to know about respiration and the biochemistry of respiration. They would have to understand the term aerobic as opposed to anaerobic and how it is involved in the total breakdown of the product”. In summary, Michelle had explained her expectations, using the terms “even sort of level”, “correctly” and “the theory”, a general set of expectations not specifically biology. She then responded using the terms aerobic and anaerobic, the biological concepts required in the answer, but not with very specific detail. Finally Michelle offered a detailed explanation of the concepts expected in the answer:

> Well there was aerobic [respiration], then the Krebs cycle. The fact they knew it moved in through the mitochondria would alert them it was the Krebs cycle that was needed in their answer, along with the total breakdown of the product.

Although Michelle does not specify the particular molecules in the chemical pathways or nominate the reduction in the carbon atom and where the energy is released, it is likely, as with Anthea, that she had this detail in mind or for a marking key. She added an extra part-answer that she would expect from a good student. This is similar to Anthea. Within Michelle’s class, some students had added the electron carrier system to their answer of the expected pathway including the Kreb’s Cycle and other students had not. This is discussed below.

> I suppose the fact that some students included the electron carrier system, or if they referred to the fact that NADH produced energy that would have been a bit extra. That is what I would expect in a good answer.

On being asked if she would omit marks if the electron carrier system was not mentioned, Michelle initially responded “I know from previous markings schemes that they do not take marks off”. Later in the interview the researcher asked Michelle if an average student would have understood the carrier system, Michelle replied, “Possibly not, so the student who showed the carrier system understood that it was needed to fully explain it”. She then continued on to say she would have “docked a mark” if students didn’t put the electron carrier system into their answer. Michelle was referring to taking a mark off in assessing a student’s work, who had not included the electron carrier system. She justified this because she was being “nit picky” because it was a homework test, but if it was an examination she would not have deducted marks. In this interchange, Michelle demonstrated the different contexts in which she would have awarded full marks or not for an extra, unexpected level of detail. In a lead up to or during a test, she would have awarded full marks for an answer, which had omitted the extra electron carrier system, but in non-essential contexts would penalise 1 mark out of 5 if the answer did not include the carrier system. This teacher discriminated between contexts in which the marks were critical and being recorded and contexts where the exercise could have been predominantly a learning opportunity. This example also demonstrated an intersection between Michelle’s expectations, her interpretations and marking of student answers.

In discussing the construction of her own answer to the sample Test Question (Table 3.3), Wendy saw the development of an answer as a “series of thought processes”. She identified the key words and ideas in the question that would lead to the sort of answer she would be expecting. Wendy described looking for “the natural progression of the four processes” and selected the biological processes she would expect to find in a student answer – transport, respiration, photosynthesis and enzyme action. For example she said:

> I would have started with transport and talked about passive and active transport and the different types and I would have related that to energy. The energy could have been used for the active transport to move things in and out of the cell. The other thing I could have related was the different cell structures that are necessary. I probably would have described a cell membrane, talked about the different types of transport and then talked about what was actually moving in and out.

After an initial conversation, Wendy added DNA replication to the list of possible important processes that the students could choose to describe. She explained each of these in its context in the cell referring to the appropriate structural components of the cell, including the structures in common between the four processes, different categories making up particular processes (such as passive and active transport), inputs and outputs, energy and its relationship with all of the processes and the chemical reactions in particular processes as well as those that linked them. Wendy particularly emphasised the linkages that could have been made using the concepts of chemicals and energy.

Philip started with a focus on the relationships and represented them in a diagram linking and demonstrating the flow of these processes within the cell. He said "With a flow diagram I would try to relate all these processes." Philip explained an example of the connections he would be looking for: "photosynthesis is linked to respiration, it [photosynthesis] produces glucose which is needed in respiration and getting ATP for active processes, cytoplasmic streaming and so on." Philip expected a certain level of detail in the answer, such as:

> respiration is related to all these other processes by ATP, so the students should be discussing how ATP is used in cell division, not in detail, but just saying *ATP breaks down to ADP releasing energy which makes cell division possible*. Because cell division requires movement of tiny molecules and organelles and active transport is an energy requiring process, so all those things have to show that ATP breaks down to produce the energy needed for these endothermic type reactions.

His discussion in this case is about the ATP to ADP reaction releasing energy helping other reactions and processes occur in the cell, therefore his emphasis is on connections. Philip expected the detail of the process to be concise and relevant to the discussion of the connections. When asked about more marks for more detail of processes, Philip responded "the question doesn't ask them to discuss in detail any of those particular processes." Philip was expecting some detail but not a lot of detail provided in each process because the question and the marks allocated to this are not enough to expect very detailed answers. Philip's interpretations of the question and students answers are influenced by his expectations from the question.

Philip had interpreted the question as requiring a focus on cellular connections and the detail of processes as arising out of the connections context. The other teachers interviewed may have started or finished with the connections, but they were eventually mostly concerned by the details of the processes and those being well-explained and correct. Therefore they were mostly focused on separate processes and then the connections made in terms of the context of processes. Howard was concerned with both the processes and the benefits to the cell.

Collette demonstrated a unique position in that she differed in her expectations of the Test Question (Table 3.3) regarding four distinctly different processes. She also had a view that the question would be given toward the end of students' biological studies. She expected students to bring all of their biological knowledge to bear in answering this question. Collette's expectation was of a high standard of response and for students to be able to select from a number of cell processes to explain four that were different from each other. Her expectations influenced her interpretation of the students' answers. An illustration describing Collette's insights into her thinking and expectations of students' answers to the test question is found below in Figure 5.1. These comments were analysed using the PaP-eR technique (Mulhall et al., 2003) and drawing out a PCK focus which is also illustrated in this example.

When comparing Collette's expectations from the Test Question with the sample Student Answer, Collette consistently spoke about and then looked for particular aspects of the biological process such as the location, reactants (inputs), products (outputs), a chemical reaction (if needed), stages such as in mitosis, the purpose for the process and relationships between that and other processes in the cell. This demonstrated a thorough biological content knowledge focus and an analysis of the question and answer in relation to her expectations.

When she spoke during her analysis of the Test Question about her expectations for an answer, she said "that's my top student… telling me those sorts of things," so when shown the common Student Answer, Collette had foreshadowed the standard expected, that of a high standard of answer, and her comments and allocation of marks described in the excerpt from her interview reflected this. From a range of student thinking possible, Collette has a perception, identified by McClelland (1995) as an *extremely rich cognitive skill*, that the question required a particular level of expertise. Bransford et al. (2000) described expert thinking as ways to think and reason effectively and Mislevy (1996) spoke of greater command of concepts and connections. Collette emulated these understandings of expertise as well as clearly described her context, that of high standards in student achievement and described the timing of the question anticipated being at the conclusion of school biology instruction. Later in the interview, she clarified this again saying:

> I would see the understanding of that level being of a Year 12, high-level student. I expect that my students that have some background in microbiology, have been exposed to this sort of thing and know the depth to which they answer it.

C: "What I would be expecting a student to do – I would have three [processes] that are essential for all students to have and they are photosynthesis, respiration and movement of substances. They would need to have those three and then after that they have a number they can choose from. If you are to enable it [the cell] to work efficiently then the students have to have those first three.

Collette constructed an answer first choosing the concepts that she regarded as essential that the students mention. She had prioritised these 3 processes above other processes.

The teacher used her content knowledge to select from possible answers. In prioritising answers, she used her pedagogical assessment knowledge.

Then look at photosynthesis – looking at my top student, what I would be expecting them to tell me about is the light and dark reaction and where it is happening in the chloroplast, about the stroma and thykaloids. That is my top student telling me those sorts of things - where is it actually occurring, what are the reactants going into that light reaction, what are the products coming out, where do the products go. Some of them go into the second stage, others leave as the by-product. I would expect the student to go into the dark reaction and talk about what are the reactants, what are the products, where this is happening and what is the end result - to produce glucose. They [students] can then say that glucose is used by the cell as its energy source to do activities, so I expect them to have explained how it is used efficiently. I would then expect the student to discuss respiration, so they talk about aerobic respiration, what is happening in the cytoplasm, going into the mitochondria, and about energy production. I would expect them to bring in how ADP is converted to ATP - the whole reason to do respiration. What are the end products? So therefore talk about what this is actually doing - producing for the cell usable energy. They should be able to make the link between photosynthesis producing glucose and the cell then taking that and putting that through respiration to produce usable energy. I would expect that for those two, this question is worth 10 marks, and so I would probably be allocating about 5 to 6 marks for that part of the answer.

Collette described the level of biological detail expected from a top student, ie reactions, structures enabling these, reactants and products, where they come from, where they go and the purpose of the process.

The teacher started to specify the level of detail that she expected in a good answer using content knowledge. For photosynthesis, a cellular process, this related to biochemical ideas of reactions and all basic aspects involved.

Regarding the Student Answer, in her interview Collette made the following comments about her assessment of the answer.

Researcher: So what do you think when you rated that answer.

C: I felt it was a very general answer. If I was looking at the student answering this question, I would be telling them you haven't actually given me the level of detail that is required of a full answer. You have given me parts of an answer and a general description of what photosynthesis is, and a general description of what respiration is. She has bits of it mixed up. Parts of it are mixed up - where it is occurring and she sort of hints at energy and she mentions ATP and how it is formed in this process with respiration. I would be talking to the student and saying *look you actually need to tell me these things, you need to understand what the stages are in respiration, where they are occurring and what is actually occurring, what is being produced, so what is your end product*? She [the student] makes some comments like photosynthesis is necessary in the products required for respiration but did not really go on to talk about why. Why we cannot use it or change it to glucose. Then you take glucose through respiration to a product, ATP. That is the depth of understanding and why you are doing all this.

Collette in assessing a Student Answer, has criticised its lack of detail. She commented about student's confusion as they are learning a complex process. She believed the student could learn stages in a process, where it occurred and what is occurring – i.e. process, products, use.

Collette changed style from providing comment to giving advice to a student who gave this answer – a role change. Also, that the student is a perceived as a girl. Collette taught girls only.

Researcher: Do you think it is inferred, do you think she does have that depth of understanding?

C: I don't think she does, I think that this student – it comes out in the way that she is expressing things like, she says photosynthesis is necessary in producing these products required for respiration. She has talked about capturing energy and sure she has talked about producing / creating glucose and oxygen, but she hasn't really talked about glucose and glucose molecules in what happens - that we extract the energy out of that to produce ATP, so I don't think she

In discussing the question of whether it can be inferred from this student's answer that the student had an understanding (or not), Collette believed that the student does not understand.

The teacher made judgements about how understanding could be inferred from the answer by using evidence, such as how a student words an answer, a proper explanation of process, relating aspects of processes and how the answer is confused or lacking correctness.

really does understand that. She is not at that level of understanding the different processes, she doesn't make lots of links. I thought her DNA replications very poor with not a really good understanding of what DNA replication actually is. I tend to think that mitosis as being part of replication and not fitting with the question, as it is talking about processes in a cell. Well I know mitosis occurs in a cell, that it is part of the process of DNA replication, so I would see that as being the same process.

Collette used evidence such as:
1. the way the student expressed her answer. C said this showed in the language the student used, such as capturing energy, creating glucose, instead of seeing these as chemical molecules within a series of chemical reactions.
2. The student's lack of links
3. Student's lack of understanding that a central process of a concept is seen as two processes.
4. Lack of understanding of how it all fits together

Researcher: So she is describing two processes not actually the same one?

C: I think this student has some understanding. If I was marking this for the student, I would say *right, you have an understanding about the fact that we need to replicate and we want to produce two daughter cells*. So you have probably got to get a ½ mark for that type of response out of 3 for the two processes together. You have not given me the essentials of what DNA replication is, but you move on from there. Photosynthesis, you know we are probably giving 2½ marks for it, she would get, you know 1 to 1½, probably 1 because she has given me the reactants, the products but she has not given me much more, and respiration, probably about the same. She has given the reactants, has some understanding of what happens, she has talked about it creating ATP which is required, so she understands that, but I don't think she actually understands how it all fits together.

Collette described a second process, connecting one with the next and the detail expected for a very good biological answer.

Collette cited evidence for understanding such as:
1. reason for a process (replication)
2. Site of a process (nucleus in the case of replication)
3. stages of mitosis
4. reactants and products from some processes (photosynthesis and respiration)

Researcher: So if you put a breakdown of marks.

C: Ok, probably in terms of my marking here, I think I would be placing it in this one where we allocating 2 marks, I would probably have given her, really she has not said much more than to have two daughter cells that are the same, so she is probably going to get a ½ out of 2 for that part. In reality she has not said much else. She has located the nucleus necessary for the daughter cells to have the same number of chromosomes, but she has not talked about the process described.

The teacher considered photosynthesis and respiration as dealt with in the same way and in fact as related processes. The student would need to describe the respiration process comparing to photosynthesis and make the connection between the two.

Researcher: But what about the stages of mitosis?

C: So maybe she gets another half point for that part of it, so all she has got 1 out of 2 for that bit.

In discussion of how to mark this answer, Collette allocated marks based on expectation of detail, much of which the student has not provided. The mark allocated is 3 out of 10.

Figure 5.1 Collette's thinking and expectations of answers to the Test Question.

Collette was distinctive amongst the teachers in applying her expectation of a high standard, anticipated answer from one of her Year 12 students and the context of an end-of-year summative assessment, to her judgment of the Student Answer, giving it a mark of 3 out of 10, the lowest of the ratings given by the teachers for this answer.

Howard commented about understanding his students and their capabilities in a discussion of pre-prepared test answers. He said "the answers would be very good and the information very good but is not quite hitting the target of what the question is about". Howard continued "Because kids are not very good at doing that, firstly figuring out what the question is talking about especially if already in their heads they have a pre-prepared answer.” In the interview Howard thought that he had not come across many prepared answers and within a classroom situation, a teacher would know if they came across a prepared answer, implying that they, the teachers, know the capability of their students. He exemplified this in his response: “You would know very quickly if that was going to happen because you know the kids. Like the one boy I had last year who was very bright you could hear him saying the answer to you in his writing, it was excellent, very good answers but you knew that and you knew him so you knew that it certainly wasn’t coming from an answer that he had picked up somewhere.”

In relating Collette’s and Howard’s ideas about their understanding regarding their own students, it could be proposed that teachers’ standards are commonly based on their expectations of the cohort of students they are teaching and that this may be a factor in their immediate responses to questions and answers.

Howard initially commented about the focus of the Test Question (Table 3.3) and the guidance it gave the students, then the biological concepts he required in an answer. He described the concepts and the detail that he would be looking for: “respiration is necessary as a process within a plant cell as it creates the ATP for cell activity”. He focused on the detail of the biological ideas in the answer.

Howard spoke about the complexity of the answer, particularly in terms of the Levels from the Student Outcome Statements, (Education Department of Western Australia, 1998) a State Government initiative that was later discontinued. At the time when Philip’s and Collette’s interviews were completed, the Student Outcome Statements were still being implemented in schools. When Howard was interviewed they were in the process of being replaced. Howard spoke about the relatively open nature of the question, with guidance for the concepts needed in the answer. Two of the points of guidance or direction were the words *relationships* and *benefits*.

> By saying relationships and benefits, you are saying: *OK I don’t want a level 3 answer.* I do not even know if they really would be given any credence for doing the level 6 answer because that is not as high as what they are asking for in that particular question.

Levels 7 and 8 responses would have been more focused on complex relationships and may have been seen by Howard as more appropriate to what was required in an answer to the Test Question.

In accommodating a range of possible interconnecting frameworks, Howard when asked about a student answer to his self-selected polar bear question (Table 3.4, Question 39c) initially responded with his expectations of biological concepts required for this question. He then commented that he had received unexpected answers in some cases, with the "students more inclined to think about the polar bears' situation. Feel sorry for them." The idea of empathy for the polar bears was a distraction from the biological content required and he was implying that students would have made a strategic mistake spending time thinking on or writing about this, within this context of testing for scientific ideas. Furthermore when asked what he would expect in a good answer, Howard responded: "Clear ideas and a planned answer". Later in the interview he said "clear and obvious that you know what you are talking about", consistent with the first response. He added to his initial thinking and responses focused on a conceptual approach in biology with discussion of strategic mistakes and an exam technique or strategy that would add value to the answer.

It is clear from Howard's comments that answering a question is a complex task requiring an intersection of a number of frameworks. He required at least an understanding of the breadth and depth of biological concepts, a focus on the appropriate concepts for the question and also a consideration of how best to order and express those ideas, that is, an appropriate choice and detail of content and best use of clarity and strategies in composing an answer likely to score highly in a test. Also he accommodated problematic answers within his overview of considerations to student responses. In a similar way to Anthea and Michelle, Howard focussed on and probed for the biological ideas and on how students should frame their answers.

5.2.3 Interpretation of answers

Each participating teacher interpreted student answers in their own ways based on their interpretational frameworks. Collette, Michelle and Howard have been selected as examples of teachers who provided extensive evidence for this idea.

An aspect of Collette's judgments and the influence of her interpretational framework regarding biology is illustrated in the following response to an interview question about the Test Question (Table 3.3).

Researcher: Why do you think we ask this question?

C: Because it is the basic process that kids understand and how it actually works, and not just whether it is a plant or animal and if it is going to function, you have got to understand what is happening at the cellular level and you have to understand how those processes inter-relate. It is the crux of what is happening in the body, whether it is a plant or animal or even a microscopic animal. And if you can talk about what is happening inside of it, then say how it happens. →	Asked about why a question like this would be asked, C said that it showed what the kids are understood in terms of relating the cellular (or microscopic) level of functioning to each other and to the macroscopic body level.

Collette had a view of the question and answer in terms of a larger biological understanding, that view being anchored in the necessary connection between the activities in the cell and the functioning of the organism. She wanted the students to connect at least the processes in the cell with each other (as required by the question) and not as discrete activities that have no meaning other than in themselves. She thought that it was important for a student to see an individual organism at a biochemical and cellular level as well as a macroscopic level and understand that processes inter-relate within the different levels of biology. Her references to understanding biology through different levels and inter-relating processes could be viewed as consistent with Shulman's (1986) idea of the structure of biology.

When asked about the common Test Question and on reviewing the common Student Answer, Michelle responded in a general way initially by saying, "A brief description of each of the four processes and as outlined in the question, how they related to each other." She suggested on further probing, that the student could: "finish off, then put a little mind map showing how they were connected to each other." Michelle has referred to a visual representation being an effecting tool in biology, corresponding with research by Gilbert (2008), who commented about the importance of visual representations in science education and Eilam (2013) in specific research in biology.

Michelle continued "they came up with more or less the same processes that I would have had. With the exception they had DNA replication and mitosis and I would have put those together**"** Michelle agreed with Collette's statement that these processes should not have been separate but she added that the way the student had described the processes she would be justified in awarding them marks as separate processes, therefore not penalising the students. This is a point of difference in interpretation and expectation between these two teachers.

Michelle was looking for particular points. There was an expectation of particular content details that had to be specified in the answer in order to be eligible for full marks. She expressed that sentiment in this comment about the Student Answer.

> I looked at respiration and there I was looking for a comparison with the products and reactants of photosynthesis, how they interacted, its connection with respiration and water was not mentioned there. So that is why I would not have given full marks for the description of respiration.

Michelle discussed examples of how the common Student Answer fared in terms of describing the relationships between processes that were asked for in the question. She said:

> the paragraph on respiration did not relate well, I thought, to photosynthesis. It did not have a sentence showing exactly how it related to it. Then I moved to mitosis and DNA replication. For mitosis I did not feel it showed any connection with photosynthesis and respiration. For DNA replication, I felt it could have shown more of a relationship with respiration and photosynthesis.

Michelle commented further: "I felt there were four disjointed paragraphs and I wanted more of a connection". Michelle remarked many times about the lack of connection and was disappointed that attempts at showing relationships between processes were not made by the student. Michelle commented on how students could have demonstrated the relationships between the processes:

> The way the processes are presented shows they are apart. If only there was an arrow going between them to show they are related. Or it could be summarised at the end, add an equation and put arrows going around it to show how they were connected.

Her explanation was a diagrammatic way of demonstrating connections and relationships that would, if used by the students, have helped relate the processes. Michelle also suggested conceptual linkages by saying "how the water produced in respiration and carbon dioxide could be used as a reactant for photosynthesis". Michelle therefore offered two different ways students could have explained the relationships, a diagrammatic method and a conceptual method.

Michelle expected to see other processes described amongst the four, such as osmosis and "enzymes, I thought could have been mentioned as well. That would have been another option as well under protein synthesis, the enzymes are needed to catalyse the reactions." Michelle was flexible in her expectations on the processes that could have been described in answering this question. She showed some flexibility within the boundaries of the question.

During the discussion with Michelle, it emerged that she thought that if the student did not get the exam technique right, then the conceptual parts or content of the answer would suffer. This indicated a consistency with a Pedagogical Content Knowledge focus in an assessment context. An example of the instructions on Examination Technique she provided to students can be found in Appendix 5.

In attending to interpretation of student answers, Howard discussed the idea of the teacher reading for clues that could signify understanding, for example by reflecting on the specific part of the Student Answer about anaerobic respiration not requiring oxygen and producing carbon dioxide and alcohol.

> I think that they were a bit confused there, but you can see that they have some idea because it is aerobic and anaerobic respiration happening. But then up here [points to the paragraph on DNA] you can see that they know what we are talking about with regards to DNA replication but they confuse it by throwing in words that go with mitosis, like two daughter cells. Somewhere, if they had actually talked about DNA replication within the interphase section of mitosis and then carried on, it would have made more sense and you could work it out. You could see where the relationship was between the two processes better and more clearly.

Howard explained this again:

> So all of that description, then student's explanation jumps. That is where the hidden message is, that one of each of the homologous chromosomes goes to each end. The student has just said identical to the first pair of cells, but what is *identical* is left out. You assume that, by whatever else they have written here, that they know what they are talking about.

Howard referred to the sample student answer having a *hidden message* or assumption, where they, the student, may expect the marker to understand what they mean. Or alternatively, the students omit less critical parts of the explanation in order to complete the examination in the required time. This example could be indicating that the student has to make decisions about how much content they include in an answer, best ways of expressing their understanding, or how to compose their understanding into a concise, ordered, whole, targeted answer. Collette looked for clues in understanding such as the way the students expressed their answer, their use of terminology, an expectation of particular detail, whether there were confused or incorrect answers and whether there were adequate links showing understanding of how the processes fitted together.

These examples showed that the teachers make decisions sometimes on whether the students have indicated particular understandings that they have not actually stated. Sadler (1998) and Pellegrino et al. (2001) discussed drawing inferences and reasoning from what is known in order to make a judgment. It could be postulated that teachers were actively looking for appropriate evidence in assessments, could make inferences on the evidence given in the explanations, even if incomplete, and be awarding marks for this.

A summary of the evidence and conclusions for Assertion 1 can be found in Section 5.4 which summarises Assertions 1 and 2.

5.3 Assertion 2 *These teachers award marks using a dynamic process consistent with their rationale and guided by a marking key.*

All of the teachers interviewed provided strong support for this assertion. The interviews provided some teachers with the opportunity to think aloud while assessing the Test Question (Figure 6.1) and constructing a marking key, and to demonstrate how they adjusted their ideas in taking account of the whole situation and in coming to a final decision or judgment in the form of a mark. The idea of a dynamic process in decision making (Brehmer, 1992; Edwards, 1962; Gonzales et al., 2003) is compatible with requirements involved in marking and assessing student work.

Teachers' use of rationale is a key idea related to the assertion. Rationale is defined as a statement of reasons, a reasoned exposition of principles, the fundamental reasons serving to account for something (Macquarie University, 2001). It will be shown that the teachers were able to give a *reasoned exposition* for their marking key and make dynamic judgments in awarding marks. Evidence for Assertion 2 is presented in this section.

5.3.1 Teachers' rationales, marking keys and marks

Evidence of participating teachers' comprehensive thinking and assessment processes will be compared in this section. Their marking schemes or keys, the marks they award for the Student Answer (Table 3.3), their reasons for their steps or decisions and idiosyncrasies are discussed.

The teachers were in some ways consistent in their judgments of a single common answer for example, in the marks given to the Student Answer. Wendy (7 marks) and Michelle (7 marks) agreed in their marking schemes and awarded the same mark out of 10 for the student work sample. Howard and Philip had different marking keys to Wendy and Michelle, and awarded the sample answer "6 or 7". Anthea awarded 8 out of 10. Collette awarded the student 3 out of 10 so was inconsistent with the other teachers.

Wendy and Michelle

Wendy and Michelle agreed about the mark allocation and awarded the same mark for the Student Answer. Wendy described her allocation of marks, "I would have given two marks for discussing each of the four processes. And I would have given two marks for the linkages then between the processes." This made up the 10 marks that were allocated to the question. In marking the Student Answer she said, "I would have given a seven out of ten for it, but perhaps I am a little bit generous sometimes." Wendy's marks were distributed in this way: 1 mark each for mitosis and DNA replication, 2 marks each for photosynthesis and respiration and 1 mark for linkages, to achieve a total of 7 out of 10.

When considering her rationale for marks for the Test Question, Michelle said, "it was an overall of ten marks and for the processes, I would have given them two marks for each process." On her written marking key, she had recorded her marks as Processes 4x2 = 8 and Relationships 4x½ = 2. As well as 8 marks for the processes as she said in her statement, she allocated 2 marks for showing relationships, giving a total of 10. She scored DNA replication 1+0, that is 1 mark for the process and 0 marks for showing relationships, Mitosis 2+0, Photosynthesis 2+½, and Respiration 1½+0 to total 7 marks out of 10.

When comparing the two rationales and marking keys which were most similar (Wendy and Michelle), their final marks were the same. However, during the marking process there were different allocations of marks to parts of the Student Answer. This indicates that an equivalent total mark and matching marking keys do not necessarily reflect the same marking process or allocation of marks to the parts of the answer. The sample Test Question and Student Answer (Table 3.3) are the only common question and answer that the teachers discussed.

An analysis of teachers' rationales for awarding marks is a critical aspect in understanding discrepancies between marks given by experienced teachers. Teachers' voices illustrated in a range of vignettes are used in this section to explore the variation in judgments by the teachers interviewed. Wendy is the first teacher whose ideas around the marking process are discussed in detail. Decisions on rating the common Student Answer were discussed by Wendy and as part of that, her rationale for awarding marks for the Student Answer (7 out of 10). Two tables were constructed illustrating Wendy's responses. Her marking key for the Test Question is shown in Figure 5.2 and marks for the Student Answer are shown in Figure 5.3.

In her marking key, Wendy highlighted the many processes and parts or aspects of processes that occur in the cell and grouped the main parts involved in four main processes she would expect to see. She identified the number of marks for each idea and listed ideas for her marking key. Wendy took account of the four processes written in the Student Answer - respiration, photosynthesis, DNA replication and mitosis - although she had not mentioned mitosis in her description of what she was looking for or in her marking key and had mentioned DNA replication as an after-thought.

Wendy allocated marks on the sample Student Answer, as shown in Figure 5.3, according to two processes she had identified on her marking key and accepted the two processes she had not identified. She totalled the number of marks. Her focus described in the following paragraph was on the processes, with a lower emphasis on linkages.

Marking Key (Wendy)

Energy
Cell structure
Chemical reaction
(2 marks)

Transport in and out of cell
Cell membrane structure, diffusion, osmosis
Active transport – pinocytosis, phagocytosis and endocytosis
Chemicals moved – water, glucose, O_2 CO_2
(2 marks)

Respiration
Inputs, outputs, equation
Energy production
Aerobic, Anaerobic
Energy storage ADP-ATP
(2 marks)

Photosynthesis
Energy input, equation
Chloroplasts
(2 marks)

Enzymes
ADP-ATP
Catalysts, Lock and Key, Temperature, pH,
Starch-glucose
Lysosomes
(2 marks)

Figure 5.2 Wendy's marking key for the common Test Question

Wendy commented about the Student Answer:

> The photosynthesis and the respiration I think were done very well and there is a linkage between those. I do not think that the DNA replication and the mitosis were done as well and so I would not have given them the full marks. They did say why it was necessary but they did not elaborate. There did not seem to be enough there to give the second mark on either of those. So I probably would have only given one of the two marks for the DNA replication and one of the two marks for the mitosis, two for the photosynthesis and the respiration and then only the one for the links because they did not make good linkages.

Wendy demonstrated flexibility in her approach to allocating marks to student work. She recognised different answers that fell within her boundaries for a well-explained answer and awarded marks accordingly.

Marks for Student Answer (Wendy)

DNA Replication
Before mitosis is able to be completed, the DNA located in the nucleus of the cell must replicate, this is necessary as the two daughter cells must have the same number of chromosomes as the parent cell and if the DNA didn't replicate, then the daughter cell would only have half the required number of chromosomes. (1)

(1/2) Link

Mitosis
Consists of the stages interphase, prophase, metaphase, anaphase, and telophase. During this process the cell replicates and divides by forming a spindle and separating the replicated DNA chromosomes to either end of the cell, the membranes then enclosed each daughter cell and two new cells, identical to the first parent cell are formed. Mitosis is necessary for growth and repair in an organism. (1)

Photosynthesis
Plants create their own nutrients (teacher: food) through photosynthesis, ie. they are autotrophs. By capturing light energy through chloroplasts (1)

photosynthesis uses carbon dioxide and water to create glucose and oxygen, glucose and oxygen being the raw products/materials of respiration and the (1)

raw products/materials of photosynthesis being carbon dioxide and water. Photosynthesis is necessary in creating these products that are required for respiration.

(1/2) Link

Respiration
Respiration comes in two forms, aerobic and anaerobic, both producing energy that is used by the cell, aerobic requiring oxygen and producing 36-38 molecules of ATP from 1 glucose molecule in the mitochondria and anaerobic not requiring oxygen and producing carbon dioxide and alcohol in the cytoplasm. (1)

Respiration is necessary as a process within a plant cell as it creates ATP which is required for several of the cells activity and produces an instant source of energy that is located on the third phosphate bond. ATP is also required predominantly for protein synthesis, where mRNA is released into the cytoplasm and connects to a ribosome and consequently proteins are made. (1)

Marks for the Student Answer
Paragraph 1: 1 + ½ marks
Paragraph 2: 1 + 0 marks
Paragraph 3: 2 + ½ marks
Paragraph 4: 2 + 0 marks
TOTAL 7/10

Figure 5.3 Wendy's marks for the Student Answer to the common Test Question

Wendy said that if she was presented with a question worth four marks:

> they are writing for four marks I would want to know four things. So if they are only giving me anaerobic and aerobic respiration, they have told me one thing basically. They have told me that there are two types of

> respiration. They get one mark. But if they perhaps explained both the processes and they told me four things about the different processes then I would be looking at four marks.

Wendy made it clear that when marking she would look for assessable points in consideration of the mark allocation for the question. Wendy's disposition was expressed well in her statement "I find the positive things that I can give a mark for, rather than finding the negative things that are there, because you do not take marks off." Also she said "I think that as a teacher you have to be adaptable to the student style in the way they answer." Wendy said:

> incorrect ideas obviously cannot get marks, nor leaving out key ideas or an explanation. I have in my mind what I am looking for in the question, though I must admit that I am open to other valid answers. I have sometimes done questions with a marking key and then suddenly I read a kid's paper and I think that answer is very valid. I had not thought about that. I am willing to then change and say, when I re-read the question, perhaps that is a valid answer and it is not one that I had on my marking key.

Also, "we do not all think along the same lines and sometimes some people have to go around about a bit to get to the same idea, so I am not sure that I would penalise kids for that." Wendy was lenient to students who struggle but arrive at the right idea eventually and said she would not penalise for wrong answers. Wendy used a marking key or had a clear idea of what she was looking for in an answer, but was willing to change if the answer was valid. Her use of valid appeared to be in the context of answering the question, not adding additional unnecessary information. Wendy reinforced this in her statement:

> I would probably have in my mind what I wanted the student to tell me, you know, what is the answer to the question that is being asked and if I did not find that answer in there then I would not be giving marks for information that is not being asked. I mean, one of the objectives is to answer the question that is being asked. So I would not give marks for giving me extra information and it is not a good exam strategy for kids to get into.

This focused on the answer receiving marks on the question asked, not on extra information or on what had not been asked. Wendy talked about students adding extra information as an exam strategy and seemed to be inferring that was likely to be unsuccessful and wasteful. Wendy discussed extra information given, that it was:

dependent on how that question is being asked and whether it was relevant to the question or not. If the question was asking them to perhaps go into detail about that sort of thing then fine, but if the question was asking them the processes of respiration and you know more about other things, I would not expect the student to tell me everything that they have learnt in a whole biology course.

The following extract from the interview with Wendy illustrates the point about marking with a teacher perspective but also considering other perspectives.

> Researcher: "if students have a different mindset from you and different students will have different mindsets, how do you assess those?
>
> Wendy: "As long as it is valid in as far as the biology outcomes and the biology course that is set, then I do not have any problem with it. As long as it fits into the question and to the scheme of it and the whole idea of biology."
>
> R: "So if you got something quite off beat, in a different way, some unusual diagrammatic form then you would not penalise them?"
>
> W: "No, not at all. As long as it would not take me a long time to figure out exactly what they are doing, I have to be able to sit and mark reasonably quickly, because if they are doing a TEE then the marker is not going to spend that much time sitting and figuring it out. So it has to be part of their exam strategy that they make the exam and examiner able to mark their question easily. If they want to be off beat, fine, perhaps do it when they write an article for something, somewhere, but not where it is going to be important for your TEE mark."

Wendy's expectations of student answers were that they were consistent with the expectations of the final Year 12 exam (the TEE). Wendy was willing to award marks if the answer was different to that expected but able to be easily understood and consistent with the question.

Another of the interviewed teachers, Michelle, said of awarding marks:

> I would look at the marking scheme first of all, see how much detail is required. I would tell them that describe would involve writing something. Then I would look for four processes. They would have to have four processes, no point writing down three. And then look at the word plant cell and then the word related. So when I was planning the answer I started looking at the four processes first of all. Then making sure that they were connected to a plant cell.

Michelle showed a methodical approach to constructing a marking key or a rationale for marking the Test Question and in her marks for the Student Answer. Her summary is illustrated in Figure 5.4. She assessed the level and amount of detail required considering the number of marks, the number of assessable points and the connections that were required by the question. Her focus was with the processes and then consideration of the connections.

Marking Key (Michelle)

Processes: Possible: 4x2 = 8 marks

- Respiration
- Photosynthesis
- Protein synthesis
- Osmosis

Relationships: Possible: 4x1/2 = 2 marks

Osmosis

Photosynthesis: $6H_2O + 6CO_2 \rightarrow C_6H_{12}O_6 + 6O_2$

(+Light, chloroplasts)

(+Enzymes)

Convert

Starch

Cellulose

Respiration

Respiration: $C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2$ + Energy

(+ Enzymes)

Marks for the Student Answer

Paragraph 1: 1 + 0 marks

Paragraph 2: 2 + 0 marks

Paragraph 3: 2 + ½ marks

Paragraph 4: 1½ + 0 marks

TOTAL = 7/10 marks

Figure 5.4 Michelle’s Marking Key for the Test Question and marks for the Student Answer

Michelle identified the descriptions of each process first, allocating one of the two marks given for each process, then she looked for a description of connection, represented as a + 0 or + ½ mark. She indicated detail of equations she would be looking for in her marking key and in the final summary of marks for the Student Answer. She allocated the mark for the process first, then the connection second, giving the connections a possible 2 marks out of the total 10 marks. She constructed a flow diagram within her marking key to highlight where the processes were connected. In a similar way to Wendy, Michelle showed flexibility in deviating from nominated processes on her marking key that were not evident in the answer, and awarding marks for processes in the Student Answer that she had not written in her marking key.

Michelle commented about the detail in answers for the marks allocated and in regard to "respiration producing the amount of molecules of ATP from one glucose molecule" in the Student Answer, said of the entire question, "When there was only ten marks given for it, I felt that was too much detail." Her view was that the answer on respiration was too substantial for the number of marks she could award it, although later Michelle commented that there could have been more of a focus on photosynthesis because that was the essential plant process.

> I began looking at photosynthesis. This was the main function of the plant cell. I looked at that and I based it on the equation that I made out, that I wanted them to mention the glucose, oxygen, water, carbon dioxide and energy, which they had. Because they covered all of those points, I gave them full marks.

In this sample answer, she awarded the photosynthesis description full marks, that is 2 out of a possible 2. Although she commented that photosynthesis was the main function of the plant cell, she did not give it preferential standing by awarding extra marks to that process, unlike Collette, whose commentary and evidence will be presented later in this section. Despite commenting on the amount of detail given in the respiration process, Michelle awarded it 1½ marks out of 2. On inspection of the question, although the student had provided a lot more than was required, they had not covered all of the basic reactants and products and therefore had not gained the maximum marks that Michelle had allocated for that process.

The allocations of marks were not completely consistent with Michelle's or Wendy's marking keys but were entirely consistent with their rationales. In this case, it appeared that the teachers had constructed a marking key to order their thinking and guide them and that the marking key was not exhaustive.

Howard

The third teacher chosen to explore the judgment process in detail was Howard, who represented his marking key by allocating marks in this list in Figure 5.5.

Marking Key (Howard)
Mitosis Benefits of (1) RNA Replication Benefits of (1) Respiration Benefits of (1) Photosynthesis Benefits of (1) Relationships – Mitosis and RNA Replication (2) Respiration and Photosynthesis (2) Ability to help cell to work efficiently (2)
TOTAL 10

Figure 5.5 Howard's Marking key for the Test Question

It is clear from this marking key that Howard would allocate most marks to the relationships and benefits to the cell. It is also clear that Howard was using the marking key as a prompt for his thinking and marking rather than an exhaustive set of expected responses. On inspection of the sample answer, he said "I would say around a 6 or 7" as his rating. In explaining the marks, he said:

> It says in the Test Question that marks will be allocated for the relationships between the processes. So when the students are looking at the processes I suppose they try and work out, *okay I have these four processes* and in their planning they look at how those four processes actually relate to one another

Howard worked through his expectations of what the students could think as they were planning for their answer, for example, how to distribute their marks allocated as they devise the content of their answer, so as to ensure they have prioritised and provide sufficient details in areas with more marks.

On reflecting while reading the Student Answer he said:

> for respiration, the student does a lovely job of describing the process but the part in brackets indicates it does not really want that. It wants the relationship between the processes and the benefits to the cell. The student is not necessarily answering that in there [respiration], but they are doing that in the first three parts.

Howard allocated most marks to relationships and benefits for the cell in his marking key. On reading the sample answer in detail, however, and comparing with his allocation of marks he realised there seemed to be a discontinuity between them because the student appeared to have just described processes. On further examination, particularly in looking at aspects of the answer determined by his marking key, Howard further reflected that the student had partially described the processes and had also addressed the benefits to the cells, so confirming that they had met some requirements of the marking key. He said:

> they are relating and they are looking at benefits, but the last one really is going off on a tangent into ATP production and how that helps protein synthesis. Which might be a benefit to the cell, *oh yes!* that would be a benefit to the cell now that I am thinking about it.

It seemed that Howard initially looked at the answer without thinking about his marking key, then after reflecting aloud during his interview and applying his marking key to the answer, he allocated a mark. Howard has demonstrated an interesting phenomenon that may be idiosyncratic among experienced teachers. He had done the thinking about a question and constructed a marking key, then appeared to have overlooked the marking key during his initial reading and assessment of the answer. On critical analysis and reflection during his interview, however, Howard realised that his initial impressions of the student work, when compared with his marking key, were consistent. A comparison of expert teachers and novice teachers in the construction and use of answer keys and the continuity between the teacher's original impressions of an answer and their real-time marking processes would be an interesting area for further investigation. As Howard read the Student Answer he was surprised at part of the answer:

> In this model answer they have separated DNA replication and mitosis. But not neatly. They have divided it up whereas I would have expected them to talk a bit about DNA and about mitosis together and then relate the two and why they are important to one another.

Howard described how mitosis and DNA replication could have been discussed as one answer or at least two very related answers and that this did not happen. He chose not to penalise marks. Interestingly, Howard then proceeded to articulate his view that the two processes of photosynthesis and respiration should have been linked closely when describing them. He said:

> the same thing with the respiration and photosynthesis, because they are not necessarily the opposites of one another but, the products of one is the reactants of the other, so how those two within a plant would work together. Even looking at say the graph where you look at rate of photosynthesis and rate of respiration, showing all of those things and that relationship between the two working 24 hours a day.

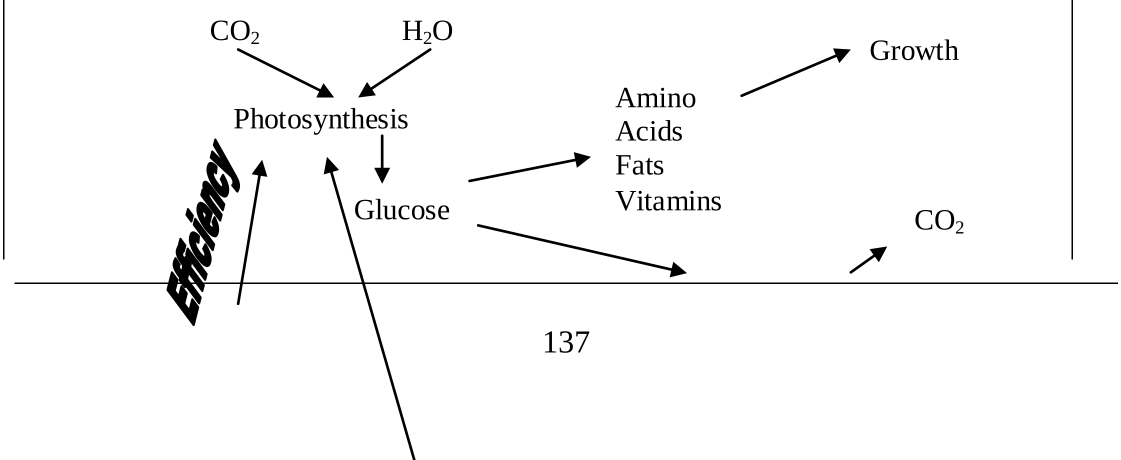
Once Howard expressed his surprise at seeing mitosis and DNA replication described as two separate processes in the sample answer compared with his idea that they were integrated and one process, he then started thinking on the two vital processes in the cell - photosynthesis and respiration - as an integrated whole.

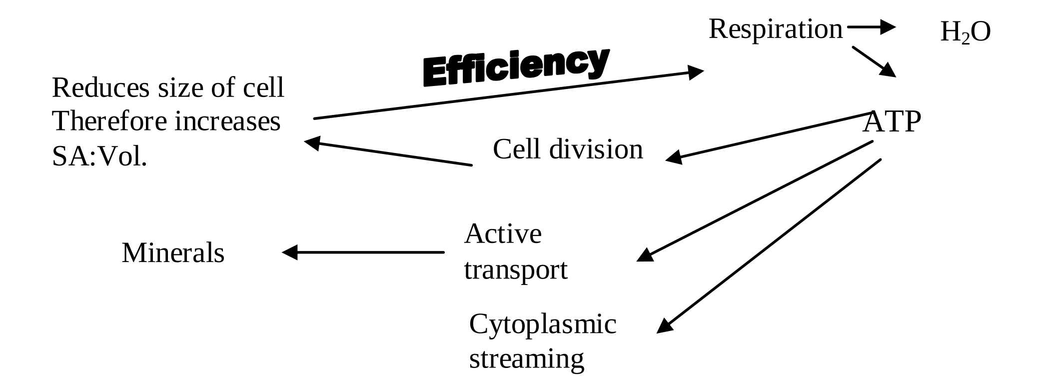
Howard made a comment about excessive unrelated information. Of the sample Student Answer, he said “they have also got a lot of gobbledy gook in there. They have to try to make sure that they do not overdo it.” He reflected on an example of a student in his class “who had answered all of the question in the first page but she still had another page of writing”. He had given her feedback about all her marks being achieved on the first page and the wasted effort and time in completing a second page. He saw the second page of her answers as a technical error. His analysis of the situation did not indicate that he would penalise marks, just recognition of the dissipation of energy on the question.

Philip

In considering the Test Question, Philip was focused from the start on the connections, not through the processes. He represented his answer key in the diagrammatic form shown in Figure 5.6. Philip represented the relationships between the processes in a hand-drawn cyclic way. The emphasis was still the same as that identified by Howard, that is, the connections between the processes are central and important and the information about the processes form part of that framework. Some aspects of the processes are included in his diagram, such as most of the elements of the equations for photosynthesis and respiration. His mark for the Student Answer was 6 or 7 out of 10. Philip explained his rationale for his marking in terms of his expectations of a student’s focus on connections rather than listing processes and in providing a certain level of detail in the answer.

Marking Key (Philip)





Each process clearly explained 1 x 4 = 4 marks
Links between processes 1 x 6 links = 6 marks Total = 10

Figure 5.6 Philip's Marking key for the Test Question

Collette

Collette's ideas are presented with a close examination of the key difference between her mark for the Student Answer and those of the other teachers. Decisions on rating the common Student Answer were discussed by Collette and, as part of that, her rationale for awarding 3 out of 10 for the Student Answer. Her marking key for the Test Question and marks for the Student Answer are shown in Figure 5.7. In her written allocation of marks Collette used the diagrammatic representation in Figure 5.7 consisting of her initial answer key followed by a brief description of a marking process and judgment for the sample Student Answer.

In summing up the allocation of marks for the Student Answer, Collette had awarded it 3 marks out of 10. She originally privileged two processes, eventually allocating the photosynthesis and respiration processes in the question 2½ marks each. She allocated 2 marks each for the other two processes.

Marking Key (Collette)

1. Photosynthesis — Light reaction; Dark reaction

5 marks for 1. and 2.

2. Respiration — Aerobic respiration → Cytoplasm; → Mitochondria

What is happening to end products, energy?

3. Movement of substances → solutes → diffusion; → active transport; → osmosis

3 marks

- energy
- description of process
- why do you need to do this? e.g. water balance to allow reactions to

4. Protein synthesis → transcription; → translation

5. DNA replication → structure; → process — base pairs — S/R backbone

2 marks

Mark for Student Answer Collette said:

Descriptions general. General organelle. Not given detail of reactions or how ATP is actually formed. Mitosis and DNA transcription are too closely related to be given separate marks so 1 out of 2 for that and 2 out of 5 for photosynthesis and respiration according to the marking key. Total = 3 out of 10

Figure 5.7 Collette's Marking Key for the Test Question and marks for the Student Answer

In her interview, she adjusted the allocations from the amounts given in her written diagrammatic representation, and then an extra mark for relationships. There were development phases throughout Collette's discussion and reflections as she solidified her thinking. Collette initially wanted to give preference to one process – photosynthesis – giving it 3 marks of the 10 allocated for the question, then 2 for respiration and 1½ each for other processes that the students may mention. In working through her ideas and in trying to arrive at a marking scheme, Collette pointed at various sections in the Test Question and reflected aloud, "I think there is probably 5 marks there, I think that's an important part and this is worth 2 and then you give them 1½ for – no sorry, 5, 6 7, probably – make that 3, 5, 3, 2 and whatever their last process was." This may not appear to make complete sense on its own, but Collette was calculating the distribution of marks for a total of 10 for the question. Some numbers are for particular processes and some are a compilation of marks and Collette may have been flustered in trying to undertake this process in the presence of the researcher. For example, 5, 6,7 were incremental calculations as she totalled various options for marks. In her numbering of "3, 5, 3, 2", the first "3" was for photosynthesis then a re-consideration of photosynthesis and respiration together to total "5". From previous discussion, she allocated "3" for movement of substances and "2" for a final process such as DNA replication and protein synthesis. She allocated marks based on the importance to the plant cell of the process, so had prioritised photosynthesis and movement of substances. Collette expected the students to include a discussion of benefits and relationships as part of each process. Calculating the marks aloud in real-time based on initial ideas and expectations was a developmental, dynamic approach as she worked back and forth between the biological processes within a plant cell, conceptual priorities and quantifying each idea. This was the only instance of this phenomenon occurring during this study.

Later in the interview, as Collette was marking the Student Answer and giving her reflections on this, she had changed her mental marking key a small amount, saying "for Photosynthesis, I am probably giving 2½ marks for it, so she would probably get 1 to 1½". The discussion about allocating marks for the question was her first experience of the question. As Collette talked through the question and then the answer she had become more familiar with the question and an example of how it may be answered and had re-assessed her mark allocation. She added her assessment of the Student Answer in connection with respiration "and respiration, probably about the same", that is, 1 to 1½ marks.

Collette said of mitosis in the Student Answer: "she has not said much more than to have two daughter cells that are the same, so she is probably going to get a ½ out of 2 for that part", then when reconsidering in the light of the student having provided the stages, said "so maybe she gets another half point for that part of it, so all she has got 1 out of 2 for that bit." Collette said of the last two processes:

> I thought her DNA replication explanation very poor with not a really good understanding of what DNA replication is. I tend to think of mitosis as being part of replication and the answer does not fit with the question.

> I know mitosis occurs in a cell, that it is *together* with the process of DNA replication, so I would see that as being the same process.

Collette allocated marks for mitosis and DNA replication as one process from the Student Answer, although they were written in the Answer as two processes out of the required four. Collette differed decidedly from other teachers in her final judgment to award marks, that DNA replication was not extra to mitosis as a different enough cell process. Her expectations were that four distinctly different cell processes were needed but only three were provided in the Student Answer. This was reflected in her assessment of the sample answer and the mark awarded.

Another issue raised by Collette that was not referred to by other teachers was the effect of relationships between students and the teacher on the judgment of a mark or grade when marking your own class. She said:

> The only thing that I think that can influence a teacher is the relationship with the student because people are human, teachers and kids are human. It can be an issue if people are not experienced enough and let the relationship with the student overcome that judgment, does not make them as objective as it should be and I have seen that happen. If teachers have an ongoing relationship with a student that may be negative, that can have a negative effect on that student's achievement. You have to be very careful if they are not being objective or if they are being objective but too hard on the student. The way to overcome that is to cross-mark.

Collette discussed the impact of negative relationships on objectivity in marking and, by implication, positive relationships on objectivity. Collette considered that neither positive nor negative relationships should have an influence on assessment judgments.

5.3.2 Comparisons of teachers' rationales, marking keys and marks

Marking keys for the common Test Question

On reading the common Test Question (Table 3.3), teachers allocated marks to aspects of the test or to their expected answer in the form of a marking key. Philip, Collette, Michelle and Wendy designed marking keys to include an expected answer with marks allocated to parts of the answer, while Howard's marking key contained the aspects of the question he thought were required with a mark against each aspect. Anthea did not provide a marking key.

Collette (see Figure 5.7) gave preference to two major cellular processes, respiration and photosynthesis (5 marks out of 10), which had to be described, and then 5 marks for two other cellular processes (any two from movement of substances, protein synthesis or DNA replication). Michelle (see Figure 5.4) gave 8 marks for biological processes (four processes times 2 marks each) and 2 marks for relationships (four relationships times ½ mark each). She nominated the processes of respiration, photosynthesis and protein synthesis. In addition Michelle wrote osmosis and Collette mitosis, as the final of the four processes in their marking keys and so they differed in one process. Wendy (see Figure 5.2) gave 2 marks to each of the following groups of ideas: linkages within the cell (2 marks allocated) were energy, cell structure and chemical reactions, then in relation to processes (four processes at 2 marks each) were transport in and out of cell and cell membrane structure, respiration, photosynthesis and enzymes and ADP-ATP. Collette, Michelle and Wendy prioritised the processes, with an expectation of students adding to their discussions of processes some details of cellular relationships and benefits.

Philip (see Figure 5.6) gave 4 marks for each of four processes described clearly and 6 marks for links between processes, to give a total of 10 marks. Philip suggested photosynthesis, respiration, cell division, active transport and cytoplasmic streaming, but didn't give a preference to any process. Howard (Figure 5.5) was similar to Philip in giving a mark each for the description and benefits of mitosis, DNA and RNA replication, respiration and photosynthesis. He also gave 2 marks for each of relationships between mitosis and RNA replication, respiration and photosynthesis and ability to help the cell to work efficiently. Philip and Howard provided a differential between processes (4 marks) and relationships and benefits (6 marks) in their answer key.

Most of the teachers who participated in this section of the current study constructed a pre-set mark allocation for the question within or alongside a marking key. Their allocation of marks varied from giving 8 marks for processes and 2 marks for linkages (three teachers) to giving 4 marks to cellular processes and 6 marks to links, relationship and benefits (two teachers). One teacher marked the question and did not provide a marking key.

Marking the Student Answer

In allocating marks to the Student Answer, the teachers' ways of marking differed. They included ticks, numbers against paragraphs, arrows or connections and comments, either against parts of the Student Answer or separately on inspection of the Student Answer in reporting the marking information.

Collette commented that the first and second paragraphs were part of the same process and the student had some understanding, but did not give the essence of what DNA replication was, so allocated a mark of ½ out of a possible 3. Later she revised that to 1 out of 2. For paragraph three, she gave 1 to 1½ out of 2½ as she said the answer had reactants, products and not much more. Her comments about paragraph four were similar to paragraph three with further comments about the student not being able to demonstrate how the processes fit together. So she gave 1 each for those two paragraphs. Her total for the answer was 3 marks. Collette made a final comment that the answer had not met what she would be expecting of a Year 12 student answering this summative question.

A contrasting case in marks but similar in one aspect of thinking was Anthea who gave a total of 8 marks. Anthea gave 1 mark to paragraph one, 2 marks to each of paragraphs two and three and 3 marks to paragraph four, to give a total of 8 marks. Anthea made comments that paragraphs one and two were related and commented on an overstatement in paragraph one. The extra mark in paragraph two was for connections with the cell, so similarly, to Collette, she treated paragraphs one and two as one process. She gave an extra mark in paragraph four because of the linking of energy, in the form of Adenosine Triphosphate, with the other processes in the cell.

Wendy and Michelle gave the Student Answer 7 marks out of 10. Wendy gave 1½ to paragraph one, 1 mark to paragraph two and mentioned that they were linked. She allocated 2 marks to each of paragraphs three and four and ½ mark for the relationship stated between the two, for a total of 7 marks. Michelle gave 1 mark for paragraph one process, 2 marks each for the paragraph two and three process descriptions and 1½ for paragraph four. She allocated ½ mark for a relationship stated in paragraph 3, giving a total of 7 marks. Although Wendy and Michelle gave the same total, their distribution of marks through the Student Answer was different. Howard gave two ticks to paragraphs one and two, and a tick each to paragraph three and four and gave a total of 6-7.

The findings about teachers' rationale and allocation of marks can be summarised as follows:

- Different teachers awarded different marks for each of the four paragraphs. No marks distributions were the same, although some of the total marks were the same.
- Most teachers identified paragraphs one and two, that is DNA replication and mitosis as too similar to be treated as entirely separate processes and so there were mostly reduced marks for describing these as two processes. In their marking, two teachers (Anthea and Collette) treated them as one process.
- Most teachers attributed a numbered mark for each paragraph, although some showed only ticks.

Michelle's response to the Student Answer was similar to Collette's, that the DNA replication and mitosis paragraphs in the Student Answer should have been put together as one process. However, Michelle eventually marked these processes as if they were different. She, like Collette, thought that photosynthesis was the most important process in the plant cell, but did not privilege it with extra marks. Likewise, Howard considered carefully the separation of DNA replication and mitosis into two processes by the student in the sample answer, "I would have expected them to talk a bit about DNA, talk about mitosis together". Anthea also noted that paragraphs one and two were related. Eventually, like Michelle, Howard marked them as if they were two distinct processes. Michelle and Howard chose to not penalise students for describing these processes as two processes out of the four required by the question.

Collette considered her allocation of marks in the Student Answer and provided a rationale. She said, "I keep seeing it as a Year 12 student summative question". She continued:

> The student does not know the relationships. She has kind of alluded to them and is probably half way there. I am probably being a bit harsh on her, but I do not think that she has really talked about them [relationships] and I would probably change the question to describe four key processes. What is really the importance of what needs to happen for the cell to function and go from there. I am probably being a bit hard on her and probably if it was the beginning of year 12, I would not mark it as hard, but because it is the end of the year we have just being doing all these sorts of things.

Collette considered the body of work, the time in the school year (the end of the final year) and the standard of her students in conferring the mark. Considering her interpretation that the question would be a Year 12 summative question, Collette awarded marks reflecting an expectation that a detailed understanding of biology should be demonstrated in this answer, in fact the culmination of 12 years of schooling in biology. The interesting point is that Collette judged this question to be a summative Year 12 question, a judgment not made by any of the other teachers. Implied in this point was an understanding of different assessment methodologies and judgments for different purposes. Collette also differed in another aspect, saying at the start of the interview on the common Test Question that:

> what I would be expecting a student to do would be to have three processes that are essential for all students to know and they are photosynthesis, respiration and movement of substances. They would need to have those three in their answer and then after that there are a number of other processes they can choose from.

Collette had expectations that students select at least the three critical cellular processes to describe in their answer. Other teachers had not prioritised these processes in their answers. By the conclusion of the interview, Collette appeared to have relaxed that requirement.

Anthea recognised relationships as important in allocating an extra mark in paragraph four in the use of energy in in the answer to link the processes in the cell. Philip and Howard prioritised relationships and benefits ahead of processes in their marking keys.

Howard discussed allocating marks for students to achieve a rating according to: “the actual problems faced and a biological reason for each. So, five problems and five reasons.” This simple summary illustrates a pragmatic solution in making numerical judgments. The teachers’ preferences and judgments are eventually revealed through their rationale, marking key and allocation of marks, but the judgment is also a solution to a pragmatic problem related to the purpose or use of assessment, in this case to attribute a numerical score for accountability and comparison. Collette commented on the use of tests for comparability in her statement “I think that the students need to know how they are going within their cohort.” In the end a mark is both a measure of understanding (Howard, Collette, Wendy, Anthea, Michelle, Philip) *and* a comparative score between students (Collette). Reference by the teachers to the curriculum and TEE or other in-common examination implied a standard of answers comparable to those expected in an examination when marking the Student Answer. Table 5.2 shows a summary of the teachers' marking keys, marks and rationales for ease of comparison.

From Table 5.2, the marking keys in Assertion 2 and rationales described in this chapter, it is evident that there were differences in aspects of the teachers' responses to the common Test Question and Student Answer. These differences include:

- the structure of the marking key,
- the allocation of marks within their marking keys constructed in response to the Test Question,
- the selection of the cellular processes that should be awarded marks,
- the differential in emphases and therefore marks, between the cellular processes, the relationships between cellular processes and the benefits to the cell,
- the amount of marks awarded to each paragraph of the Student Answer,
- the final mark for the Student Answer, and
- their rationales, contexts and pragmatism in undertaking the marking process.

5.3.3 Howard's Way – a case study of Howard in making judgments

There have been indications in the discussion so far, that marking keys are a first step in assessing a question or students' work. Marks are a quantitative measure of these teachers' interpretations and judgments of student achievement of success in answering the question.

Howard made comments about assessment, which may be reflected or inferred in other teachers' sentiments. In this section, Howard has been selected from the other interviewed teachers to focus on a range of issues in assessment on which he commented in an expansive way. Excerpts have been taken from Howard's interview to provide evidence regarding these issues.

Table 5.2 Summary of the teachers' marking keys, marks and rationales for the Test Question and Student Answer.

Teacher	**Mark**				**Other**	**Total**	**Marking Key**	**Rationale**
	Par 1	**Par 2**	**Par 3**	**Par 4**				
Collette	½ for both paragraphs		1	1	1&2 related	3	Lists five processes with flow diagram after each, included benefits to cell. Ph + R 5 marks, Mo 3 marks, DNA / PS 2 marks.	Different processes than expected, concerns re Mi and DNA being one, so marked as three not four processes. Looked for content at TEE standard, so expected reactants, products, reactions, expertise. Context of high-rated school, admitted hard marker.
Anthea	1	2	2	3	1&2 related	8	No marking key.	Expected definitions, appropriate descriptions or explanations, marked for content and open to similar correct answers.
Wendy	1	1	2	2	2 x ½ cell benefit	7	Lists five groups worth 2 marks each. Overarching cellular connections, then 4 processes Mo, R, Ph, En.	Expected a series or natural progression of four processes, but different processes found. Flexible. Marked content points and chemical, energy links. Followed Key for marks distribution.
Michelle	1	2	2	1½	1&2 related ½ cell benefit	7	Combination points and flow chart processes, equations. Four processes Ph, R, PS, O x 2 marks each, 2 marks for relationships.	Discussed different emphasis and processes, concern with two processes being one. Pragmatic – answer detailed enough, gave marks to content points in all four processes, then links. Used Key in mark distribution.
Howard						6-7	Briefly lists four processes: 1 mark each, three relationships: 2 marks each.	Discussion and Key used as prompt for thinking. Saw likeness in Mi and DNA but marked as two. Looked for content points.
Philip						6-7	Concept map. 4 marks for processes, 6 marks for links.	Emphasis on coherent ideas flow describing relationships in cells and expected some detail of processes to arise as a result.

Ph: photosynthesis, R: respiration, Mo: movement, PS: Protein Synthesis, O: Osmosis, En: enzymes, Mi: mitosis.

Problems with marking keys and marking

During his interview, Howard critiqued the past and current emphasis on marking keys and marks in order to assess student answers and their understanding of biology. Howard gave an example of using a marking key and the thinking involved, for a sample, self-selected question. In a:

> pre-conceived marking key I might say allocate five marks, but in my head I am going to give them an extra mark because I think that they have done other things in there [the answer] that are good. But someone else will come along and say *no! I can only see 5 marks there*. *Even that one* [part of the answer], and I think I know what they are saying, *they have not made clear enough so I am not going to give them the mark for that,*

Howard reflected on awarding marks. In this next statement, he referred to the common Student Answer (Table 3.3):

> I think the problem with giving it marks is that you are rating, you are looking for the answers that are on that answer key, you are not looking at how much they understand. And I think that this person [the student who wrote the Student Answer] understands a lot more than what is in that test question. I think you are stifling a bit of that creativity and also that ability to show understanding.

When asked about pre-determined answer keys, Howard replied that he had always thought there were problems with them. Howard raised issues of following (or not) a marking key and even then having teachers disagree on the interpretation of the number of marks appropriate to a student answer. The critical comment, above, by Howard highlighted his view that creativity, alternative answers and complexity are lost in looking for answers on a marking key.

Flexibility and negotiation

With regard to teacher flexibility when using a marking key, Howard said: "I hope the majority, having done TEE marking, are pretty flexible because you get a range [of answers]." Howard further commented on flexibility in TEE marking with the pre-determined TEE key:

> Because you have got the two markers what I think is happening, and you will often find that the one marker will be a bit more lenient than the other marker, is that you meet in the middle. So in a sense it is fairer. You have a negotiated mark.

Howard commented on the many years he was a TEE marker for human biology, but in the last year, he was pleased that he had not been marking biology because it had "gone on to computer". Howard made some strong comments, including expectations of marking using pre-conceived marking keys and that in important cases of assessment such as the TEE, the marking key is agreed and marks are reconciled and negotiated by having a two marker system. Even though he flagged a dis-satisfaction with the current system of marking keys and marks he thought the introduction of the computer implied an even more inflexible approach.

In the spirit of the TEE two-marker system and negotiation process if differences occurred, Howard spoke about negotiation and co-marking with his students. Howard had a dialogue with his students about their marks and allowed them to be a co-marker and negotiate their marks. He said:

> I always tell them when I am going through the test, that they are the co-marker and if there is an answer that they believe is correct, they need to come and we talk about it afterwards. Or I re-mark so they are the second marker. I tell them I cannot be perfect and they are to see me once they have looked at it and ask me to re-mark. Then I will go back and look at it and have a dialogue with the student about their answer.

Howard indicated that he wanted the students to understand the marking process and have a say in the marks they were awarded. He gave an example, however, of inappropriate student negotiation for extra marks.

> The physics kids were arguing over half a mark which out of, I don't know what it was, it was not 200, but it ended up making a difference of something like 0.3 to their mark. When they realised that, they went *oh*, and *yes we are making such a fuss about it*. They needed to be clearer right from the word go. I think it is important getting that message to them to be clear and check everything during the exam.

Howard reminded them that the TEE was the final arbiter and they cannot negotiate in that situation. He said "the students are very naive on that score [they cannot argue for marks for their final TEE assessment]. I tell them they can argue with me in class about the mark because I am making them the second marker. The two-marker system is the process that happens in the TEE".

Howard seemed to have a number of understandings relating to purposes for assessment and student engagement in the assessment process. Knowledge about assessment, consultation and negotiation were seen as worthwhile student learning outcomes. It would be difficult, however, to expect the students to understand the processes involved in the TEE of making judgments on a whole set of samples, comparing papers as the marker proceeds, a dynamic decision-making process that draws on experience, knowledge and an iterative approach.

Dynamic judgments

A significant issue is the consideration of marking as iterative and dynamic, changing as more experiences are gathered in a particular examination or in assessment activities over years. Discussion of Howard's assessment ideas revealed some critical observations that he made about the marking process. He said, "when I start reading the answers, that [my marking] starts changing and then I have to go back and re-mark some of the papers from the beginning of the set". He added:

> there can be this dynamic process, especially in essays or extended answers. I read the question from a teacher's perspective and the thinking is *Well that is what I want them to answer* and I will construct my marking key. Then when I start reading the student answers, I am thinking *which angle are they coming from?* I go back to reading the questions and it of a sudden comes to me and I think *Oh of course, they are coming from that angle* and that is a perfectly natural place to come from.

Howard reflected on his practice and commented about judgments being revised after reading a few answers. This practice also has implications for the marking key, which would then need to be altered in line with the actions just outlined. Re-reading earlier scripts and revising judgments could be common practice amongst teachers. Howard ventured comments about the dynamic nature of the marking and by implication, the judgment processes. He also commented on the possibility that the teachers and students had different perspectives in thinking about and addressing a question and thus the teacher needed flexibility in these cases. Howard's views corresponded with the definition of dynamic decision-making in its degree of complexity, occurrence in real-time and use of experience to control a particular complex system.

The jigsaw puzzle

Howard discussed inferences made during the assessment process, for example, reading between the lines and putting together a complete picture in marking student answers.

> Often you can actually tell what they are wanting to say and I think that in some ways it does push you to accept a bit more, or give them another mark. You work out that they know what they are talking about because you relate it to some piece in the jigsaw. So you bring the jigsaw together as you are reading, especially if you are fresh and in the morning when marking.

Howard commented “to be open-minded and to realise that there is more than one way to answer some questions, that kids will come in at different places to answer a question. And sometimes you have to rearrange their answers in your own mind to see that they have answered.”

The idea that the student answers are like a jigsaw puzzle appears an apt analogy for the assessment process. This analogy clarifies the problem of an examination or test situation inducing incomplete, raw and/or hurried excerpts of knowledge, to which the teacher has to apply their experience, synthesis skills, discretion and flexibility to work out in their own mind what the student is trying to communicate. Based on their interpretation of this puzzle or ‘jigsaw’ the teachers assess and make a judgment, typically of a numerical or quantitative nature.

Lost opportunities

Howard commented about lost opportunities or types of student answers that could lose time or marks. He commented on unnecessary paragraphs where the students were filling space, answers that were correct but not related to the question, for example: “all their ideas were correct but at no stage had they related it specifically to those two graphs”, not reading the question properly, “not planning, and then repeating”, jumbling ideas, “jumping points” and “also no clear thinking and ordered thinking, and they will lose marks with that too”. He said, however, “Bad grammar, spelling does not really worry me that much”. In terms of maximising their opportunities, Howard thought that careless application of efforts and non-strategic thinking could affect their achievement of high marks.

An interesting comment Howard made whilst talking about students’ lost opportunities was the statement, “you are reading something really fast and you get to the end of the sentence and you think *Oh what was that?*” This provided a window into the teacher’s context in marking, that of needing to read quickly and sometimes read over again if the answer was not expressed clearly. “You go back and you think what are they trying to say. That sometimes happens but it really throws you because you read these things very quickly." This could be seen as part of a dynamic process the teachers use in marking.

There are several important ideas here. One idea is re-reading because a flow has been interrupted, the concentration of the marker is tested by extraneous material, the "jigsaw" has morphed or a piece of the jigsaw is taking shape. Another idea is that the teacher can fit the student's answers from a test into a jigsaw of understanding and that this cannot be done piecemeal and without significant concentration and awareness of that jigsaw task being undertaken. Also amongst Howard's comments is the understanding that, as well as the student hurrying to perform at their best in a test, thinking and writing in limited, set time, the teacher also has pressures of time in which they assess students' work and this is demonstrated by the reference Howard makes to reading, as well as thinking, interpreting and assessing, "really fast". The teacher usually has large numbers of tests and limited time in which to undertake the judgments of assessments, which are characteristics of dynamic-decision making (Brehmer, 1992; Edwards, 1962; Gonzales et al., 2003). Both teachers and students face the limiting factor in their assessments of time to undertake a complex set of mental processes and communicate them accurately and comprehensively on paper.

Using levels as an alternative to marking keys

After Howard had analysed his ideas on assessing he suggested the use of a way of determining levels of complexity on a progression of understanding (levels) rather than using a pre-determined marking key checking for points.

> That is why I like levelling because with levelling you are not looking for predetermined answers but for understanding of concepts and the answers. You still want the answers and you still want the students to see their progress, but that is inherent in the free flow of showing understanding rather than the stricture of having to show marks. In a marking key, all marks are going to be allocated for particular ideas. I think that this answer, the last paragraph [of the Student Answer, Table 3.3], you can see that they really want to show that they understand and they do, but you cannot give them marks for it, because it is not necessarily in the answer key.

Howard had a strong perception that marking keys and marks do not help measure understanding, and that teachers pre-conceived answers and looking for marks stifles the recognition and determination of understanding, particularly of a whole concept. Howard thought that teachers should be looking for complexity within an answer rather than lots of detail or points. The processes of marking impacts on the marker, the students being marked and the students’ preparation for tests over lifetime of learning.

Howard mentioned the ability of the question to “also take them to a higher level rather than just describing, it is actually looking at relationships so it is more open-ended in that”. Other teachers have talked about shifts in student thinking. This is an idea that will be explored further in Chapter 7 as part of Assertion 6.

5.4 Concluding Comments

In this chapter, two assertions describing analyses on the theme *Making judgments of student achievement*, have been explored and provided evidence and understanding related to the aim of the study. Assertions 1 and 2 provided analyses and represented two areas of commonality well supported by all of these teachers, so addressing Research Question 6. The discussion about these two assertions has highlighted the commonalities and differences between the teachers. Assertions 1 and 2 also address Research Questions 2 and 3 as shown in Table 5.1.

The teachers in the study demonstrated that they had insights into interpretations of questions and responses and into student thinking when assessing answers. They had clarity and the ability to perceive different levels and complexities of explanations of biological content that they expected from their students.

In Assertion 1, *These teachers’ assessment judgments are dependent on their expectations of and interpretations of the students’ biological explanations to questions*, the teachers viewed questions as providing guidance on direction, complexity and boundaries to students in planning and constructing an answer. Clues such as keywords, concepts and content contained in questions could either be explicit, alluded to or inferred. Questions in biology often relied on an understanding of different contexts or applications of the concepts. The depth and diversity involved in understanding questions and their complexities interacted with the teachers’ interpretational frameworks. In the discussion of the questions and student answers the teachers demonstrated how various aspects of the assessment process contributed to and interacted with their interpretational frameworks. These aspects included understandings of students and their development and thinking in the biology domain, and the teachers’ knowledge of assessment and pedagogies and strategies for reading and answering questions. Into this complex mix, the teachers demonstrated understanding of the contexts, details and appropriate practices of all of these intersecting frameworks for each question and answer.

These teachers expressed similar and some different priorities, expectations and interpretations leading to the ideas and concepts necessary to form judgments. Analysis of these comments has provided responses to Research Question 2. Wendy saw answers developed through a series of thought processes as very important and she highlighted logical follow on in answers. After initially focussing on connections in the Test Question, Wendy, Howard and Philip looked at details of processes and how they were related. Collette and Michelle commented on the details of the processes and then thought afterward about the relationships. Collette talked through an expected answer and in a think aloud process determined a mark appropriate to her context. Michelle suggested students may finish their answer with a mind map, drawing visual representations into the discussion. Philip drew a mind map to explain his thinking and this served as his marking key. Howard' marking key was the briefest of those produced by the teachers. This could have correspond with his aversion to strict adherence to pre-prepared making keys. The teachers each had some different, idiosyncratic ways of approaching and analysing questions, which were evident at the time and with the teachers' choice of ideas discussed within the interview. It is proposed that these varied ways of approaching, prioritising and thinking about the Student Answer affected teachers' expectations and judgments and each forms a part in the individual teachers' interpretational frameworks.

The teachers were generally flexible in accommodating a variety of suitable student interpretations. They searched for clues and evidence to make inferences about student understanding, exhibited expectations from particular questions and of answers. Collette demonstrated an expectation of a standard that was comparable with her usual cohort of students and this standard differed from the other teachers. These teachers could often predict student answers from their past experiences, as commented on by Philip and Howard. All of the teachers expected a clear representation of the biological concepts asked for in the question. These teachers applied an understanding of molecular processes and structures to cellular and organism processes and relationships similar to those proposed by Shulman (1986) who utilised a BSCS model of biology in describing multiple levels of content. Shulman suggested an experienced biology teacher would be aware of these and other organisational models of biology and choose which to use in each different situation. This would constitute a pedagogical approach to subject use as well as knowledge understanding, a description that fitted the teachers in this study.

Although Collette had the qualities in common with the other teachers as described in the paragraphs above, her case provided a point of difference related to Assertion 1. This is not a discrepant case, as it supports the assertion. The difference was in the degree of expectation she had in reading and judging the Student Answer. Her final assessment judgment differed from other teachers, as it did depend on her expectations and interpretations (Assertion 1) of the Student Answer.

Just as Collette's assessment judgments supported Assertion 1, it also supported Assertion 2: *These teachers award marks using a dynamic process consistent with their rationale and guided by a marking key*. From the evidence presented regarding Assertion 2, these teachers had their own perspectives on answers, but also considered student perspectives as well. In answer to the Research Question 3 *In what ways are different teachers consistent in their judgments of student achievement in biology?* the teachers' allocation of marks was not necessarily consistent with their own marking keys (Figures 5.1 – 5.6) but was consistent with their rationales (Table 5.2). Both the marking keys and their explanations show how teachers conceptualise their answers. Wendy and Howard constructed a written answer key, Michelle and Collette showed a flow diagram and Philip drew a mind map. Significantly, Howard and Philip whose answer keys were most diverse from each other in structure, had the same final mark and emphasis in their answers on connections and benefits to the cell. There were differences in the amount and type of qualifying information teachers gave in their marking key. There were also different degrees of flexibility and prescription in forming judgments, including deviation from their marking key after the teachers reviewed student scripts or on reflection. The marking key was not seen by the teachers to be exhaustive but as a flexible tool for their reflection and as a guide for their marking. The marking keys presented by teachers in this study provided an indication of the thinking of each teacher, along with their description of their expected answer. The teachers' final judgments were based on their explanations and rationales as summarised in Table 5.2 and represented by their comments throughout Chapter 5.

Noteworthy in teachers' judgments of the Student Answer, was that teacher scores against each paragraph of the Students Answer showed differences even when the final scores were the same as other teachers (Table 5.2). No teacher in the research group gave the same breakdown of marks for each paragraph of the Student Answer. The final marks from these teachers showed considerable variation from 3/10 to 8/10. Therefore there was variation in marking keys, allocation of marks and final totals to the common Test Question and Student Answer. In answering Research Question 6 *What are the commonalities and differences among the interpretational frameworks used by teachers in assessing senior school biology?* this analysis suggests there is significant variation within the marking process and final marks awarded. In this aspect of teachers' interpretational frameworks, it is proposed from this research that there are differences as well as commonalities in biology teachers' marking and decision-making.

Real-time reflections, reasoning and marking processes were characteristic of the discussion. Teachers' starting point in developing their rationales in assessment was the question, what it required and the marks indicated on the question, explicitly mentioned by Howard, Michelle and Anthea. All of the teachers constructed and flexibly used an external or internalised marking key. Comments by teachers indicated that they developed an internal standard where they considered the body and recency of work covered in biology and the detail of the coverage, the time in the school year, the purpose for the assessment (for a class test or system-wide examination) and their standard of students. Howard, Collette and Michelle stated that they looked for assessable points and complexity of ideas. Howard's descriptions of marking and Collette's marking aloud process demonstrated that teachers were intensely focused, responded to written and inferred answers, and dynamic and iterative in their assessment processes. Howard saw assessment as a jigsaw process in understanding the achievement of the whole student, and all of the teachers were experienced decision-makers as well as being pragmatic, and flexible. Collette and Howard spoke of being amenable to reasonable negotiation. These teachers understood in their assessment of student achievement that tests and examinations took place within a limiting factor of time in which students were expected to undertake a complex set of mental processes and communicate them well on paper.

With regard to Assertion 1 there emerged a strong connection between the teachers' expectations and interpretations, the targeted biological content, strategies for understanding the question and explanations (Section 5.2). A major part of this connection could be seen as Pedagogical Content Knowledge in the assessment context. With regard to Assertion 2, the aspects of dynamic decision making in awarding marks consisting of an iterative process, complexity and experience in the biology domain, and reasoned explanations of rationale are shown to be at the heart of assessment activities undertaken by these teachers (see Section 5.3). Marking is demonstrated also as a pragmatic solution for the purpose of assessment in attribution of a numerical score. Marks have been shown in this section to be a quantitative measure of these teachers' interpretations of student achievement in answering the question and both a measure of understanding and a comparative score between students.

Teachers raised examples and discussion points that demonstrated application of a PCK approach in the context of biology assessment. The teachers demonstrated a range of interlinked and complex decisions on assessment. These were based on models, detailed understanding of and appropriate biology content and understanding of their own and students' strategies in constructing comprehensive, appropriate answers. The teachers understood how and to what degree the students accomplished comprehensive answers or if they fell short, whether they had really understood the concepts or not, or had not attended to different interpretations of questions, clues to understanding or hidden messages, good explanations and targeted details. It is proposed from the discussion that PCK of assessment forms a significant aspect within the participating teachers' interpretational frameworks. The connected system that has emerged so far in Assertions 1 and 2 contributes to the biology teachers' interpretational framework in the assessment context. The next chapter, Chapter 6, *Teachers' strategies for assessment* discusses the evidence for two assertions, Assertion 3 *These biology teachers design the most appropriate assessment strategies for their purposes and to meet internalised or external frameworks* and Assertion 4 *These biology teachers recognise the importance of feedback about assessments to student learning.*

Chapter 6

Teachers' Strategies for Assessment

6.1 Introduction

Assertions 3 and 4 viewed together as *Teachers' strategies for assessment,* emerged from the data collected. These assertions attend to practical aspects of assessment and add to the knowledge and formulation of biology teachers' interpretational frameworks in the assessment context. The data and evidence to support these proposed assertions are presented in this chapter. Analysis and understanding are built for Research Questions 4 and 6 as shown in Table 6.1.

Table 6.1 Research Questions in results and discussion for Chapter 6.

Research Questions	Assertions	Chapter
4. What strategies do teachers use in assessing senior school biology?	3. These biology teachers design the most appropriate assessment strategies for their purposes and to meet internalised or external frameworks. 4. These biology teachers recognise the importance of feedback about assessments to student learning.	**Chapter 6** **Teachers' strategies for assessment**
6. What are the commonalities and differences among the interpretational frameworks used by teachers in assessing senior school biology?	Data compared from Assertions 3 and 4.	**Chapters 5, 6 and 7**

The teachers needed careful balancing in their development of assessment strategies and constructs. They considered external frameworks (Figure 1.1) such as student developmental frameworks, general education frameworks, assessment frameworks and biology education frameworks. They also took account of the biology curriculum that was being taught, learnt and assessed as well as the shape, design and timing of external examinations and the conditions in which they were held. The study examined the teachers' internalised interpretational frameworks in understanding and organising biological, educational and strategic ideas in relation to assessment. The discussion of Assertion 3 provides evidence related to their balancing of external and internal frameworks and discusses six experienced biology teachers' implementation of successful strategies and constructs in an assessment context. Section 6.2.1 describes the selection and purposes of examination questions, Section 6.2.2 discusses the interpretation of examination questions, Section 6.2.3 reflects on the qualities of a good examination question, Section 6.2.4 considers external factors in designing the best assessment strategies, and Section 6.2.5 discusses strategies for answering questions.

Except where tests or examinations were in the form of a final system-wide examination where students' scripts cannot be accessed, the teachers generally took every opportunity to use tests, questions and examinations to improve student learning and prepare the students for future tests. In this study, the teachers were asked about their ideas relating to particular test questions and tests. The priority of the study was not a formative assessment but feedback to the students was considered in a post-test environment. Notwithstanding, a number of the teachers interviewed made extensive comments about the feedback dialogue that they had with their students. Assertion 4 illuminates insights that these teachers had regarding the dialogue that they had with their students about questions and tests and highlight surprising counterpoints and outcomes of feedback discussions. Section 6.3.1 discusses benefits of feedback, Section 6.3.2 highlights strategies and issues in feedback, and Section 6.3.3 discusses directions for teachers provided by feedback.

In Section 6.4, a summary of the teachers' explanations related to Assertion 3 and 4 conclude the chapter. These two assertions on *Teachers' strategies for assessment* provided substance and substantiation to the interpretational frameworks that biology teachers hold in the context of assessment.

6.2 Assertion 3: *These biology teachers design the most appropriate assessment strategies for their purposes and to meet internalised or external frameworks.*

This assertion was supported by all of the teachers − Howard, Collette, Michelle, Wendy, Anthea and Philip − who were interviewed. The teachers discussed their design of the best possible tests, the purposes of tests and their preparation of students for tests. They contemplated interpretations and idiosyncrasies of questions and question types and commented on a range of considerations such as examination conditions, targeting the content required and strategies in answering questions and the impacts of these on students. Within these discussions, each of the teachers applied external frameworks such as those described in Figure 1.1 particularly the state constructed curriculum and examinations as well as their own internalised interpretational frameworks.

6.2.1 Selection and purposes of examination questions

Observations and insights about the selection and purposes of questions were provided by teachers Howard, Michelle, Collette and Anthea. Philip and Wendy did not select a question to discuss, but both discussed the common Test Question (Table 3.3).

Each of the four teachers made comments about external motivations for asking particular questions. For example, when Howard was questioned about why he asked the polar bear question (Question 39c, found in Table 3.4), he replied, “It covers about five of the objectives in Module 2 [in the current biology curriculum] in some way. I also like it because it contextualises the situation on content I am asking about”. Similarly, Anthea responded about why she asked a particular examination question with the comment that it was “a big part of the syllabus.” Michelle said of the sample cell question, “it linked in our course, it linked a number of chapters, a lot of the questions that they would be asked would be very specific to a chapter or there might be a slight link to another chapter.” Pragmatism in content coverage is evident in those remarks and in these three cases was focused on external requirements of the state curriculum or a sense of covering the required course content.

Howard’s comments also signalled a function of a question in providing an opportunity to test student ideas through application in other contexts. The question Howard was referring to,

> *A polar bear is a large thickly furred mammal, which inhabits arctic environments in Canada, Alaska and Russia. Polar bears used to be kept in Perth Zoo, but a few years ago the zoo decided not to replace the polar bears after they died. Describe the problems that an arctic mammal like the polar bear would experience in a warm climate like Perth’s and explain the biological reasons for those problems.* (39c, also found in Table 3.4),

was about applying knowledge of adaptations into a new context. The difference in locality described in the question was the context change and the question required the application of knowledge about adaptations in two different environments. Using application questions was one way of identifying if students know or understand the subject. Howard described the way the question was constructed for the content and application of student thinking that he was expecting. His choice implied a particular educational practice – application – as described in Bloom's Taxonomy (Bloom, 1956), which suited his purpose. Mislevy (1996, p. 390) discussed experiencing situations with enough familiarity to be meaningful but with "unanticipated patterns or consequences". In application questions, students were expected to make the connections between familiar and unanticipated contexts, and undertake operations in the new context, thereby applying their knowledge and showing their understanding in the domain of biology.

In discussing her chosen question,

> *Describe the structure and importance of enzymes to the body. Include in your answer an explanation of the factors which affect enzyme activity (10 marks),* (36a, also found in Table 3.4),

Anthea commented that her essay question was testing "an important concept for them [the students] to understand" as well as "it can be transferred to a whole lot of other concepts" and that enzymes was a factor that impacted on many other process in the cell. She noted that the topic of enzymes was a critical concept in biology because of actions within cells and the effects on other cell processes. Anthea had prioritised the importance of this concept, a critical concept and one relating many aspects of biology, in her selection of concepts to test.

Michelle's reason for the question she chose for her test,

> *In aerobic respiration, the product of the first stage moves to the mitochondrion. Outline subsequent events in the total breakdown of this product. (5 marks),* (11b vi, also found in Table 3.4*)*

was because "We had just finished the section on respiration and I wanted to give them [the students] a question from the papers [examinations] and so they could see and answer it after doing the material." Michelle used the question in this instance to assess the students' understanding of an area recently learned. At the same time the question provided practice in answering examination questions of the type and standard that could be expected in end of year system-wide examinations.

In commenting on the common Test Question,

> *38. (Written Question) 10 marks*
> *Describe a series of four (4) processes that occur in a plant cell and how they are related to enable the cell to work efficiently. (Marks will be*

allocated for the relationships between the processes and how they benefit the cell, not just for the names of the processes) (Table 3.3),

Collette stated, “If I thought my purpose in using that question would be to give me the detail and information that I would want, I think that question could do that quite happily.” Collette used particular questions to give her detailed understandings of student learning in a targeted area and she was aware of that goal when choosing the question. It would not be an accidental or random choice of question.

Howard discussed styling a question to the modes of thinking, application of knowledge and content knowledge that he wanted information about, as well as covering the curriculum. Anthea, Michelle, and Collette focused on their choice of a question that would provide them with the understanding of concepts that the students had recently learnt and the detail of their understanding, including the understanding of critical concepts in the curriculum. Michelle also used the question to give her students practice in answering at a standard expected in a system-wide examination. All of these teachers were purposeful or had a variety of purposeful intentions when selecting or designing a question. These intentions within the context of question selection reflected Shulman’s (1986) discussion of PCK, including recognition of circumstances in which to use particular frameworks of knowledge, particular subject matter and central rather than peripheral ideas in a domain.

Michelle said of the common Test Question, “I thought it a bit off-putting having a small bracket afterwards - *marks will be allocated for the relationships*.” Further, “I thought it actually put me off. No, I did not think that it was necessary”. Michelle gave a critique of the question’s layout and believed the brackets in the question, that contained a further part requiring relationships and benefits of processes to be discussed, may have caused confusion or have been ignored by students. This was a critique that highlighted that the structure of a question may not be the most optimal for achieving its purpose.

It was evident that teachers Howard, Collette, Michelle and Anthea had multiple purposes in asking a particular question, in selecting questions carefully for a purpose and in providing themselves with the maximum information and level of detail about students and student thinking and understanding.

6.2.2 Interpretation of examination questions

The teachers commented that there were differences in the interpretation of a question between the teachers and students. Mislevy (1996) referred to a chain of inference in assessment being associated with conjecture and uncertainty. The United Kingdom Assessment of Performance Unit review of Science at Age 13 stated that “pupils frequently misinterpret questions which require them to operate a process other than recall” (Department of Education and Science, 1989, p. 98). Problems arose when different interpretations or the possibility of different interpretations were not acknowledged or recognised by the teachers. If questions were too open to interpretation, they risked being unsuitable, and therefore were not the most appropriate assessment strategy. Collette commented about liking interpretation questions but that she probably made them “too hard”.

Teachers’ recognition of interpretations

Howard, when asked in relation to his polar bear question, (39c, above and in Table 3.4), if the students could have interpreted the question, in another way than expected, he responded that the students answers were, “more towards maintaining constant temperature and availability of the various methods to control this”. However his expected answer consisted of physical adaptations such as, “surface area to volume ratio”, “insulation”, “adaptations to the cold”. His comments highlighted that interpretations of questions were different between different people and that some answers, although correct in a sense, were not sufficient.

When he read the common Test Question, *38.* (Table 3.3) Howard commented about his interpretation and then his revision of his interpretation once he read the Student Answer.

> Well I looked back at the Test Question and when I looked at my answer key, I had designed my answer key very much for the part of the question that was in brackets [relationships and benefits] but then when I have gone back to the main question it says *describe a series of four processes that occur in a plant cell*. So the kids will read that and then just start describing the four processes.

Howard reflected on his reading of the Test Question, highlighting the tendency of the students to rush in and write an answer without considering the extra information in the brackets, *Marks will be allocated for the relationships between the processes and how they benefit the cell, not just for the names of the processes*. Howard implied that the content in the brackets in the question was ignored. A critique on the inclusion of brackets was also made by Michelle and supported the concerns of Howard, who inferred a problem with question reading and interpretation. Wendy commented about "misreading the question" being a problem. Michelle commented about the tendency for students to superficially read the question and gave an example of the common Test Question - "they may have seen *describe four processes* and just ploughed into it."

Alternatively, Wendy responded about the common Test Question by saying:

> Yes, I did like the question that you gave me. The question was simple but specific. It said plant cell, four processes, wanted relationships and how they benefited the cell. So the question was actually fairly explicit in what was said. So it was a very good question I thought.

Aspects of the question mentioned by teachers that they considered important included clarity and stating explicitly and specifically what was required in an answer, such as identifying processes, location, functions that could relate to other processes, interactions and benefits. Teachers differed in their views of how well the question could be interpreted, with Wendy commenting on its clarity and Howard and Michelle indicating it was confusing.

Anthea referred to a word in her chosen test question that presented difficulties for students to interpret:

> *A cell biologist obtained the following images when examining a cell with an electron microscope. (This is followed by two micrograph images, image A with arrow pointing to the grana of a chloroplast and image B pointing to the internal structure of a mitochondrion.) Describe and explain the effect of a slow increase in temperature on the metabolism of these cells"* (36d also found in Table 3.4)

"Metabolism was not explained. They just went for the words temperature and cell and they did not worry too much about what metabolism really means." Anthea highlighted a problem in her question that a single word, which may not have been understood well or in that context, could result in overlooking the word and as a result, not providing the best answer. Wendy said, "being able to read what a question wants is part of the whole strategy." This insightful comment reflected ideas of interpretation, reading for meaning, strategy and understanding in context when reading a question.

The examples discussing questions 38 (Test Question on cells), 39c (polar bear question) and 36d (metabolism) above suggest that questions have a degree of interpretation involved. The coding and decoding activities of interviewers and participants (Foddy, 1993) is relevant to this discussion. Recognition by the teacher of the degree of interpretation and possible decoding variations and the teachers' strategies to reduce this variation indicated that they were choosing appropriate assessment strategies. Very pertinent to this recognition was the resulting flexibility of the teachers' assessment responses to students' answers once the question had been answered. In Assertions 1 and 2, the teachers illustrated that they were dynamic in their judgments of student work and made allowances for many factors, including legitimate interpretations of the question answered. Wendy's comment in the paragraph above attributed some responsibility to the students for reading the question correctly. She revealed that reading a question for its meaning and identifying what that question wanted was important and she referred to a "whole strategy" in relation to understanding questions which included appropriate interpretation, identifying the focus concept, relating the content in context and devising an appropriate answer.

Clues in examination questions

Howard, Wendy, Michelle, Anthea and Collette commented about clues in questions. In designing the best assessment strategies, the teachers selected or designed questions that directly stated or alluded to the concept they wanted explained by using defining words or concepts. The researcher identified the defining words as clues.

Howard identified the helpful clues in his selected question on the polar bears (39c above and in Table 3.4), "thickly furred, arctic environments, Perth environment", which he thought should have led to the concept of adaptations. Anthea discussed the difficulty of students analysing and understanding the word *metabolism*, which was the major indicator or clue leading to a correct answer. Michelle described the word *aerobic* in her question (11b *vi* above in Section 6.2.1 and in Table 3.4), which should have given the students a clue about the content and direction for their answer. Michelle described how the students could translate the concept of "aerobic". She said - "there was the Krebs Cycle. The fact they knew that glucose moved in through mitochondria [during the aerobic process] would tell them it was the Krebs Cycle and entailed a total breakdown of the product". These comments by teachers suggested they thought that consideration of particular words should lead the students to the main concept or process expected in a question. *Adaptation* was the concept inferred in the first example, *metabolism* in the second example and *Krebs Cycle* inferred in the third. These concepts defined the direction and content of the answer.

Michelle continued her speculation about main concepts or clues using the common Test Question (Table 3.3) as an example:

> *Describe a plant cell*. That is why I wanted to keep to processes in the plant cell as opposed to looking at mitosis. I was a bit wary because mitosis moves the process onto the next cell and I wanted to contain it within the one cell. Also the fact that written in brackets were marks allocated for the relationships. So that's where marks were given - for the relationships, but the main thrust was on describing the four processes.

Michelle's reflections were an indication of her flexibility in thinking about the question. As the question had stated *plant cell* she reflected on general processes that occur in all cells and the need to confine discussions to the context outlined in the question. For example in her statements, Michelle wanted "to keep to processes in the plant cell" and "to contain it within one cell". She had identified mitosis as a process that would have resulted in the production of two cells. Michelle commented on the marks allocated to the question and her view that the main focus of the marks was on describing the four processes rather than the relationships. In this case, the clue referred to was not a content clue but an indication of the value of the question.

Later Michelle summarised her thinking about the clues in the common Test Question (Table 3.3) and her thinking on applying the clues to develop an answer:

> I would look at the marking scheme first of all, to see how much detail is required, then the word *describe*. I would tell them [the students] that describe would involve writing something. Then I look at *four processes* - that they would have to have four processes. No point writing down three. Then look at the word plant cell, and then the word related. So when I was planning the answer I started looking at the four processes first of all then making sure that they were connected to a plant cell.

Michelle described a series of clues, including the number of marks given for the question "so that was one thing that I was looking at, when they see ten marks, they know how much detail to give." Michelle thought that her students would understand what complexity was required depending on the marks allocated for a question. She gave an example "respiration [pointing to the paragraph on respiration in the common

Student Answer, Table 3.3] producing the amount of molecules of ATP from one glucose molecule. When there was only ten marks given for the whole question I thought that was too much detail in the respiration answer." Michelle thought the student who wrote the sample answer should have negotiated the aspects of competing time, complexity and length of answer better when she calculated how few marks were allocated to the respiration process in the question.

Anthea also used the allocated mark as a clue, encouraging her students to look for marks "and in their heads, break it down into a mark allocation". Anthea gave a description of how they [the students] would do that - "so if this is worth 10 marks, they [the students] would know that they need at least 10 important points probably five for the first bit and five for the second bit, or something like that."

Anthea commented twice about the importance of the students looking for key words in a question and focussing their answer accordingly. She said - "So looking at key words, I get them to underline all the key words, but particularly the descriptive words or the words that are used to ask them really what they have to do." In illustration she added, "there was that key word … *slow increase* in temperature and a lot of them did not really take much notice of the *slow* and so they went straight into an increase in temperature. Therefore the enzymes are just going to be denatured or will be inactivated." She said that if they had taken notice of the word *slow* their answer would have included the process leading to denaturing and been a better answer.

Collette, Michelle, Howard and Anthea each spoke about looking in questions for key words or clues that may have represented concepts or a direction. The message from the teachers was that clues to understanding needed to be clear to students and able to be interpreted to get the best outcomes. Several of the interviewed teachers raised the issue of the need for students to read a question carefully, looking for less obvious clues as well as obvious ones. Obvious clues cited were key words and number of marks. A less obvious clue mentioned by teachers was in translating the message contained in the question to identify the main concept required for the answer. The quality of a question to provide an unambiguous message to students about what answer is required was considered important in conducting a fair assessment process. In undertaking assessments of complex and subject-specific knowledge, clues in questions to concepts and levels of detail needed to be analysed in order for a complex understanding to emerge and be demonstrated.

6.2.3 Reflections on the qualities of a good question

The previous discussion leads to the analysis of what is a good question. Howard was ambivalent about his chosen question. He thought initially that the question he had chosen on the polar bear, (39c, in Section 6.2.1 and in Table 3.4) was not a good one because "It was looking at the objective from the opposite end. Normally we ask how the bear is adapted to survive in its environment not in another context." After further discussion on how students best demonstrate their learning, Howard decided the question was appropriate because "it asks for students to apply their knowledge". Howard eventually concluded that, "Questions that are more straight-forward and are scaffolded [structured question with increasing steps of difficulty]" may be best. Wendy liked the common Test Question (Table 3.3) as it specified a number of requirements and appeared clear in its meaning.

In choosing good quality questions, Howard, Philip, Michelle and Anthea considered external demands, looking at the requirements of the syllabus, government initiatives and styles of questions found in final examinations. Howard said he tried "to ask questions which are open where possible and close to what they could get in the TEE. In relation to the reason for asking the common Test Question (Table 3.3), Howard said "because it is in the syllabus". Anthea commented about the question that she asked in the class test as "it is also a big part of the syllabus".

In the TEE, there is a mix of multiple choice, short answer and extended answer questions. The five Western Australian teachers were not just preparing their students for learning and understanding of the biology in the syllabus which is set at a system-wide level, but also availing them of a range of question types that students needed to be familiar with to complete the final year examination successfully. The teachers in this study used system-wide final examination style questions and layout in tests in the years leading up to the examination. Bearing in mind the classical test theory paradigm, which emphasised expectations of particular ways in which students would respond to questions, subjects and contexts (Mislevy, 1996) and understanding that in the final year system-wide examinations, students would be compared for selection, the teachers were maximising their students chances in that selection process. They built similar style questions and content to those in the final examinations into their two or three final years of school programs. Broadfoot and Black (2004) found that the reliability of assessment data for students is *disturbingly low* and that system-wide tests *do not satisfy the standards for testing.* The teachers adopted the strategy of training students in the style and predictable content of examinations to help students minimise the misinterpretation of questions, instructions and lay-out of the examinations, therefore reducing some variables that might otherwise result in poor performance.

In analysing other aspects of questions, Howard commented about the Test Question: "But the question is also taking them to a higher level rather than just describing. It is actually looking at relationships, so the question is more open-ended in that style." Howard specified the advantage of an open-ended question was in seeking higher-level thinking and a more relational answer rather than unrelated facts that may be adequate for a closed question.

Philip compared,

> a more structured question to more clearly, open questions which are great because they are interesting and see how creative people can get, but we have also got people who are lateral thinkers. So you have that level of difficulty with an open-ended question, but maybe quite often we structure extended answered questions so we can tease more out of a student than we might otherwise get. They are not a bad idea. There is a place for those questions. And I think there's a place for Multiple Choice questions, because Multiple Choice can be very interesting.

He also commented, "Multiple choice is good to discuss. They learn a lot from actually doing the test and going over it." Philip discussed the advantages of each question type and his conclusion was that all types were needed, that is, a range of question types within a test. In his discussion, Philip covered the purposes of the question types, level of difficulty and types of students who used different questions to find different opportunities for demonstrating their knowledge. He discussed the range of question types found in the TEE.

Michelle had a different view about multiple-choice items: "I do not particularly like multiple choice" because "I feel a student could be just part looking and answer the right one. It does not really test them." Further Michelle said - "I do not mind long or short questions, I like to test the students on long and short as I know that on the examination paper they will have both… questions like I ask in class, they are snappy short questions”. She also commented:

> If I was giving them a test I would give them 30 short questions, including drawing a diagram. I feel that it gets more from the chapter and tackles all the detail of the chapter. Whereas if I give them one long question, it might only focus on one part of the chapter and they could have just been lucky the previous night, looked over that part and that was it.

Interestingly, Michelle also said “And I do not ever give them the choice”. While Michelle reasoned that students could achieve in multiple choice when they were not concentrating and that these type of questions were not testing enough, Philip felt there was a place for multiple choice questions because they provided interesting and helpful data.

In Michelle’s reasoning about short and long answer questions, she thought that short answers could be “snappy” and obtain more information from students. Michelle approved of long answer questions, but felt that the content of the question was limited and students who had selectively concentrated on studying one area that was the nub of the long answer question, could maximise their own achievement, perhaps undeservedly. Conversely, Howard commented that questions should be as open as possible and that the test structure should be like the TEE. He viewed question style in terms of the purpose of the question, that is, to achieve higher levels of thinking, demonstrating relational understanding, and meeting the requirements of the system, both the current syllabus, outcomes-focus system and style of the TEE final school exam. Wendy commented on questions that required single and longer answers in the context of assessing biology.

> It is very hard with biology, as it is such a wide field, to get them to tell you what you want them to tell you, which shows relationships rather than just recall. I like the questions where the kids have to show that they have understood what is going on rather than giving a one-word answer. So it needs to be a mix in the paper. You need to allow for the recall of the facts as well as the understanding.

The insightful commentary below acknowledged the difficulties of assessing students’ knowledge of the complexities in the domain of biology. Collette’s comments seem to represent a lot of teachers in her summation regarding the types of questions to achieve various purposes.

> Have they understood what these words mean [in any specific question]? I am happy to give them a multiple choice. So if I am talking about basic ideas, like can they do a calculation about births, deaths and immigration, give them a multiple choice and they can work that out. I am quite happy to have those questions because I think they do have a purpose and that purpose is - do you have the basic content of this course? I also like seeing kids given interpretation questions and that is probably a fault of mine. I put too much emphasis on interpretation and make them too hard. Because I think if they can interpret and apply to a different situation then they do actually understand what you have taught them. I think short answers have their place and I think also extended answers because if you really want to see where your top top kids perform, it's in an extended piece of work - where they have got to make links between their knowledge and show it. In short answer questions you certainly get a glimpse of it and you can certainly use it to get kids to train themselves to read better, to interpret better, to see how someone can ask them to apply their knowledge somewhere else. But it is this sort of question [extended] that will show you, if you really want to see what they know. If you are actually after that, then it will be an extended answer [question].

When asked which question would allow students to show most depth Collette answered - "That will come in an extended answer."

> You get the depth, breadth, variation, the lateral expansion as well as the vertical expansion of what is happened… if I look at where my top students perform in extended answer. They will get the multiple choice right because they know all of that, so do the other kids - they can do that for short answers, your good kids will do better than the others because they are better in interpretation and application, but where they really come into their own is the extended answer.

Anthea made perceptive comments about the style of test questions and her students' interactions with them, illustrated in this extended quote.

> I would think the short answer questions are the best, because they break down a concept into smaller bits. Generally you start off with easy recall, *what is this? what is this relating to?* and then you can work into it more in-depth, more analytical type questions. I think that a series of short answer questions really gives them the opportunity to show what they know by actually writing it down.
>
> Whereas with multiple choice questions, even though you proof read them and you think about it really carefully, quite often there is an answer they really believe is right, and as you have not read the question the same way as they have, it confuses them. The other thing is that you could get a kid who cannot be bothered and they will just guess and could possibly get them all right, so it's not really showing what they know.
>
> The extended answers I think are very good for the brighter students and the students who can write, have the terminology and enjoy writing but I

> do not think that they are beneficial for the students who really struggle with expressing themselves on paper. It is just not the way that a lot of people do, especially these days because they are so reliant on computers and other sort of electronics. They are not practicing their writing as much as perhaps 10 or 20 years ago.

Anthea described her preferred type of question when the student was a “big picture thinker”. She said:

> I think that big picture thinking is long answer, definitely, so they can really, really show what they know although some of them will tend to waffle on a bit as they want you to see that they know things that are not truly related to the question. But I think a long answer question is certainly an advantage for those students but not for other students who do need it broken down a little bit more for them. But clearly they are not the A students so you have to have something that is going sort them out. Certainly those extended answers do.

Anthea’s mention of ‘A students’ referred to A-grade or top level students. She critiqued the different question types usually found on biology test papers and provided a rationale for styles that would best support the expressions of understandings of different students. She also raised the critical aspect of tests and examinations, to sort students, a major goal of assessment.

6.2.4 External factors in designing the best assessment strategies

Curriculum factors

Curriculum set externally to the teacher and school was a critical factor in the purpose of the assessment and the writing and selection of questions for tests and examinations. A good question ensured fit between the curriculum and the focus of the question and guided the judgment of an answer.

Howard spoke of the educational and assessment basis of the curriculum that was current: “If the students can show the relationships and the benefits, well that is going higher up into levels”. This referred to a State government initiative, Student Outcomes Statements (Education Department of Western Australia, 1998), where students received higher ratings when they achieved higher levels. This initiative was later replaced by other curriculum directions. Howard, who also spoke about levels in Section 5.2.2 and Section 5.3.3, used the levels to write or select particular questions and assess students' answers in order to stimulate the students to undertake higher order thinking and more complex and relational answers.

Collette discussed Student Outcome Statements (Education Department of Western Australia, 1998): "I have played a bit with the levels and given kids work back which was marked using level statements". Collette had used levels to make judgments and explained them to her students but was not convinced they had helped the students understand the concepts. Collette used the levels as a goal and added, "I use the levelling statement out of the scales of achievement. This is what we try and aim for". She discussed that the student responses to the levels were "*so what does that actually mean in terms of my answer?* indicating the students were having problems interpreting the scales of achievement". Further, "They [Student Outcome Statements] are not meant for the kids but I was using them as a guide" for them to be progressing towards. Collette also said:

> Some of the students said *it is ok* but we need a much clearer response from me to say what it is, *what bits of knowledge do I need to know, specifically? What specific facts have I actually left out of this piece of work* that has not given its full answer*?*

Philip also commented about the Student Outcome Statements (Education Department of Western Australia, 1998).

> I am not sure whether it would be much help, because you already have the underlying understandings of the students' thought processes. You already know without reading that description here [Level 8 Life and Living description] what they can and cannot understand. I know what they are capable of doing. They are at a stage where they could move beyond this.

Neither Collette nor Philip saw much merit in the Student Outcome Statements (Education Department of Western Australia, 1998) and, although they could apply the Statements, these two teachers thought they already had more detailed information about their students and knew the way forward for their learning. Comments by Howard, Collette and Philip discussed the use of the Student Outcome Statements in assessment and disagreed on their value. The teachers' comments regarding the Student Outcome Statements demonstrated the impact of a system-wide curriculum document on their assessment practices.

Examination factors

Howard, Philip, Wendy and Collette discussed external examination factors such as distractions, time availability and students being mentally alert as possible factors in poor performance in answering questions. Comments were made about reducing distractions in tests and examinations and the possibility of the traditional test conditions being modified. Howard asked "whether the kids can do tests easily in a test situation and whether there are noises and various distractions that might take them away from what they are doing" regarding external considerations in test situations. Howard reported his own experiences with distractions from other students, including when students left examinations early. He commented that, unlike students in his student days, "Quiet is their distraction I think", in commenting about current students, observing that the conditions of tests perhaps were not suitable to students now, "kids of today can actually do work while listening to their music". Howard advised students about "things like rest, do not take any drugs, do not take too much coffee, stay mentally alert so that you can actually get the information down on the piece of paper in a coherent fashion".

Philip commented: "You generally try to make accommodation so they have plenty of time to do the test" and his solution is, "Sometimes I have split these tests and, from past experience, seen they are a bit long and done the written part on a separate day [from the multiple choice]". Collette also identified time as an issue and said: "I have a bit of leeway, timing is an issue, so they can give me all of their information, not governed by a time span". Wendy remarked that students sometimes "run out of time, they are confused, they are trying to get as much down as possible and sometimes there is no continuity." She also mentioned "Repeating stem of the question; I hate that sort of thing." She further commented, "they would have been better off spending time thinking about the question rather than rewriting the question. Thinking about what they wanted instead of doing that". Philip also identified the time spent on the learning, "You might also take into account just how much exposure they have had to the whole area".

Collette described some examples of allowances that needed to be made in testing regimes, such as, "time off school for illness", "not being there to sit the assessment", "not there for the lead-up" or "kids with learning disabilities". She would take account of student situations, including after completion of marking, "if we feel there is a legitimate reason as to why they have not achieved". Collette described in more detail the example of one of her students with a learning disability, severe dyslexia, for whom she made allowances in tests:

> There is a bit of give and take there, where we give her a little bit to keep encouraging her, but we have to show her the reality of an examination situation where she needs to sit down and mark her paper, so she has to have practice in this for the school to do well for her.

Collette explained in this comment that the school (in the person of Collette), in order to help the student reach her potential in external examinations, prepared the student for more difficult situations where she could not expect help: "At the same time you have to explain to them that allowances are not going to happen in a final examination".

These four teachers − Howard, Philip, Wendy and Collette − have demonstrated that they attend to a range of examination factors that may impact on assessments in order to make the assessments as fair and equitable as possible.

Timing of tests

Collette spoke about the timing of tests in this excerpt from her interview:

> I would expect, if the test were held straight after the teaching, some of the students would do very well. Some students would need more time, because for some, understanding the functioning comes a bit later in the year, for example, and so they are still practicing this type of work. Some of them tend to tie it together later on, so they may not have understood it the first time. As you keep coming back to them and saying: *Right, it is in the semester one exam so you need to go and learn the things you did not understand, now do you understand them? Let's go through your understandings*, they get more practice at it and the brain for some of them locks it in. It doesn't happen straight up.

Collette reinforced the differences between students with her statement, "the top scale kids, they have understood it straight up, because that is where their brain is working when you have them in the room. But for most of the kids the sort of cohort that you get doing biology, it takes them a year to actually get to that point where they can do the answers". Collette identified individual differences and capabilities, that would affect the timing of the test and have the capacity to disadvantage either group.

Philip said:

> You might also take into account just how much exposure they [students] have had to the whole area and you might mark it harder if they have had more time to digest the material they have been given. Like, in a few weeks, they can absorb all this information and then suddenly given a question, they might not have time to mentally process all this stuff.

In this statement, Philip suggested that exposure to an area and adequate time for students to absorb and process ideas is likely to have a beneficial effect on student performance in a test.

Howard commented about the timing of the test well after a period of work has been completed, and that the students "might do better because they have actually improved, have gone back, thought about it and all the ideas are starting to jell better." Howard believed the timing of the test depended on the context. He thought it would be better immediately after a section of work was completed if an unrelated topic is about to commence. However if the new topic was helping build the ideas of the previous topic, then the test would be better held sometime later.

Students would respond differently to the timing of the test. The teachers' ideas on this varied. They understood that as students get more information and practice they could process the information better. They also said, however, that some students do well immediately after the learning. The research by Siegler and Araya (2005) suggested recency is important in the use of relevant strategies in learning. Therefore it was more likely that the most advanced active cognitive strategies would be used in examinations and this may be a factor in timing of and students producing better results in examinations.

6.2.5 Strategies for answering questions and examinations

In discussions related to designing the best assessment strategies, teachers included strategies for educated participation of students within the assessment process. Michelle, Anthea and Howard prepared students in the technical aspects of answering questions. They detailed a number of strategies and tips for successful completion of examinations and tests. Michelle discussed the preparation she gave her students before tests:

> I always ask them to leave room at the end of a question, that if they go on and do another question and they think of something, they can come back. Just small little things like that. When they are drawing diagrams, they need to be large diagrams in pencil and clear labelling, so that the person who is marking can read them. *Never use correcting fluid*.

Michelle also gave students other tips:

> How to draw a graph, organise their diagrams, bullet point their answers, leave a line in-between each bullet in case they think of something and can come back and fill it in. Not to spend too much time on one particular question and allow a certain amount of time for each question. If they for example, have to answer four big long questions, allow 20 minutes for each of those and not to run over time on a question.
>
> Another thing also when I am preparing my students, I asked them to sit down and read the paper for 10 minutes and just spend time reading the questions because often they might miss a little tag-on part.

Michelle provided a description on assessment that may have been regular classroom practice for many teachers in an environment where examinations had considerable weight:

> I believe in regular assessment. Every single day they are questioned in class. They always get homework, which I always take it up, correct it and I date and my comments. I believe in having positive comments and so it is very important to encourage students. I give them regular tests when we finish sections and I give them questions, reasonable questions, questions I know that they will be able to answer. Not vague questions, they are very precise, they know exactly what is being asked for. I also like to give them a major test once a month and base the material on what they would have covered. So they would not have a whole pile of information to learn before the big examination, but continuously revise.

Anthea gave her students advice and practice in preparing for answering examination questions. She described the help she gave students when she was asked about her selected examination question (36a, in Section 6.2.1 and Table 3.4).

> It really was so straight-forward. When I teach the kids how to answer questions I tell them to underline the key words. We go through what *describe*, *explain* and all those sorts of words actually mean. I also ask the students to try and in their heads break it down into a mark allocation.

She elaborated on the students' difficulties in reading some words from the question in that they "misinterpret *describe* and *explain*". When asked to confirm whether this was the mechanics of answering a question, Anthea said, "Absolutely. So looking at key words, I get them to underline all the key words, but particularly the descriptive words or the words that are used to ask them really what they have to do". She described the school test context discussed in the interview and the problem of students not reading the key words carefully and missing out on the intent of a simple word such as *slow* increase in temperature.

Anthea added more information on advice she gave to students about reading and answering test questions. She said - "encourage them to use diagrams where ever possible, because I think that a lot of students struggle with getting the words on paper. They struggle to write it in a really good comprehensive way". She advised the students to "draw the pictures and as you are drawing them the labelling might come to you and then a really well-labelled and well-structured diagram will get you marks as well."

Howard commented about the Test Question (Table 3.3),

> when I show the kids how to approach a question I try to make it so that they realise that it is not an essay. They have to give the points, look very carefully at what they are being asked to do and make sure that those points are shown clearly for the marker.

This was a different strategy, involving identifying specific ideas within the concept or process required by the question, along with some planning of how the students will present these in written form.

Michelle, Anthea and Howard described frustration regarding their students' carelessness in reading the question and hurrying to an answer that did not reflect properly what was being asked. Each of these three teachers mentioned strategies that they had used with their students in preparing them for accurate reading, noting and interpreting test questions. Anthea said - "when we went through the exam we made a point of going through and looking at those descriptive words, that make it a very specific". Howard commented that he wanted his students to "look very carefully at what they have been asked to do", and "read the question very well."

When students answered a question all of the teachers expected logical, evidence-based, well-explained answers and the use of examples and diagrams when appropriate. Wendy and Michelle provided good examples to support this statement. Wendy stated that she would like students to "Use evidence and good examples. It is very important to use examples, and I believe that is the way to get your marks. You give an explanation, you give an example. Good order and continuity." She also gave an example of the work of one of her students, that it had:

> lack of a clear overall picture. I am marking biology, I am not marking English. It had an incomplete answer, not enough different points well explained and not concise. I have another student in chemistry who wanted to write me five pages on an essay that was supposed to take 20 minutes.

Wendy identified the need for the students to be concise in answers, make points, not fill space, give a complete answer and provide a clear overview.

In response to the researcher's question about the common Student Answer (Table 3.3), "So what was the thinking expected in the Student Answer, what complexity of thinking in biology would you expect them to show in their writing?", Michelle replied:

> Usually a logical approach, bullet points, more steps and I would have expected probably, as well, a balanced chemical equation for respiration and photosynthesis to be included. And to have arrows coming out from that to show how they where connected, to show the relationship. I felt that the relationship was not shown that clearly in the answer.

In addition to responding to the question with expected biological concepts, Michelle referred to expected general technical aspects in answering the question, such as the provision of balanced equations and arrows demonstrating relationships. In understanding PCK, Shulman (1986) described teachers' communication of subject knowledge to students, the use of explanations along with appropriate purposeful instructional conditions as integral.

Michelle, Wendy and Howard emphasised the importance of clearly explained yet concise answers. The inclusion of labelled diagrams and equations and the construction of a number of well-illustrated points were stated as considerations that, if appropriately used, would be advantageous in an answer. These teachers recognised that it was useful for students to be exposed to successful strategies in approaching and completing assessments in order to maximise their outcomes. These activities could be considered within the bounds of PCK.

6.3 Assertion 4 *These biology teachers recognise the importance of feedback about assessments to student learning.*

Questions related to feedback on assessment were not asked in the interview but Philip, Howard and Collette chose to discuss it and their interview responses supported

Assertion 4. Anthea, Michelle and Wendy did not raise the issue of feedback in their interviews. The context of the interviews for this study was the discussion of test questions and examinations in a summative context (Pellegrino et al., 2001) rather than a formative one. Even so, the three teachers said they used the assessment information to aim for improvement in student outcomes, not just as an audit tool (Wiggins, 1998). Feedback was a critical part of the investment of students and teachers within the assessment process (Hattie, 2009). Feedback was useful for students and teachers. Test discussion could be a reliable way to get feedback from students for teacher understanding of students' capabilities. The teachers recognised the importance of feedback about assessments for a number of purposes, including for student learning.

6.3.1 Benefits of feedback

Philip, Howard and Collette teachers reviewed tests and examinations with students, the benefits of which included gathering more information about students, sharing information with students, teachers adjusting their methods and content and a focus on students' continued learning.

Philip commented about the learning achieved by reviewing tests: "When you go over the test, the students might appreciate the question a lot better, having done it and gone over the answer." He said, "You would expect them to get a lot better at it, than if they did not". Philip made a pertinent observation about tests:

> The students learn a lot from actually doing the test and going over it. It is all part of the learning really. Testing has a very important role in gathering all the information you have to on the kids, but it is also very important for their learning to go over the test.

Philip succinctly summarised two learning outcomes from discussion of the completed test. The first was what the student was learning, which may be more biology concepts, structuring the biology for best communication of responses and understanding the expectations contained within questions. The second outcome was what the teacher was learning, in understanding the students better through their answers and argumentation. The context where students had a stake in understanding the result of a considerable personal effort in preparing for a test and writing responses was used as an opportunity for more effective teaching. Pellegrino (2012) highlighted that practice and repeated exposure to content are not enough for acquisition of knowledge and skills but students also needed understanding of results. Pellegrino argued that “Individuals acquire knowledge much more rapidly and appropriately if they receive feedback about the correctness of what they have done” (p. 71). Philip’s observations and instincts about his students’ preparedness for learning after tests and in discussion of tests were in accord with Pellegrino’s idea.

Philip made an interesting comment about the level of teacher knowledge needed in going through answers: “You need to be very confident about the answer yourself if you are going to engage in a discussion with the students”. Sadler (1998) emphasised that highly competent teachers held superior knowledge about the domain content and what was to be learnt and that the idea of *teacher-as-assessor* (p. 81) assumed that the teacher had a mastery of the domain area.

Collette’s ideas were similar to Philip’s in regard to the significance of feedback. She stated that “Feedback to a student is important” and commented about factors in relation to feedback:

> It is how you give it to them. Frequency is very important, it should be very soon after they have had the assessment. If you delay it too long, the kids have in some way forgotten what they have done

She reinforced this with the statement “but it is recency of what they have done in the assessment”. If the feedback and its preparation are timely, then teachers have more chance of understanding the individual students, as was evident in Collette’s statement: “You have to say, this is what you have done with it, you have a better chance of revisiting that and going: *Right I think I know what she is talking about*”. Siegler and Araya (2005) discussed recency in the formation of new strategy construction related to learning in conditions of still active, relevant strategies. Collette raised several points about feedback. She considered feedback to be important, that recency was critical and also that feedback from the students helped the teacher to understand them and their answers.

Collette also commented about comparative feedback, where students understood their answers in relation to the class’s responses: “I think that they need to know how they are going with their cohort. For them it is important. *Am I floundering in this subject, along with everyone else, or am I actually doing OK*?”

Collette concluded with:

> I think there is a need for some sort of picture for the student: *where do I fit in this cohort of students*? Give the students some idea of where that is and that it is an important piece of information. I think the students need some indication whether they have achieved very well or not and a comparison of results provides the sort of the levels they are expected to achieve. What is the ideal?

In these excerpts from her interview, Collette expressed the need for students to have a realistic understanding of their achievement within certain cohorts. The assumption is that the answers are not absolute but are relative with regard to complexity and can be compared along a continuum. This is one of the ways that Collette has suggested for students to identify their grasp of domain knowledge and plan for improvement.

6.3.2 Strategies and issues in feedback

Collette referred to mechanisms of feedback, tailoring feedback to meet individual needs and outcomes of feedback. In considering the mechanisms Collette used to provide feedback, she spoke about outlining the answer for students so they knew the requirement of an expected answer, "these are the specific things that you have to do." Collette discussed the mechanisms of the initial feedback: "I give them a mark, give back the assessment and the answer key I have used to mark it with. Sometimes I'll underline key bits that they have missed out on, and highlight bits". Howard said, "when marking, I will probably write a comment: *ok next time be more specific about this*".

Philip said it was "important to go through the written questions particularly. You do not have time to go over all the multiple choice questions." In regard to reviewing the multiple choice questions he said, "Sometimes you might go over the key ones you think are really good questions and just give them [the students] the answer for a lot of the other ones". Philip understood the importance of going through content in test questions and acknowledged that there was a difficulty with time, such as the relatively long period of time needed for feedback on multiple choice questions:

> This test [a test from which the Test Question had been selected] had a lot of longer multiple choice questions with long preambles, which involves a lot of reading and thinking and sometimes in class you do not have time to go over every one of those multiple choice questions.

Philip said that he thought there was more value-adding in selecting questions for improving students' understanding through discussion of mainly short and long-answer questions and selected multiple choice questions.

In thinking about the range of responses by different students and the need for addressing individual problems, Collette referred to feedback in the light of the reality of the school, time and the variable needs of students:

> I think one of the better ways of giving feedback is to try to find a time where you sit down with them. It does not necessarily happen in class, but you say *come and see me at lunchtime and I will go through the question with you*.

Collette reiterated the importance of targeted individual feedback: "the best thing is individual discussion with the student". She commented "that takes time and you cannot always do that". Collette worked with the students individually as well as in a class group to discuss their answer and help them understand what a better response would be: "go through what was wrong with your response". She commented that it took time and that time is a limiting factor.

Collette discussed some outcomes of feedback: "You can offer them the chance also to see whether they can do it." Further she said, "I would have a similar question to go here, *do this and see how you go*." Collette thought that students may like to re-do questions or do similar ones to give themselves confidence for answering a comparable question they may encounter in the future. Howard also commented on individual interactions regarding tests: "I will have a dialogue about that answer" and "if there is an answer there that they believe is correct that they need to come and we talk about it afterwards".

One of the benefits of feedback that Howard identified was the opportunity for a student to act as a co-marker for their own questions - "I always tell them when I am going through that they are the co-marker". Howard said, "I might have to re-look at it and negotiate another mark." Howard had a number of outcomes, including that the student reasons, demonstrates their understanding and recognises that the answer needs to be able to stand up to scrutiny by other markers. "What are the reasons that they give, because they could not do that if you were an external examiner in the TEE. But they must have something in their mind." Howard advised students of the differences in opportunity in the school context and the external examination context: “So you cannot go to an answer and say *oh yes but I meant*, it makes no difference, so you try and really instil that idea into them. Because at school they can always argue”. There is motivation for the student in carrying out this reflection or metacognitive activity. Howard considered that it opened a dialogue, enabling the student to develop a marker’s perspective in order to respond better in exams and allowing them to negotiate for marks at the school level.

Howard raised ideas about dialogue and co-marking with the student after the test. There was also the implication that Howard went over the test afterward with the class, but he had not said this. As Howard did not mention it specifically, the researcher asked if feedback was important and Howard said “Oh yes” and when asked if it helped the students to write a better answer, Howard responded with, “Oh yes it does” but did not elaborate on that. There was an impression that he had already sufficiently discussed class feedback in his interview.

6.3.3 Directions for teachers from feedback

Philip said, in regards to dialogue with students and use of anticipated results:

> You have a pretty good idea about what kids will get in tests and exams by just talking to them, so have a discussion with them, and that those who know the answers will come out with them and those same students will do well on all the written tests. It is not 100% reliable, because some people are fairly quiet and prefer to have other people answer questions they know the answers to, so it is not really in itself enough. It really needs to be written. Gives the opportunity for everyone to be able to say something.

Sadler (1998) proposed that teachers could assess how their students would perform in tests based on the teachers’ judgment of ability levels and on recent experiences with teaching and student performance on tasks in class. Philip illustrated the view that tests reinforced teachers’ judgments based on class discussions and other indicators of student achievement during teaching and learning.

In discussing feedback, Collette highlighted that one outcome of undertaking feedback sessions with students was providing more information and direction for teachers, as described in this commentary:

> You may use the question as a teacher to not only help the kids renew their understanding but also to see whether they actually understood what was happening in the teaching and learning process. Then you reflect: 23 of my kids bring back an answer I was not expecting, *Hey wait a minute, something is not happening here,* it results in an information sharing between me and the kids. So *Right something has gone wrong in the teaching process*, if there is not one student that I know has the capabilities to master that, then there is an issue. Going over questions gives me feedback on how the kids are performing, it gives the kids feedback on how they are performing and it allows the joint thing to move forward to what is required next. I think going over the question can do those sorts of things.

Collette described various outcomes for the teacher and the students achieved by reviewing questions and answers after a test.

During the interview, Collette changed her voice from commenting to the interviewer as an interview subject to advising the students on improving their answer. This was a subtle difference in tack but demonstrated a seamless, unconscious, shift in roles made by the teacher. She had a number of roles, which she used at different times for different purposes. Sadler (1998) discussed the teacher-as-assessor where the teacher had a good knowledge of their students and the subject in an assessment environment and had extensive evaluative skills, whereas students were mostly responders to assessment. In this interview, Collette had transformed the purpose from discussing a judgment in an assessor/reflector/judge role to what feedback and discussion she would have with a student in an educator/helper/providing feedback role. This demonstrated role transference in the context of assessment and may point towards the different purposes of assessment from formative in an educator/feedback role to summative in an assessor/ judge role. Collette switched roles during the interview.

6.4 Concluding Comments

Teachers provided support and evidence related to a common theme for this chapter, *Teachers' strategies for assessment*. The chapter contributed answers to Research Questions 4 and 6 as shown in Table 6.1.

Assertion 3: *These biology teachers design the best assessment strategies for their purposes and to meet internalised or external frameworks* was constructed in this study to make sense of the teachers' comments about questions and test strategies. There was a strong flavour of an assessment pedagogy framework underpinning the discussions with these six teachers supporting this assertion. PCK was palpable as the teachers discussed test items, test answers, preparation of students for tests both in biological content and in examination interpretation and technique and the provision of appropriate, targeted feedback. The teachers emphasised the appropriateness of question style, for example, open-ended compared with closed. They also commented on the importance of setting different question types related to their purpose, for example multiple choice questions for basic content, calculations, interpretation and application questions, short answer and extended questions for demonstrating knowledge, links, depth, lateral and vertical expansion. The teachers understood the idiosyncrasies in different question types and what was required in answering them. They designed best assessment strategies for their purposes. The teachers were aware of factors affecting student performance in tests and exam conditions and tried to control these factors or at least take them into account. They understood that different students needed different amounts of time to answer questions. Teachers demonstrated their use of external frameworks, for example Bloom's taxonomy, curriculum documents and examination requirements within their interpretational frameworks in assessment contexts. These teachers showed expertise and PCK underpinnings in their biology and assessment knowledge and practices. This discussion provided informative answers to Research Question *4. What strategies do teachers use in assessing senior school biology?*

Within Assertion 3, regarding the use of internalised and external frameworks to design the best assessment strategies, details of many commonalities between teachers have been outlined. This provided support and responses to Research Question 6. *What are the commonalities and differences among the interpretational frameworks used by teachers in assessing senior school biology?* Versatility of thinking, application of concepts and ranking students were favoured by all these teachers. Michelle mentioned the importance of *inspecting* a question – using marks, determining the number of points to make and finding key concepts. Anthea, Michelle and Howard discussed the use of clues, keywords and concepts to direct student thinking and to target content. Michelle, Anthea, Philip, Collette and Howard used allocated marks as a clue to students on the expected length, number of points or complexity of answer and to manage time. Collette and Howard considered that extended questions gave most information about the complex understanding of biology, but that they were difficult for many students. Anthea and Howard particularly mentioned the difficulty for those with low levels of literacy.

Anthea, Wendy and Michelle liked short answer questions the most in eliciting the information they needed. Philip reflected about all question types and how they met different purposes. Multiple-choice questions were described as useful but problematic by Anthea and Michelle. Different question types may have provided longer, shorter or more detailed *snapshots* (Pellegrino et al., 2001). The challenges faced by teachers in producing the best tests and questions for their purposes could be viewed as an awareness and management problem for teachers within their interpretational frameworks.

Similarities and differences between the teachers are discussed. Michelle, Anthea and Collette taught examination strategies to their students so they would be more effective in answering questions. Complete quiet in the examination room to students who are surrounded by noise in their daily lives was noted as a possible hindrance by Howard and individual differences such as disabilities were raised by Collette. Collette and Philip found the Student Outcome Statements (Education Department of Western Australia, 1998) did not add value, while Howard found them useful in promoting complexity in student thinking.

Teachers using these frameworks in deliberating about questions and assessments, at the same time reflected on the answers and judgments expected from the assessments. The design of the assessments and the intentions for judging answers are bound together in the same planning process and both are dependent on the interpretational frameworks held by the teachers.

Considerations relating to Assertion 4: *These biology teachers recognise the importance of feedback about assessments to student learning*, indicated that biology teachers have many commonalities in purposes and opportunities regarding feedback after summative assessment and that these form part of their interpretational frameworks. The major focus of Assertion 4 was the learning that takes place by both the students and the teachers after tests if appropriate discussion and feedback of tests is built into teachers' programs. It could be referred to as summative assessment leading teaching and learning. Teachers planned for learning experiences from feedback as a result of assessment (Hattie, 2009; Pellegrino et al., 2001; Sadler, 1998; Wiggins, 1998). This feedback included the re-teaching or re-visiting of particular concepts or processes, providing practice for the students and reflecting on and amending content and strategies, mentioned by Philip, Michelle, Howard, Collette. Collette commented on students benefitting through a chance to reflect and amend their ideas and strategies. Philip, Howard and Collette acknowledged the place of discussion and student talk about biology as a good predictor of examination success and opportunities in discussing test questions as opportunities for these informative discussions. Students' receptivity to learning when they had completed a test and recency of feedback was cited as being important by Collette. Howard, Collette and Philip commented that assessment gave both the teachers and students feedback on what they had learnt and information helpful in improving that learning. These commonalities and differences contributed to Research Question 6, while the strategic ideas involved in feedback contributed to Research Question 4. The analysis of the teachers' ideas on feedback provided more details in building understanding of the teachers' interpretational frameworks. Their insights regarding the feedback process, such as encouraging students to understand an assessor's perspective and to be self-aware in and prepare for test processes in the biology domain, showed a strong PCK identity as well as a novice/expert dimension.

In Chapter 7, *Frameworks for biology thinking* evidence for two assertions is outlined and discussed: Assertion 5: *These biology teachers have a multi-level, three-dimensional understanding of biology and prefer visual models,* and Assertion 6: *These teachers consider that students differ from each other in their thinking, with most being linear thinkers that progress through shifts in learning.*

Chapter 7

Frameworks for Biology Thinking

7.1 Introduction

Assertions 5 and 6 viewed together as *Frameworks for biology thinking,* emerged from the data collected. The teachers reported on and discussed their own organisation of ideas and possible thinking leading to understandings of the interpretational frameworks they were using in a biology assessment context. These frameworks are directly relevant and contribute to Research Questions 5 and 6. Data and evidence related to Assertions 5 and 6 are presented in this chapter. Table 7.1 shows the relationships between the research questions and the assertions.

Table 7.1 Research Questions in results and discussion for Chapter 7.

Research Questions	Assertions	Chapter
5. What do teachers consider are their own and their students' frameworks for organising biology?	5. These biology teachers have a big picture, three-dimensional understanding of biology and prefer visual models.	Chapter 7 Frameworks for biology thinking
	6. These biology teachers consider that students differ from each other in their thinking, with most being linear thinkers who progress through shifts in learning.	
6. What are the commonalities and differences among the interpretational frameworks used by teachers in assessing senior school biology?	Data compared from Assertions 5 and 6.	Chapters 5, 6 and 7

In Section 7.2, Assertion 5: *These biology teachers have a multi-level, three-dimensional understanding of biology and prefer visual models,* evidence from teachers is presented regarding their understanding of biology, including big picture or three-dimensional biological understanding, particular ways of organising and understanding biological content, relational understanding, how concepts interrelated in dynamic ways in biology and in what ways the teachers liked to share these ideas with their students.

Teachers in the study identified what they considered were students' interpretational frameworks, leading to the development of Assertion 6: *These teachers consider that students differ from each other in their thinking, with most being linear thinkers who progress through shifts in learning.* In the first part of Section 7.3, evidence from teachers about students' frameworks includes ideas such as two- and three-dimensional thinking and that abstract thinkers, for example, quickly internalise ideas, rapidly relating concrete information to their mental picture and grasp processes and ideas easily.

Regarding the second part of Assertion 6, evidence of the ideas relating to students undertaking incremental shifts in learning is presented in Section 7.3.2. The teachers commented that students, when given new information, stepped though processes starting with concrete thinking then moved to interpretation, analysis and evaluation. They looked for shifts in learning, from students describing a process to students having a more holistic connected view. The teachers commented that each process or step needed understanding before the whole process could be understood. In documentation to support Assertion 6, teachers referred to and described their contexts, mostly classroom, biological and assessment contexts.

7.2 Assertion 5: *These biology teachers have a multi-level, three-dimensional understanding of biology and prefer visual models.*

All the teachers provided data to support this Assertion. The teachers reflected during interviews on their own thinking, possible preferences and interpretational and organisational frameworks. One interview question (Interview schedule, Appendix 2) that led them to undertake this sort of reflection and introspection was "What was your thinking when you rated/answered the question [referring to their self-selected question and the Test Question]?" The researcher asked the teachers probing questions to encourage them in their reflections on how they organised biology and thought in the biological context.

7.2.1 Multi-level thinking in biology

Several researchers have commented about levels of organisation in biology (Australian Academy of Science, 1981b; Shulman, 1986). In BSCS (Biological Sciences Curriculum Study, 1993) the levels were represented in a detailed way ranging from molecules, cells, tissue/organ, organ system, individual organism, population, ecosystem/community and ecosystem/biosphere. Tsui and Treagust (2013) described their four main translation levels in biology as macro, micro, sub-micro and symbolic. In discussing how her thinking in biology was organised, Michelle structured her thinking around:

> three main sections, based on the syllabus that we produced. Unit 1 is just biology the study of life (ecosystems). Unit 2 moves into the cell and then unit three moves into the actual characteristics of living things that each of the cells would carry out. So unit two is the cell, metabolism, enzymes. Unit 3 then is the organism, the different process that go on, organisation, nutrition, excretion, response, reproduction. We would have touched on the introduction in biology in unit one, the science of life.

Michelle organised her biology thinking around sections in the Republic of Ireland syllabus (Department of Education and Skills, 2013), in a similar way to Shulman (1986) who used the BSCS syllabus to describe how teachers organised their knowledge. The Irish syllabus was structured as cells, the organism and ecosystems. This enabled analysis and connections between the biochemical basis of life and structure and function at the microscopic level, a macroscopic focus on adaptation, structure and function within individuals and then a large-scale organisation through interrelationships in ecosystems and evolution.

When asked about her preferred way of thinking about biology, Collette explained her view regarding her thinking through a teaching lens. When asked about her mental model she responded with a description of her view of teaching biology:

> Take the big picture. Take the macroscopic aspects and start to show them some of the microscopic aspects of biology. Then you show an even more microscopic view of what is happening at the biochemical level. You have to build that back again, from those biochemical aspects into the whole general animal or plant. These aspects are all happening… from macro to the cell to the biochemistry.

This is an interacting macro- to microscopic to biochemical view of biology and is the common view expressed by Michelle and Collette. Collette expanded:

> But at the same time, you are also talking about how this animal has its own niche and you start to talk about interrelationships. So there are two sorts of things happening at the same time. You are talking about a single organism but then also about the relationships between organisms. So kids have an understanding of niche and a bit of an understanding of communities, and then you start to talk about the shifts, or if you change

> these things in the community what is going to happen to the relationships between the organisms. So I think, it is relating.

Collette compared biology with the view she had of chemistry another science subject she taught: "If I was talking about chemistry, I would talk about atoms and build it up to interactions between atoms. You would talk about the general equations and then about calculations. It is very much a hierarchical structure." Collette identified a similar structure in biology.

> I think in biology there is some hierarchy about what we are doing certainly but we have lots of cross links that have to be made between these two things at the same time. Micro to macro as well as interrelationships, communities and ecosystems, and if I make changes, well that is going to change communities and to change how the organism's biochemistry copes with, for example, a lack of nitrogen or too much nitrogen or something else that may happen. Those sorts of things happen at the same time. So it is complex. When we are talking about a cell we have to deal with all the things that are happening. We help the kids to understand about DNA replication and genes and then we talk about genetics, so there are lots of branches coming into the side. Once you have got down to that level, you start to bring other things in.

The comparison Collette made highlighted that her thinking and organisational framework in biology had a structure and hierarchy similar to that she had for chemistry. She indicated, however, that there were some differences, challenges and complexities, such as interrelationships between several factors in an individual's internal and external environment and the effects of changes in these interrelationships.

Howard's view of biology was "you are moving micro- to macroscopic and at the same time moving relational and transitional". Howard used the word *dynamic*. The descriptions of biology given by Michelle, Howard and Collette included topics as well as the levels in biology. Howard elaborated on the micro to macro view interaction and describing his thinking as including that view and also relational, transitional and dynamic processes congruently in a multi-dimensional way.

Wendy spoke of levels in her comment "Well, you have to look at it at all levels because it is all interrelated". By levels, Wendy was referring to cellular levels to ecosystem levels in biology, implied in her statement, "The whole organism and then the whole organism relates to the community it lives in etc. etc." These views were very similar to those put forward by Michelle, Howard and Collette related to hierarchical levels in biology and the need to address ideas from different levels simultaneously and in a related way. Schonborn and Bogeholz (2013) involved teacher experts in Germany in discussing a hierarchical model of biological knowledge. Erickson (1986) pointed to cause in biology as being multi-directional and therefore causal relations in biology being more complicated than in physics or chemistry. Riess and Mischo (2010) stated that cognitive analysis and cognitive representation are principles of complex systems which also include “non-linearity or the existence of numerous interactions” (p. 706). Wendy, Howard and Michelle spoke about biology on a *grand scale*, Wendy and Collette as *all interrelated*, Michelle as *a spider map* and Howard as *three-dimensional*, as well as *relational, transitional* and *dynamic*. These different statements emphasised that teachers had interpretational frameworks encompassing the multi-level connectedness and constant changes within biology and demonstrating the complexity and difficulties in teaching and learning biology.

7.2.2 A three-dimensional view

Reference has been made in the previous comments to a *grand scale* and *three-dimensional*. When asked about relationships and a three-dimensional picture in her mental model (question in the Interview schedule, Appendix 2) of biology, Wendy said “Yes I suppose I do, because everything is connected, not in a line but on the grand scale of things, yes.” When Howard was asked about his mental model or schema he said “I look at everything in a three-dimensional way, at how everything affects everything else, looking at it from a much higher perspective and you do not see things in two dimensions” Wendy and Howard spoke about biology as being non-linear and three-dimensional. Other studies have referred to the complexity of biology. Tsui and Treagust (2013) referred to a cube model in biology showing a three-dimensional organisation framework and Biological Sciences Curriculum Study (1993), developed different cube-shaped structures (Appendix 1) with each face recording a different aspect to represent different biology frameworks.

Howard gave an example of two connected processes that necessitated a number of different lenses being used at the same time:

> You may have a relationship between these two things, say for example photosynthesis and respiration, but you also look at, with respiration for example, the transport of all the elements that need to come into the cell in order for those two to work, the products of that process, what happens to

> the products, and all those things are going around in your head at the same time.

In this example, Howard has referred to his own thinking, illustrative processes and structural and relational identification of characteristics when explaining biology. He did not consider that the students were able to do these things. “Then you have got to break that down for the kids, because the kids cannot do that.” This was his first comment about the difference between the thinking expected in students compared with their teachers. When asked if equations on respiration, for example, were non-linear, Howard responded, “Oh it is not linear, oh no”. Howard further commented - “It all of a sudden expands and involves the sun, photosynthesis and where it all starts”. When asked about his mental model (Interview schedule, Appendix 2), Howard considered ideas in a three-dimensional way. He looked at relationships and effects, the detail of each element, processes and multiple levels of biology. Equations that are normally seen as two-dimensional or linear, Howard saw in a more holistic, three-dimensional way.

In considering the teachers as having three-dimensional organisational frameworks, evident in their comments when discussing assessment in biology, a PCK focus was also apparent. Shulman (1986, p. 9) described PCK as the “subject knowledge for teaching” and Abell (2008) included “content-based, dynamic, synergistic and transforming other knowledge” (p. 1407) in PCK. These terms are congruent with descriptions of the three-dimensional frameworks related to biology assessment held by the teachers in this study.

Howard considered his students as part of his three dimensional framework. He said that students were inexperienced thinkers and still trying to get the details right, although in comparison

> even in my head when I do the three-dimensional view, I am not looking in huge, fine-eyed detail, I am just looking at the whole, like you know the equation and the bits of the equation, how they all come into being, where it all comes from and how it all fits together. It is a bit like the systems in the body.

It was clear that Howard was illustrating another example of his three-dimensional view and his experience of students led him to think that they were learning parts of knowledge and putting these together in a linear or two-dimensional way. Howard said "Their thinking is very two-dimensional and slowly becoming three-dimensional".

Howard gave an example of an exercise he thought would train the students to develop a three-dimensional view and finished by describing his larger view:

> I am Joe. I am a blood cell in the left foot. Now tell me what happens to me between the left foot and I all of a sudden find myself in the right foot, the journey, what happens? I like to see it in 3-D and what happens to the blood cell because of the nutrition, the oxygen, losing the carbon dioxide and all those sorts of things. So you have to look at the whole thing in 3-D, and try to get kids to see it in 3-D.

Howard was concerned about doing the best for his students and had developed activities or experiences that he provided in order for the students to explore thinking differently, in this case, three-dimensional thinking.

In thinking about his framework for biology, Howard developed a recommendation for developing a similar framework in students:

> I think as a teacher you have to go right back to the structures and the processes and work on those. Then at some stage ask the question like the blood cell to encourage the students to think 3-D because that is very difficult for some kids.

Howard's concern for his students' learning and the comparison with his own way of thinking formed part of his internalised *framework* as a teacher. He used the example of the movement of the blood cell within a mammalian body to highlight him helping his students to think in terms of interrelatedness and change inherent in a three dimensional view of biology. As demonstrated in this example, Howard was motivated to help the students think in a more cohesive, holistic way taking account of the interrelationships between macro- and microscopic and using three-dimensional thinking. Howard demonstrated that his professional concern for his students' learning was deeply held. In his explanations of his thinking and framework, he moved between explaining his thinking, how he thought the students saw the world of biology and what he could do to help them think in different ways. Sadler (1998) referred to teachers bringing particular dispositions of concern and helpfulness towards students, which resonates with Howard's comments.

Notions similar to those mentioned by the teachers, of multi-level, three-dimensional understanding in biology, are found in systems thinking and a brief outline of the related ideas within systems thinking follows. Biology and biological inquiry have been linked with systems thinking approaches (Campbell & Reece, 2003; Townsend, Begon, & Harper, 2008). Riess and Mischo (2010) specifically described the complex systems required for understanding living things, which are parts of populations, ecosystems and the biosphere. In describing systems thinking, Ossimitz (2000) discussed network thinking including feedback loops, dynamic thinking with inclusion of time and thinking models. He referred to "*a bundle of abilities"* (p. 532) such as abilities to identify elements, properties and relationships, recognise cause and effect and time dimensions within systems and abilities to organise systems. A major aspect of systems thinking that also relates well to analyses within the current study is the stated ability within a system thinking approach of constructing an internal model of reality, to attend to multiple and relational aspects within a system. The research by Dorner (1996) regarding people having basic difficulties comprehending complex systems may cast light on the struggle that biology teachers and students are encountering with their teaching and learning of biology every day.

7.2.3 A problem-solving framework

The diversity within organisms and the content of biology need a problem-solving framework in order to be fully understood was raised by the teachers in the study. When asked about her thinking in biology, Wendy replied, "Well it is problem-solving, biology is a problem-solving thing as far I can see." She provided an example:

> You can learn facts. But every time you get a question or an example or even a multiple choice question there is a lot of information. Then you have to put in what you have learnt and how it fits in to that situation because every single organism is so different from every other organism and there are things that will work but there are exceptions and differences all the time so you have got to be prepared to adapt your thinking and adapt what you have learnt to a particular situation. Which is why I like biology a lot.

Wendy identified a property of biology and why it may lead to a different way of thinking. She identified the need to be a problem-solver to understand biology and described the need for problem-solving by exemplifying the uniqueness of and differences in biota, that each case or situation was different and therefore there was a need to “adapt your thinking”. Collette was of the same mind and encouraged her students to identify the problem with which an organism is faced in order to work out their structure or function. For example, in her request for students to ask themselves “Why do I need to take in light energy and go through this process of photosynthesis? So what is the problem? What problem do we have as living things that need to do that?” In developing different ways to understand biology, Schonborn and Bogeholz (2009) described qualitative differences between areas of biology, such as the need for abstraction in genetics and analysis in evolution. Lopez et al. (1997) suggested that different cultures had qualitatively different ways of approaching biology. Biology is built on general principles and so an expectation of problem-solving would be realistic for biologists. The idea of problem-solving as the predominant way of thinking about biology was an interesting one and it could be investigated further in other studies. Wendy also commented that the problem-based approach was the reason for her positive feelings about biology: “I like biology a lot”.

Wendy gave her students

> information they can mull through and get the right answer, not just give them tables with information they have to learn. The kids always say: *you give us more than other teachers do on other subjects,* and it is very different.

In all of her comments related to in this section, Wendy appeared to be providing her students with diverse information and promoting a problem-solving and reflective outlook. She continued and gave a comparison of biology with chemistry: “I teach chemistry as well and in chemistry you learn this, you learn that and you learn something else”. There was a switch in her communication as she moved from self-reflection to a style of communication as if she were talking to the students. With regard to the content of her comments Wendy implied that in chemistry you can learn facts and it was more straightforward. She viewed biology as problem-based and more amenable to an information-rich environment.

7.2.4 Biology teachers think visually

There was no question specifically asking about a visual preference in biology on the Interview schedule (Appendix 2), but it was the focus of probing questions in some cases. The researcher followed up on some teachers’ comments about the visual preferences of students and asked whether the teachers also highlighted visual preferences in their own frameworks and teaching. Treagust and Tsui (2013) and Eilam (2013) associated visual representations with the biology domain and Gilbert et al. (2008) provided evidence of extensive visual representations in the science education area.

When asked whether he thought in words or pictures, Howard said, “More words, and places, visual, not pictures as such but visual”. When describing his way of understanding biology, Howard used terms such as, “I look at everything”, “I suppose you are looking at it from a much higher perspective”, “you do not see things in two dimensions, you see things as…” “you look at…”. These comments indicated a visual preference by Howard.

Collette saw biology in pictures and trained her students:

> I form pictures of what is happening and you are often talking about this to kids. You say: *this is what is happening inside of you, think about this*, and so you create a visual. Most of the time you are using models, even if they are animations off the web, they are models, for the kids and so becomes visual. We do a lot of that vision.

Anthea demonstrated her visual proclivity with these words, “to think, I suppose with pictures, I like diagrams” and “a labelled diagram and then describe or say what the functions are. I like to tabulate things”. With students she encouraged visual processes: “we basically drew a great big cell, we had pipe cleaners and we modelled the whole process”. Anthea’s statement, “I think that doing practical work has been very beneficial” was made in close proximity to her discussion of visual processes, and thus she may have considered practical work as visual. Anthea’s views were largely centred on her visual preferences, such as pictures, labelled diagrams and tables, all connected to functions. The benefits of practical work were included in the same series of reflections. Anthea, in these descriptions, referred to examples of visual representations.

Philip drew a mind-map (Figure 5.6) that he referred to as a flow diagram, as a marking key to the Test Question (Table 3.3). The mind-map succinctly related structure and functions in the cell, which were critical to the processes of the entire organism. Both Michelle and Collette drew flow diagrams as part of their marking keys for the Test Question.

Michelle said that some questions were “more amenable to a diagram”, therefore identifying that visual choices were often made concerning particular aspects of biology assessment. Michelle said, “I would put down a mind map or a spider map first and show the connections and then put the paragraphs underneath.” Her ideas such as connecting ideas with arrows, using equations and using structures could be viewed were visual strategies for thinking or learning as proposed by Eilam (2013).

A visual preference in biology was apparent from teachers’ comments through their interviews, in some cases about themselves and in other cases in giving examples of the visual cues to learning they provide for their students. It was evident that visual preferences are a part of the biology teachers’ interpretational frameworks.

The area of attitudes to biology, commented on by two teachers, Wendy and Anthea, was difficult to categorise. Asked a question by the researcher on what was her mental model, Wendy said:

> For me? I suppose it has got to do with the wonder of biology and that, for example, when you are looking at the cell, how on earth all those chemicals get together and they are actually able to reproduce another cell or how they are able to become a heart cell, a skin cell or something else. The wonder of all that sort of stuff.

Wendy interpreted the question differently to the researcher’s expectation and talked about wondering and questioning. Her interpretational framework included motivation and engagement regarding biology. Similarly, Anthea commented about her feelings toward the subject of biology: “I have enjoyed teaching biology this year”. Although these six teachers did not refer to an emotional connection with the subject specifically, two of the teachers mentioned aspects that indicate a very positive disposition toward biology. In the same way as it was important to capture Howard’s sensitivity and caring attitude to students in relation to his interpretational framework, so enchantment and positive feelings had a place as preferences within each teacher’s biology framework. Within his discussion of PCK, Shulman (1987) viewed attitude and enthusiasm for a domain as important in the communication of understanding. Berry et al. (2008) commented that teachers need to have affection for biology in order to teach it well.

7.3 Assertion 6: *These teachers consider that students differ from each other in their thinking, with most being linear thinkers who progress through shifts in learning.*

The analysis of the interview data indicated Anthea, Philip, Collette, Howard and Wendy supported the assertion. Michelle commented on aspects of the assertion. When asked about their expectations of students' answers, these teachers' views about student frameworks emerged.

7.3.1 Different students have different capabilities and frameworks in biology

When discussing assessment all of the teachers identified the different capabilities of their students in biology and thought that they knew their students sufficiently well to make judgments about their achievement. Howard said:

> You get to know your kids and to know their mental process intuitively. You cannot sit down and describe *this child thinks this way*. It is not that so much, it is just an intuitive thing when you look at their answer [to an examination question].

Michelle trained students in order to minimise differences in her and her students' views on assessment in biology so that different interpretations and other problems were reduced: "I have trained them that way as well, they have gotten into my thinking and they know what I want".

The teachers described ways that the students differed from them and each other in responding to biology questions. All of the teachers apart from Michelle hypothesised about students' understanding and capabilities. Pellegrino et al. (2001) suggested that students' intermediate states of understanding could be identified in a subject domain from theories of cognition and in the context of classroom assessment. In this study, the teachers often used coninua in describing the variation in students' thinking frameworks. This does not deny their understanding of the intermediate nature of their students' achievement in biology. The continua that teachers identified are elaborated using teacher evidence and the titles of these sub-sections are derived from terms the teachers used.

Box or pigeon-hole thinking to big picture thinking

The teachers used ways to describe differences among students. One way that differences were described was in some students' use of a big picture, holistic framework, connecting complex concepts, compared with other who used pigeon-holes or boxes.[1] Anthea illustrated her understanding of these terms in the classroom, stating:

> Students like Ken would have a big picture and he would be able to link it all together. Whereas others would not. They would pigeon-hole different aspects of it and not make those links. It really just does depend on the student, and of course their answers show that I think.

The teacher used her experiences in working with the students and the evidence that she found in assessments to make judgments about the ways she thought students viewed and processed information. Anthea distinguished two quite different frameworks that students may use to process and make sense of ideas and gave an example of what this would look like in a test answer. She said:

> The kids with the bigger picture understand catalysts and they understand what that means. Then they realise that enzymes can catalyse other reactions. So therefore the substrate concentration, all those things are linked together. A student who understands that linked set of ideas on catalysts would be able to explain it in that way. Other students who pigeon-hole it would probably give you three or four facts but completely separate and not use linking words or link it to a diagram.

Anthea provided examples to differentiate two different student frameworks. The first showed complex, connected biological concepts that students with a big picture framework may use in their answer. The second example considered of unconnected facts and lack of representations that did not refer to a biological model, characteristic of students' frameworks demonstrating a pigeon-hole approach.

Two-dimensional or linear thinking to three-dimensional thinking

Comments made by teachers included the ideas of two-dimensional thinking, incorporating linear thinking, and three-dimensional thinking.[2] Howard made a generalisation about his students: "Their thinking is very two-dimensional and slowly becoming 3-D".

[1] *Big picture* is defined as the entire perspective on a situation or issue (Merriam-Webster, 2014) and *pigeon-hole* is defined as one of a series of small compartments (Macquarie University, 2001) or a neat category which fails to reflect actual complexities (Merriam-Webster, 2014).

[2] *Dimension* is a magnitude or scope (Macquarie University, 2001). *Linear* is measurement in one direction (Macquarie University, 2001). *Two-dimensional* is defined as having two dimensions, lacking depth of characterisation (Merriam-Webster, 2014). *Three-dimensional* is defined a having three dimensions, describing well-rounded completeness (Merriam-Webster, 2014).

He compared students' thinking to his own which he considered was three-dimensional. Howard expressed the view that the system of levelling, used in the Western Australian system at that time encouraged more relatedness and therefore more three-dimensional thinking in students. He said:

> This is where the levelling system comes in so well, in that the students know if they want to get more marks or they want to get a higher level they have to start relating, they have to start seeing models and compare and contrast. But they have to see how one thing affects another so basically going into that 3-D thinking as well.

Howard described indicators of three-dimensional thinking in students: identifying the students' use of models, use of comparisons and contrasts in their answers, relating concepts, and explaining processes and effects in biology. Wendy commented that "a uni-dimensional answer would receive less marks because it is not explaining an idea." Wendy thought students' uni-dimensional thinking was a disadvantage in test contexts.

Single-idea, recall to higher-level, complex student thinking

The teachers at various times identified the thinking of their 'top' students using terms such as A-level, complex or higher level thinking.[3] In his statement, "some kids are very high level and they can really get into it, other kids, they sort of have very simplified responses", Howard started to distinguish between students on the basis of their capacity for *high level* compared with *simplified* information and responses. Howard commented that some students could not link ideas together because they were still constructing their individual ideas: "they are still getting all of the small details right". This comment was about students still trying to master facts rather than developing complex understandings. In discussing the student thinking involved in the sample Student Answer (Table 3.3), Wendy stated, "I don't think it shows connections, I think it shows recall. The information is recall". The teachers' expressed views that their students either had single ideas, simplified and recall activities or complex, high level and connected understandings. These views resonated with research related to expert/novice understandings.

[3] *Complex* is defined as composed of interconnected parts (Macquarie University, 2001). *High-level* is defined as occurring, done or placed at a high level (Merriam-Webster, 2014). *Single* is defined as one only, separate or individual (Macquarie University, 2001). *Simple* is defined as having few parts or not complex (Merriam-Webster, 2014).

Bransford et al. (2000) stated that experts *chunked* elements, Sweller (1994) showed that experts remembered configurations as a *single entity* and Sadler (1998) spoke of their greater *integrative activity*. Mislevy (1994) spoke of experts' greater knowledge and connections between concepts and their particular perception and approach to phenomena or problems. The experienced biology teachers in this study demonstrated characteristics of experts and could therefore be considered expert in biology teaching and assessing. It is evident that in the teachers' descriptions of students they considered them as having characteristics of novices with a few students becoming experts. Pellegrino et al. (2001) suggested that providing understanding of intermediary states of student knowledge from novice to competent was helpful. The teachers used continua in their descriptions of student competencies, with the understanding that students were intermediate between these extremes and progressing along a continuum or through discrete stages.

Philip, commenting about Level 8, the highest level in the Student Outcome Statements (Education Department of Western Australia, 1998), said: "We probably now have four or five kids in that group, at least, but this is not uncommon with a good biology class." He recognised that not all students will be at a high level "getting the breadth of the level" but he would have expected some students to achieve at Level 8 in biology. Philip said: "Some students are probably not going to be at this stage. You have got to move onto something different that these kids can cope with". He continued in relation to students working at a higher level, they could "relate a new structure that we have not discussed before with its function". Philip drew out not only differences between students relating to their capability in biology, but that after giving students substantial opportunities to progress in an area, if they did not understand, then the teacher needed to move the class to the next topic.

Student thinking frameworks in the classroom context

When discussing complex ideas that could be presented to students, Philip commented that although the 'top' students could grasp the concepts, he felt reluctant to provide the same material for the rest of the class. Philip used an example of Kreb's Cycle:

> You cannot do that in detail with your very top kids because you have the other students in the class to consider and they are not required to go beyond a brief understanding of Kreb's Cycle. They will be struggling to

> cope with all the material in all the other modules in the other parts of the course.

Philip's comments recognised practicality and the need to consider time restraints and cater for the whole class with a range of activities. He highlighted the need to move onto new materials at an appropriate time rather than provide complexity for better students. He said:

> You immerse them in the area, do experiments and discuss all of these things with them but there comes a point where the weaker students are not really going to understand the concepts and detail to the depth that the brighter kids do, and you have to move on to something else. Every student is not going to be level 8. Some students will end up as level 6 doing biology and they will not progress on from that level so you move onto something else in biology in a different area that they are interested in.

This point reinforced Philip's belief in differences between students and demonstrated a pragmatic approach to teaching and learning in recognising such differences. He thought that some students will not become complex thinkers in biology and will not move beyond a certain level. The evidence he used was in: "the level of understanding the students demonstrate in their answers, that is reflective of their marks." Words he used in describing students were top, brighter, level 8 and level 6 or weaker in relation to learning the complexity of concepts in biology.

Philip raised an interesting point demonstrating complexity in the variation within the population of students: "We also have people who are lateral thinkers and I do not know whether being a lateral thinker necessarily puts you higher up in the levels or at the same level of understanding but more creative". Philip's comments highlighted variation in student thinking including their use of cognitive and creative thinking. Philip's comments on his judgments regarding student competencies were always in relation to biology content.

Student thinking frameworks in the test context

All the teachers made extensive comments about students' thinking during the time they were undertaking tests. The teachers identified particular question types that may have advantaged some students over others depending on their skills and thinking frameworks. In her discussion of question types and their differing impact on students, Collette elaborated on these ideas:

> Extended answers - if you really want to see where your top top kids perform it’s in an extended piece of work, where they have to make links between their knowledge and show it. Short answer - you certainly get a glimpse of their thinking.

Collette differentiated between students by selectively mentioning her “top top” students and said that the longer answer question type allowed them to demonstrate links between aspects of their knowledge. In accord with Collette’s ideas, Anthea identified that:

> The extended answers I think are very good for the brighter students, the students who actually can write, have the terminology and enjoy writing, but I do not think that they are beneficial for the students who really struggle with expressing themselves on paper.

Anthea made a judgment about a question type, extended answer questions, which may have suited some kinds of thinking and processing but did not favour those students who had fewer literacy skills. She stated the relationship between her categories of thinking frameworks in a test context:

> I think that big picture thinking is long answer, definitely, so the students can really, really show what they know, although some of them will tend to waffle on a bit as they want you to see that they know things that are not truly related to the question. But I think that is certainly an advantage for those students but not for other students who do need the question broken down a little bit more for them. But clearly they are not the A students so you have to have something that is going to sort them out. Certainly those extended answers do.

Anthea made comments about her perception of advantage provided by a question type to students who were at a particular level and had a particular thinking framework. She equated big picture thinkers and grade A students. She also commented that students with big picture thinking want to demonstrate to their teacher how much they know, even if it is not completely relevant. Anthea described the sort of question needed for students with pigeon-hole thinking as a scaffolded question so the students could address one idea or a limited number of ideas at a time. Howard commented, “you have got to break that [an extended question] down for the kids, because the kids cannot do that.” His statement was very similar to those made by Anthea, who indicated that the students who needed a question broken down into parts was a subset of her student population.

Michelle looked for processes required in responding to the sample Student Answer (Table 3.3). She commented that the sort of answer she would expect included:

> Usually a logical approach, bullet points, more steps and I would have expected probably as well, a balanced chemical equation for respiration and photosynthesis to be included. Also to have arrows coming out from descriptions to show how they were connected, to show the relationship. I felt that the relationship was not shown very clearly in the answer.

Here, Michelle detailed ways of answering the question, *bullet points*, *equation* and *arrows to show the relationship* and quality needed in answering the question *using a logical approach*.

Wendy discussed using a range of descriptions of thinking involved in the Student Answer (Table 3.3). She said: "I mean it is related to a basic principle that you will learn in Year 11 and Year 12, so I would be expecting the students to tell me that basic principle". Wendy observed that the Student Answer did not show that level of understanding. She commented that the Student Answer was "Single idea, uni-dimensional. It would be less marks because it is not explaining an idea." When asked about the thinking involved by the student who wrote the sample Student Answer, Wendy said - "I do not think it shows connections, I think it shows recall. The information is recall". She added that the understanding shown in this answer "is linear". When asked if that applied to her students, she responded:

> With most of them, I would find that thinking. There is the odd student that has a passion for biology and you can see that as soon as they start writing, you can see there is a feeling for what they are writing down.

Wendy was implying that her students were mostly linear thinkers except for a few who had a feel for biology as evidenced by their written answers. Wendy used a number of terms to describe the thinking exhibited in the Student Answer including *single idea*, *uni-dimensional*, non-connected, *linear* and *recall*. She did not appear to distinguish between these terms and spoke about them interchangeably. She also identified students with a passion for biology inferring that they had a different order of thinking.

Collette expressed an expectation about the level of complex understanding that her student cohort would have had related to the topic of the sample Student Answer. Collette was "expecting that my students have some background in microbiology, have been exposed to this sort of thing and know the depth to which they understand it." She also said:

> The sample Test Question would give me the detail and information that I would want, whether the student has fully understood what is happening and how the processes interrelate, through to someone who kind of knows what is going on but is not there, through to the person who does not understand.

Although she expected a high level of complex understanding, Collette recognised that in answers for each question there may be variations in student understanding. She also stated that the question was able to give the information required and allow a range of student answers, providing a comparative measure, as described in test theory (Mislevy, 1996), which is a goal of system-wide examinations.

The problem of not knowing the *framework* of the student being marked emerges in external tests and examinations. Howard gave an insight into the problem of assessment of unknown students compared to a student whom he knew, in relation to interpreting their thinking and frameworks:

> When you are looking cold at completely different students that you don't know and you are looking at their answers, sometimes you can work out, by what they are saying, what is between the lines and what they are actually trying to say, but you cannot take that on board because you do not know the child. Whereas in your own class when you are marking, I will probably write a comment *ok next time be more specific about this* in this particular point. But I will end up giving them the mark for it, without realising because I know what they are saying. But I can see the flaw in that, because sometimes you might be a lot easier on their marking than somebody else because, really, they should be writing to an audience that is not known to them and who do not know them. I mean, that is the way that it works in the scientific fields anyway.

Howard reflected on the interpretation of a student answer where an awareness of everyday interactions with the student indicated their expressed and implied understanding. He compared that to a marker's reaction to an answer from an unknown student. The only means of interpretation of an unknown student's thinking, organising framework and understanding, was what was written in the answer. When Howard's students wrote an answer, he could understand their thinking and therefore what they might have been trying to say. He thought he might be able to predict the thinking contained in unknown student answers from their responses, but because he was not as certain in his predictions he considered he would be more conservative in his marking.

In the following comment, Howard clarified the situation by identifying the perception and then the consequence: "often you can actually tell what they are wanting to say and I think that in some ways does push you to accept a bit more, or give them another mark". Sadler (1998, p. 81) confirmed the legitimacy of teachers making judgments as assessors having "evaluative expertise" and experience in the range of ways that students answer questions.

7.3.2 Preferences of different students

In relating their views on student preferences and thinking, Howard, Wendy and Anthea described aspects that could have affected students' interpretational frameworks. The teachers described their actions in the classroom to progress student learning, with attention paid both to student thinking and to preferences in learning.

In describing the thinking and response patterns of different students, Anthea talked about "a range of learning styles", how they were related to students' interpretational frameworks and the impact they had on her actions in the classroom. Below are three examples, each highlighting a different aspect of Anthea's judgments of her students' frameworks. In the first example, Anthea discussed her perceptions regarding preferences of high achieving students:

> I think that the more intelligent ones who are the A grade, B grade students, like structure. They like to have a little bit of a lecture. I introduce the idea. I tell them why we are learning about it and then we might have some notes on an overhead and diagrams or I make a lot of use of power point presentations. So they can actually see with the key words next to pictures or diagrams and they love that. They like to jot notes down and they like to draw graphs and be able to link ideas. I then think that they like to read and take more notes and then we do case studies or particular, related questions. We will start off with some straight-up recall type questions and then we look at more critical thinking questions. So how to apply that information into some sort of situation. They really like doing that and then they feel that they have consolidated the whole thing.

In describing the way she perceived the accomplished students think and process information, Anthea gave a context-rich description of the sorts of prompts to learning she used as a teacher and the responses to those situations that she observed in the students. She described a variety of teaching and assessment strategies she thought matched the students' learning preferences. In this example, she gave information about her perceptions of the alignment between students' ability in biology, learning preferences, responses and feelings.

Anthea gave an example of her view of an individual with different preferences to the students in the example above:

> Matt [a student] is very quiet. You have not actually interviewed Matt but he is another one who really struggles and I think he struggles in term of literacy. I think that all the words completely bombard him, so I have tried to encourage the glossary idea, putting pictures with words and other strategies. I think that would help him a lot and he has come a long way since we have done a lot of work on breaking down the questions and telling him how to describe verses explain verses compare and contrast. So he has really benefited from the breaking down of the question and the interpretation because I think that is what he struggles with. But again, with his learning style, he is not a good writer. He does not like to write, so I think diagrams and other ways. Recently I think he has been quite enjoying the case studies that we have been doing and been able to apply the knowledge to a real situation.

The example by Anthea, describing perceptions about a student named Matt, discussed a judgment about his level of skills (*he struggles*), then an interacting context of situation, response, intention, intervention, strategy development, preferences and a learning outcome. Her perceptions of the student are a complex interplay of ideas. Later in the interview, she said about Matt: "I like to create models with the students because I really think that it benefits students, especially kids like Matt who cannot picture it in their head, so we do a lot of modelling." Anthea identified a framework that she thought was not present in Matt's thinking and a teaching strategy that she thought may have helped him. Anthea explained a modelling activity she used with students when teaching cellular biology: "for example with meiosis and mitosis we basically drew a great big cell, attached pipe cleaners and we modelled the whole process." Anthea had a range of strategies she drew on in order to help students with their thinking in biology.

In another example Anthea discussed a student named Jane:

> who scored well in many tests, but I do not know what her learning style is because she seems to lack motivation and she does not concentrate very well in class at all. If I am entertaining and I do lots of role modelling she will sort of sit up and listen but generally she is not a good note taker. She is probably better at looking at pictures but she will not put effort in to make links, so it is very hard to know how to approach ideas with Jane.

Anthea had not identified this student's motivation but had identified one teaching strategy that the student seemed to respond to. These examples from Anthea exemplified the range of interpretations related to students that she made, in particular with regard to their perceived individual or group learning preferences. Anthea used these interpretations in her planning and actions within the classroom.

Howard described an example of students with particular talents, who sometimes applied an inappropriate literacy, English or history writing framework to a biology answer.

> You think, *ok some extraneous information* at the beginning, then you think *Ah thank God you are into it now*. Especially if you have a history student or an English literature student, because in their head they have to have the introduction and the conclusion in their essay, so you deal with that because you know that is what background they have.

Howard's comments reflected his view that there was a different framework or structure students use that was involved in demonstrating understanding in English or history. His comments indicated that some students were using a non-biological framework, specifically in extended answers, to try to demonstrate their understanding in biology. Howard believed that this interfered with the student's ability to express their biology answer succinctly. Wendy highlighted the problem in students choosing an English framework to express a chemistry extended answer. Not only was the answer very long, it took more time than allocated. She noted that it was a detrimental strategy. Anthea had a different view. She was concerned that her students had problems with writing and representing their ideas fluently on paper. She said:

> I think that a lot of them struggle with getting the words on paper. They can, often verbally, tell you what it is all about. But they struggle to really write it in a really good, comprehensive way.

Anthea indicated that lack of literacy was a problem, in coherence and adequacy of student answers. Wendy commented about students running paragraphs together and having "their own style of writing" but that they were not penalised with fewer marks in biology. She said: "as a teacher you have to be adaptable to the student style of the way they answer." Wendy was focused on "evidence and good examples" in her assessment of answers and allocation of marks.

Two teachers, Wendy and Howard, proposed that students had other ways of operating or organising knowledge such as an English or history framework with the perception of bringing problems of unnecessary length, different ways of framing the answer and a poor strategy in time management to the biology context. Another teacher, Anthea, highlighted the problem that students with poor literacy skills could have difficulties in expressing answers, which could therefore affect the teacher's assessment of the student's response and perception of their capabilities in biology. Wendy, spoke of teachers' need to adapt in assessing answers, allowing different for styles and remaining focused on the important aspects of a question, such as evidence and good examples.

The teachers commented on a visual style as a preference that they thought was prevalent in biology students' organisational frameworks. In the examples above Anthea discussed using pictures and diagrams in her teaching. When asked how her students learned, Michelle said: "I would say sequence diagrams, bullet points, short summaries." Michelle identified sequence diagrams that could be described as visual. Collette was more expansive about visual learning and expression and said: "you can almost see them mentally picturing". She later gave an example of her classroom practice to describe the differences in visual learning between students:

> We do an activity. It is quite interesting. I gave them a pile of materials, butchers paper, coloured and black pens, and I said *I want you to provide me with a chart showing your knowledge on corals*. We had done something on corals. *Give me an explosion chart*. We put them up around the class and they were all completely different. There were some that were completely black, black pen in boxes, and others with colour all over the place and I used it as a learning tool for the kids. I said, *just have a look around the room and it will show you that you are all different in how you learn. Some of you will have to have colour to remember what is the major point and what is the minor point, others of you will have put it in boxes, others of you*, I said *the girls over here have actually pinched some beakers* and had put some beakers on their piece of paper to show the concepts.

Collette had a theoretical perspective and a practical view about students thinking visually and illustrated that with an example in her classroom. She recognised students who had other ways of processing:

> They are not pictorial. It is almost like a written list I think, for some of them. I have a girl who uses sound recognition and you can see it all the time when she hears things, she needs to hear the sound for her to remember what is right so she talks to herself all the time. I think for some kids it is sound and for some kids, those abstract thinkers that are not

> pictorially thinking, I think they are almost language oriented, that language is in their brain. Quite different.

Collette recognised that a few students were not predominantly pictorial or visual thinkers but had different preferences in learning. These included hearing and repeating sounds and language-based thinkers, including those who used written lists.

Howard referred to a collaborative style in describing his students. When asked about his students' learning preferences, Howard responded: "With this class it is very difficult because they are a very social class. Some of them are very good at making notes and working on summary work". Howard indicated that classroom observations on individual learning were difficult because of the students' social interactions in the classroom. However, he had identified a learning and communicating style that his students engaged in very regularly. He also mentioned students taking notes and summarising and this helping their learning.

7.3.3 Teachers consider that students' progress through incremental shifts in learning

In the context of assessments and the evidence they found in student answers, the teachers spoke about students progressing incrementally through stages in their learning. The teachers' idea of incremental shifts made by students in their learning added a facet to their views on student interpretational frameworks. Ideas related to students' learning in incremental shifts have also been discussed by a range of educational researchers (Biggs & Collis, 1982; Bronson & Merryman, 2009; Hattie, 2009; Piaget, 1960; Vosniadou, 1992). Piaget (1960) and Biggs and Collis (1982) identified developmental stages in learning, largely based on progressions from concrete to abstract thinking. Pellegrino et al. (2001) suggested that to locate evidence of stages and student progress the teachers needed: "to provide such pictures of progress, multiple sets of observations over time must be linked conceptually so that change can be observed and interpreted" (p. 257).

Vosniadou (1992) proposed that students had alternative frameworks in science, Taber (2000) proposed multiple frameworks in the same content area and students' selection of the best alternative depending on the context, and Siegler (2005) referred to learning as students' variation in strategy use in the selection of more advanced strategies. The teachers' comments regarding their view of observed shifts in learning are congruent with these ideas from the literature.

After a discussion of the Test Question and Student Answer (Table 3.3), Philip described a clear difference between stages and a shift in student understanding in biology: "the ability to relate a new structure that we have not discussed before with its function. It is a very important indication of the level at which students work". He continued to delineate some stages in learning needed to answer the common Test Question:

> learn what all these processes mean and that's the first level. They are able to explain how photosynthesis differs from respiration, for example, so when they move up a stage is where they understand the relationship between the two, then interrelating these two with a whole lot of other processes. I do not know whether it's a continuum or whether we are getting two or three discrete groups of people.

Philip considered students' frameworks according to the complexity of their understanding, including applying understanding to a new context, moving from describing to interrelating two ideas, then developing a coherent network of interrelated ideas. Philip indicated he was unsure whether the shifts were incremental on a continuum of content learning or through understanding discrete groups of ideas. The researcher could not be sure if Philip was referring to students being on a continuum or grouped or whether the shift in learning was a continuum or group of ideas. The ideas appear to be interrelated when discussing student achievement. Philip reiterated an order of learning for students: "each one of these processes needs to be fairly well understood before they understand the whole." Michelle reinforced this idea and stated: "complete that one area and make sure they know it and then move on to another area, but as we are building on it refer back continuously, refer back to different areas we would have covered that may overlap a new area." Philip described an example of steps in understanding photosynthesis, starting with the equation. He said the subsequent effects of amounts of reactants and products on each other was not well understood and concepts interrelating in dynamic ways were difficult for students. For example:

> they do not understand that if you keep taking something away on the right hand side of an equation that the reaction will continue to proceed more rapidly towards those products. They do not understand those basic principles of chemistry.

He also commented that: “some students are prepared to learn those and others, I suspect, reach a stage where they do not understand, and decide not to proceed any further. There is a bit of a block. That could illustrate an attitude.” In summary, Philip thought that there were stages in learning a process and different students would cope with understanding different levels of complexity in learning an idea. He thought some students may stop when they felt the complexity of information was beyond them. Within these reflections on stages of learning, Philip viewed the shifts in learning as a continuum or as separating the students into discrete groups.

Collette reflected on the sample Test Question and the sample Student Answer (Table 3.3):

> I keep seeing it as a Year 12 student summative question and I would be expecting this is what my model answer would be based on and this is what you work back from. You are trying to get these kids to that point, where they make those shifts and they can go from just being able to describe a process and know that something happens, to have a full understanding of what is going on.

Collette referred to a shift in learning when she described her thinking about the way biology was structured and the processes involved in more complex understanding. When thinking about students’ learning Collette anticipated the teaching context in which she would be helping students to learn. Collette’s discussion about shifts in student learning in the context of the sample Test Question was consistent with the views of learning that she expressed at various points in the interview.

Collette had the view that as a topic was explored learning and thinking were incremental. This was indicated in her statement: “they get more practice at it, and the brain for some of them locks it in *Oh, that is what I should have been doing*. It does not happen straight up.” Collette was alluding in this example to a moment of learning experienced by some students at a point in their engagement with content or experiences. When asked to clarify she said that with: “most students who are doing biology, that is mainly the case”. Collette continued:

> But the top of the scale kids, they have understood it straight up anyway, because that is where their brain is working when you have got them in the room. But for most of the kids, the sort of cohort that you get doing biology, it takes them a year to actually get to that point where they can do the answers. So when you give them something like the Test Question and

> they do not do so well. Then we need to work out the explanation of why they did not do well.

Collette differentiated between her top students and the rest of the cohort and in addition raised the idea of incremental progression, including the time and number of explanations before students developed understanding. Csikszentmihalyi (1990) stated that the top students seem to be in *the zone*, *a state of mind*, or *state of flow*, *an optimal experience*, so that they pick up the ideas quickly.

Collette thought about student learning and how she could best present new ideas. In the following example she described a process of steps in learning:

> I believe in the fact they start off with concrete and you have to give them examples. Then they move through to things they are able to do. Things like, interpretation and analysis and then evaluation. I still think kids go through those processes. You can pick out kids in your class who are able to analyse information and you have kids in the class who cannot. You know they are still kids and even when I introduce new concepts I will always start off as concretely as I can because you have to give them that to move through. So I still think kids do have that need and go through those processes and sometimes when you are introducing new information even for your top thinkers, you have to go to something concrete first.

Collette structured learning in a way that was based on her thinking about how students learned. The terms *interpret, analyse* and *evaluate* that she used were akin to the ideas of Bloom (1956) and the idea of *concrete* in this discussion could have originated from the ideas of Piaget (1960) or Biggs and Collis (1982). Collette indicated that it was important to return to a concrete approach in introducing new ideas and proceed through a learning process based on child development principles. In the following example Collette described the process of instruction she used with a *top-level* student when she introduced the new topic of antibodies and antigens.

> I had a very talented Human Biology student but when I was talking about antibodies and antigens we went back to playing with play dough and pop sticks. She got it straight away but the others took ages. But she said *Oh yeah that's fine*. Sometimes when it is a new concept that they have not dealt with before, you have to go back to that concrete level just to help their thinking processes. Talented students rocket off [experience accelerated learning] and they can take it to whatever level.

In introducing new information Collette used hands-on, concrete activities even with abstract thinkers and described the rapidity with which those students were then able to accept the new idea and move to thinking abstractly about it. Collette gave another example:

> I saw one student playing with play dough making antigens and antibodies on the cell … you could see it on her face, having played, within the minute she was off and racing [experience accelerated learning] but we had 20 others who were still playing because they were not at that level.

Collette considered that the process included internalising the ideas and making connections:

> I think that they internalise it very quickly. They say, *Oh yes, that is what is happening with my cells. I can picture that.* You can almost see them mentally picturing what is happening inside their bodies so they have actually moved on and said, *yes, I can see what is happening all over the place.*

In this example, Collette described the students' use of *mentally picturing* a process and their awareness of a bigger picture helping them to understand and progress.

Collette referred to the need for processing time in learning a concept, stating her view that better students, once given appropriate guidance and appropriate learning strategies, could process and connect the ideas quickly, sometimes in the space of a lesson. She thought that this was not the case for most students. Philip, in discussing the timing of assessments said: "in a few weeks, they can absorb all this information but then suddenly given a question, they might not have time to mentally process all this stuff yet". Collette and Philip have raised the notion of different students needing different periods of processing time to make shifts or progressions in learning. Philip made the inference that, although the teaching had occurred, the shift in learning might not have taken place and that time and mentally processing the information were critical.

7.4 Concluding Comments

The evidence related to Assertions 5 and 6 making up *Frameworks for biology thinking* has provided answers to Research Questions 5 and 6. The relationships between the research questions and the assertions discussed in Chapter 7 are shown in Table 7.1.

The question of why different assessment judgments were made by the teachers in this study about the same information has led to an examination of the interpretational frameworks used by teachers, as well as those that the teachers think are used by students. But it would be simplistic to assume that similar interpretations of questions and answers are made by teachers and students. In order for assessment to succeed as an educationally valid practice it is essential that the teachers' and students' interpretations be considered and understood. The evidence from teachers' comments in interviews was that teachers have different interpretational frameworks to their students. There was also evidence from their comments, however, that teachers' interpretational frameworks take account of their knowledge and understandings about the interpretational frameworks held by their students.

The teachers demonstrated that they had particular views that were formulated as interpretational frameworks. They used these frameworks in interpreting their worlds in the contexts of biology and assessment. In addition to organisation and use, a significant part of their interpretational framework was their professional concern for their students' learning and preferences. The teachers' ideas about the ways in which they thought their students organised understanding and frameworks in this biology assessment context formed part of the teachers' frameworks.

In Section 7.2 the data relating to Assertion 5: *The biology teachers have a multi-level, three-dimensional understanding of biology and prefer visual models* have been analysed and discussed. The teachers' interpretational frameworks are conceived as three-dimensional, problem-solving, cohesive, holistic, relational, transitional, dynamic and multi-levelled. Other aspects that formed their organisational or interpretational framework were evident, such as their sense of wonder about biology and their passion for the subject. It was evident from the data that the teachers had a particular biology interpretational framework in the assessment context that comprised a three-dimensional understanding, multi-level biological models with interactions between biochemical to ecosystem levels, a propensity for a problem-solving approach, a strong professional concern for their students, a wondering and positive biological disposition and a visual preference that together affected the way they taught, assessed and organised their ideas and framework in biology. Very often it appeared that the teaching lens was the most predominant aspect of their framework.

The data indicate that the teachers' frameworks in biology assessment could include systems thinking frameworks and problem-solving frameworks. Erickson (1986) said causal relations in biology were more complex than in physical sciences, Schonborn and Bogeholz (2009) suggested qualitative differences were evident in different areas of biology and Lopez et al. (1997) that different cultures had qualitatively different approaches to biology. Principles of complex systems were evident in biology (Riess & Mischo, 2010), systems thinking approaches were found in biology (Campbell & Reece, 2003; Townsend et al., 2008) and systems relied on an internal model of reality and multiple and relational aspects (Ossimitz, 2000). Dorner (1996) suggested difficulties in dealing with complex systems. It was evident in the study that these experienced teachers had developed, and continued to develop, elaborate and sophisticated interpretational frameworks.

The teachers were keen to share their insights on biology with their students, encouraging them in questioning, exploring, responding and applying their ideas in a relational way in order for them to become more experienced biology thinkers. Particularly prevalent was that the teachers used a number of different lenses at the same time in their understanding of biology and they used a variety of strategies in trying to help their students think about biology in ways that took account of its complexity.

In Section 7.3 related to Assertion 6: *The teachers consider that students differ from each other in their thinking, with most being linear thinkers that progress through shifts in learning*, these teachers expressed views on student assessments, on the interpretational frameworks they thought were used by students to make sense of biology and on the differences among these. They commented on several components that were included in student frameworks. The teachers speculated about these aspects of frameworks or student thinking as a result of analysing assessments and from direct consideration of test questions and student answers. The teachers developed understandings of the students' frameworks by using words suggesting several continua, although typically their comments and terminology referred to students at the extremities, such as "top students". Their continua related to student thinking are summarised in Table 7.2. These continua raised by the teachers highlighted the variation within populations in these teachers' classes. Generally the teachers could identify a few *top* students, the majority of their classes somewhere in the middle and a few students at the far end of each continuum. The teachers were keen to progress or widen their students' thinking by using a variety of classrooms strategies in their teaching.

Table 7.2 Teachers' continua related to student thinking in biology

Teachers' continua related to student thinking		
Box or pigeon-hole thinking	*to*	*Big picture thinking*
Two-dimensional or linear thinking	*to*	*Three-dimensional thinking*
Single-idea, recall, or simple thinking	*to*	*Higher-level, complex student thinking, top student or A-level*

The teachers distinguished concrete thinking from abstract thinking. They used colours and models, particularly visual models, collaboration within groups and class sharing activities such as the classroom display conducted by Collette. These teachers helped students use many techniques to assist them to learn, such as drawing boxes around information, colour, visuals, props or equipment to show important ideas, models, stickers, sounding out words and lists.

The teachers discussed diversity within their student populations in relation to the classroom and the assessment contexts. They thought that students' preferences and ways that teachers influenced which of these preferences was most useful had impacts on the students' interpretational frameworks in biology. The teachers considered a visual learning preference to be very useful in biology. A factor mentioned by teachers within the assessment context was the type of questions: for example, extended questions providing a better opportunity for students to demonstrate understanding in biology. They commented that extended questions, however, were not well done by students who were operating at the lower ends of the continua or those who had poor literacy skills.

Another major area of comment by the teachers related to Assertion 6 and their view of student frameworks was the concept of incremental shifts in learning and factors affecting those shifts such as processing ideas and time needed for learning. The teachers spoke about moments in time when they or their students could see a progression in the learning. There was reference to shifts taking sometimes one day or sometimes a year as information was processed and incorporated into students' frameworks. Philip commented that some students reached a level of understanding and could not go beyond that, for example having a blockage or an attitude related to a topic. Collette and Philip referred to the different stages in answering a biology question at higher levels of complexity and this being seen as an example of a shift. The idea of whether it was a continuum or whether there were discrete groups of shifts/progressions or populations was raised. This could merit future study. The view that students make incremental shifts in their learning and therefore shifts in their interpretational frameworks was a strong one amongst the teachers in the study.

The analysis related to Assertions 5 and 6 provided evidence of commonalities within these biology teachers' frameworks. These commonalities in frameworks included big picture or three-dimensional biological understanding, particular ways of organising and understanding biological content, how they saw concepts interrelated in dynamic ways in biology and how the teachers preferred to share these ideas with their students taking student preferences into account. They also had common interpretations of frameworks that they thought students held and ways that students progressed in their understanding in biology.

A significant result of the analyses in this chapter was the emergence of an expert/novice emphasis. The teachers' understanding and organisation of ideas in biology and, by inference, their interpretational frameworks, were aligned with an expert status, and their views of student capabilities in biology were those that could be attributed to novices. In their comments and references to continua in student thinking within the student populations they were teaching, the teachers used the terminology related to experts and novices. An expert/novice framework was evident in the interpretational frameworks held by these teachers.

As well, a PCK lens can be applied to the discussion in this chapter. The discussion related to Assertion 5 shows the nature of the teachers' knowledge and understanding of the domain of biology in an assessment context, which is their content knowledge. Their views on students' knowledge and preferences and the strategies they applied in biology assessment contexts, discussed in relation to Assertion 6, is their pedagogical knowledge. This study is firmly situated in the intersection of these content and pedagogical aspects. The strong presence of PCK in the data and its emergence in the analysis of this chapter on *Frameworks for biology thinking* suggest that assessment was an integral part of the PCK framework held by the biology teachers. This idea could be referred to as Pedagogical Content assessment Knowledge, PCaK. The PCaK notation provides a shorthand way of emphasising the assessment context in which PCK was applied in this study.

Chapter 8

Findings, Conclusions, Recommendations and Limitations of the Study

8.1 Introduction

The aim of the study was to investigate what interpretational frameworks teachers have in biology in the assessment context and what characteristics, commonalities and differences can be identified. Data were collected based on the researcher's belief that teachers each have an interpretational framework in which they have organised their experience and knowledge in the area of biology education, including in assessment. Six experienced biology teachers were selected as participants in this study. Five - Collette, Howard, Anthea, Philip and Wendy - were from government and non-government schools in country and city locations in Western Australia and one – Michelle – was from Ireland. Deep interviews were conducted regarding the teachers' involvement in senior school biology assessment and data were collected and analysed to build understandings of teachers' interpretational frameworks. Each teacher's views and insights were synthesised and commonalities between teachers were analysed.

This chapter summarises the outcomes related to the aim and research questions, including 8.2 Findings from the study, with 8.2.1 Teachers cases and 8.2.2 Analysis – assertions. 8.3 concludes the chapter, summarises the findings and suggests recommendations for further related study.

8.2 Findings from the Study

8.2.1 Teacher cases

The theories, worldviews and interpretational frameworks discussed by each teacher in an interview were presented and discussed in Chapter 4. The focus of Chapter 4 was to address Research Question 1. *What are the views and perceptions of each teacher regarding assessment in senior school biology?* A summary of characteristics and aspects of the interpretational framework of each teacher follows and the teachers' views and theoretical positions forming their interpretational frameworks have been summarised in Table 8.1.

Table 8.1 Issues emerging from teachers, indicating their views and theoretical positions on assessment and contributing to their interpretational frameworks.

Issues and ideas discussed by the teachers	**Howard**	**Collette**	**Anthea**	**Michelle**	**Wendy**	**Philip**
Biology is multi-level, relational, complex, dynamic	√	√		√	√	√
Biology is problem solving		√			√	
Students mostly think in linear ways about biology, or pigeon-hole information, rather than look for connections	√		√		√	
Students lie along a continuum of biology understanding or in discrete groups		√				√
Students undergo shifts in their biology thinking and processing, and move from concrete to abstract thinking		√	√			
Biology teachers think in big-picture, multi-dimensional ways	√	√	√	√	√	√
Focus on the curriculum and system-wide examinations in choosing questions	√	√	√	√	√	√
Look for particular biology knowledge and explanations in an answer	√	√	√	√	√	√
Try to fit the student's answer into a jigsaw that shows their whole thinking	√					
They are willing to compromise	√	√	√	√	√	√
Have expectations of the complexity or appropriateness of an answer	√	√	√	√	√	√
Diagrams or visual representations are common in biology test questions or answers	√	√	√	√		√
Discuss feedback after tests	√	√				√
Teach and expect test strategy and techniques to be used in doing tests	√		√	√	√	
Duality and balancing roles, adapting roles to particular contexts	√	√	√		√	

Howard referred to teachers' understanding of biology being multi-dimensional, dynamic and relational and within assessment, the importance of attending to multiple aspects of questions and answers. He saw the assessment process as a jigsaw puzzle, interpreting incomplete student knowledge in order to determine their holistic achievement. This is similar to systems thinking (Ossimitz, 2000; Riess & Mischo, 2010).

Collette focused on detailed, problem-based, multi-level biological knowledge, both vertical and horizontal, similar to that proposed by Shulman (1986). She also discussed her high standards and expectations of students when they answered biology questions. Collette maintained that students had shifts in their thinking and she moved students from concrete to analysis stages in new learning, similar to ideas proposed by Bloom (1956). She spoke of detailed feedback as information sharing between her and students.

Anthea focused on strategy in selection of questions, in teaching students to interpret questions in their preparation for tests as well as on detailed understanding of biology and the curriculum, thus exhibiting PCK in biology (Shulman, 1986). She thought that many students pigeon-holed information and a few had big picture understanding, with most having visual preferences in biology.

Michelle expected detailed biological content knowledge and specific techniques to be used by students in answering test questions. Her descriptions of biology were relational and multi-level, considering biology from metabolic to ecosystem levels. She used tests to assess students' understanding of the theory of biology and expected the use of well-labelled diagrams in appropriate questions. Michelle exhibited thinking about the structure of biology and PCK as described by Shulman (1986).

Wendy was flexible in accepting student responses within appropriate boundaries of knowledge and expectations regarding questions. Her emphasis in the assessment of students was to identify what they knew in biology. She considered that student thinking was linear and that they needed increased problem-solving abilities in order to be successful in biology. She demonstrated interconnections at all levels in biology and showed that she felt a wonder for biology.

Philip focused on appropriate complexity in students' answers and emphasised students' responsibility to read and answer the question as asked. Within these boundaries, he was prepared to accept a range of answers. Philip considered post-test feedback to be important and mentioned that talking to students increased the accuracy of assessments. He demonstrated that he thought in a multi-dimensional way and considered that students' understanding was along a continuum or in discrete groups, in a similar way to expert/novice perspectives (Sweller, 1994).

The teachers' ideas, expectations, practices and views were subjected to a cross-case analysis leading to the development of six assertions. 8.2.2 summarises the results of this analysis.

8.2.2 Analysis – assertions

Six assertions regarding the biology teachers' interpretational frameworks emerged from the researcher's engagement with the data in response to the research questions. The assertions were developed from analyses outlined in Chapter 3 and were explicated in Chapters 5, 6 and 7. These assertions were organised into three categories: *Making judgments of student achievement; Teachers' strategies for assessment;* and, *Frameworks for biology thinking*. The three categories were the headings for each of Chapters 5, 6 and 7 to provide a structure for the findings and discussion related to each assertion. This section summarises the findings related to the assertions and addresses the research questions.

Making judgments of student achievement

Two research questions provided the focus for Chapter 5, *Making judgments of student achievement:*

RQ 2. What are the influences on teachers' assessments and judgments of student achievement in senior school biology?

RQ 3. In what ways are different teachers consistent in their judgments of student achievement in biology?

A major group of responses from the teachers interviewed related to their gathering and explaining evidence in tests in biology, accounting for contexts, expectations, inferences, experience, perceptions and knowledge, to make a decision on the quality and complexity of a student's answer to a particular question. Essentially, the teachers made judgments with all the factors and awareness in the spectrum of their interpretational framework on the achievement of individual students in biology tests. Sadler (1998) endorsed the legitimacy of teachers making judgments and referred to their *evaluative expertise* and experience. Two fundamental aspects of making judgments emerged: firstly the teachers' expectations and interpretations of the questions and the students' answers and secondly the dynamic marking process the teachers developed consistent with their rationales. A full explanation of the results and discussion and a concluding summary of *Making judgments of student achievement* is found in Chapter 5.

The first assertion *These biology teachers' assessment judgments are dependent on their expectations of and interpretations of the students' biological explanations to questions* emerged from the analysis as an aspect of teachers' interpretational frameworks. The teachers' interpretational frameworks, related to this assertion and demonstrated by their design and selection of questions, comprised expectations of students, quality of questions and qualitative and quantitative expectations of the answer. The assessment questions included characteristics such as guidance on direction and complexity, providing clarity of interpretation and achievement of several purposes. These purposes for questions included testing understanding of particular biology curriculum areas (Department of Education and Skills, 2013; SCSA, 2009) and important concepts and relationships (Australian Academy of Science, 1981b; Biological Sciences Curriculum Study, 1993; Erickson, 1986; Shulman, 1986; Treagust & Tsui, 2013) and determining student understanding (Biggs & Collis, 1982; Bloom, 1956; Hattie, 2009; Piaget, 1960). These teachers used the expectations and experience in their interpretational frameworks to make sense of students' answers. The teachers were specific regarding the biological details needed for each question and answer and this detail contributed substantially to each interview in the study. Teachers demonstrated flexibility, considered other perspectives, used internalised and external standards and were idiosyncratic in their approaches, analysis and conclusions concerning a question.

There were no disconfirming cases to the assertion although Philip provided a different view of the answer to the Test Question from the other teachers, where his answer was represented as a concept map. In addition Collette provided a difference in her expectations of the Student Answer to that of other teachers in the study. Collette's expectations and rationale were based particularly on her experiences with high quality student responses, expectations of a proper distinction between processes in the question and the context of a summative, end-of-school, state-wide examination.

The second assertion in the category *Making judgments of student achievement* that contributed to teachers' interpretational frameworks was Assertion 2. *These biology teachers award marks using a dynamic process consistent with their rationale and guided by a marking key.* The teachers drew on the knowledge and experience from their interpretational framework to determine a marking key. They then used a dynamic process of continually analysing and comparing their own and student answers, including re-assessing individual answers in comparison with answers from the cohort, culminating in attributing a mark to the answer.

Teachers understood that complex mental processes and clarity in communication were important when students were completing answers, particularly in a time-poor environment. Marking keys ordered the teachers' thinking, provided guides and prompts about the assessable points and were flexible.

In the study the teachers also evaluated a common Test Question and Student Answer, the findings of which the researcher used as a triangulation instrument. Teachers showed similarity in that they had similar understandings of the biology needed to answer the question. They constructed a marking key and used it flexibly during the marking process, generally as a group of guiding elements in order to determine a mark. The teachers looked for and rewarded assessable points. It was found that there was variation among the teachers in the structure of marking keys for the common Test Question. Two teachers wrote dot points, two completed flow diagrams and one drew a concept map. There was variation in the allocation of marks, from 8 marks for processes and 2 marks for connections, to 4 marks for processes and 6 marks for connections. There was variation in score emphasis in each section and the final marks attributed by the teachers to the common Student Answer ranged from 3/10 to 8/10. Table 5.2 compared the variations in the teachers' responses to the Test Question and Student Answer. The discussion above provides a response to Research Question 3.

The final mark awarded by the teacher was a judgment of the student answer in numerical terms arising from the teachers' interpretational frameworks and contexts. The marking process was a dynamic event limited by time and influenced by knowledge, expectations, interpretations, discretionary decisions, rationale, context and experience and these influences provide further clarity concerning Research Question 2.

In *making judgments of student achievement*, it has been demonstrated that these teachers were pragmatic in what was achievable by students in an examination question. The teachers understood that answering a question was a complex task. Wendy commented that developing an answer was a series of thought processes, Howard commented on distractions and students spending time on providing extraneous material and superfluous answers. Collette was very clear on a central focus for an answer, which was a little different from the other teachers, while Michelle and Collette perceived interrelated levels in biology within an answer. Michelle emphasised two ways students could answer a question, diagrammatically or in written format. Howard highlighted that students may take shortcuts with answers and expect the teacher to read into the answer the complexity and completeness the student intended.

Howard compared the assessment process to a jigsaw. All of the teachers interviewed commented about their and the students' interpretations of the question and their own inferences about student achievement in tests. Howard noted that in the current summative TEE examination, a number of procedures are put in place to confine the variation in marking.

A clear link was demonstrated between the teachers' interpretational frameworks in the *Making judgments of student achievement* category and PCK, with teachers' content knowledge of the domain, the knowledge of students and of contexts and teachers' pedagogical knowledge of strategic practices evident. The PCK perspective was a helpful way of conceiving aspects of the interpretational frameworks held by a teacher.

Teachers' strategies for assessment

Research Question 4 *What strategies do teachers' use in assessing senior school biology?* provided the focus for Chapter 6, *Teachers' strategies for assessment.* The major category of response from the teachers interviewed, *Teachers' strategies for assessment*, highlighted the teachers' practices in constructing assessments for their students and the interactions with students both before and after assessments. A strong sense of teachers determining appropriate strategic processes for particular outcomes emerged from the interviews. Two assertions emerging from the teacher interview data contributing to this category drew together findings to answer the research question. *Teachers' strategies for assessment* forms a part of the strategic basis underpinning a teacher's interpretational frameworks and adds to the knowledge and experiential aspects of their framework. Detailed findings, discussion and a concluding summary of *Teachers' strategies for assessment* were provided in Chapter 6.

Assertion 3. *These biology teachers design the most appropriate assessment strategies for their purposes and to meet internalised or external frameworks* emerged as part of this category, with implications for teachers' interpretational frameworks. Teachers considered many strategic aspects of assessments in order to design appropriate questions and to prepare students for tests. In interviews they discussed questions, their appropriateness, their properties, their purpose, different questions to meet the needs of different students and conditions of the test environment. These teachers drew on their interpretational frameworks and understood the use of and requirements of external frameworks.

Teachers had preferences for particular question types. Multiple choice questions were considered important by Philip and Collette, and problematic by Michelle, Wendy and Anthea, although all of the teachers used multiple choice questions. All of the teachers appreciated short answer questions and considered them valuable in allowing students to reveal understanding. Extended answer questions drew comment from all the interviewed teachers, with Anthea considering them unhelpful to students with low literacy, although all of the teachers thought they enabled complex, relational, big picture answers from students. The teachers recognised that, as well as meeting different student needs and preferences, different question type gave different snapshots of understanding, an aspect considered important by Pellegrino et al. (2001).

Teachers spoke of providing students with strategic tools in answering questions. They encouraged students to highlight key words, read the question carefully for meaning and use the most appropriate representations such as labelled diagrams, graphs and equations, as discussed by Michelle, Anthea and Howard and in the literature by Yore and Treagust (2006). Strategies for test taking suggested by teachers were considered as the mechanics of answering questions.

There is a clear link between Assertion 3 and PCK. The teachers' comments identified pedagogical aspects of assessment in teachers' design of questions and tests and in directing their students' practice in strategic planning within test contexts.

The second assertion within the category *Teachers' strategies for assessment*, with implications for teachers' interpretational frameworks is Assertion 4 *These biology teachers recognise the importance of feedback about assessments to student learning.* Diverse outcomes arose from the discussions with teachers on feedback with classes after summative tests. The teachers recognised that feedback using the test was beneficial for teachers and students, as suggested by Hattie (2009). Class feedback gave these teachers opportunities to learn more about their students' achievements through discussion and to re-teach and value-add to ideas. The students appeared more receptive after having completed and received feedback on test questions. The teachers also commented that they adjusted their methods and content in the situation where most students had the same answers wrong. They said that feedback engaged students in learning from their own efforts and gave them specific information and metacognitive and reflective practice. Students were also provided with expectations regarding a question, confidence in answering a comparable question in the future, an understanding of differences between class scores and external examination contexts and strategic thinking strategies for future tests. These outcomes are congruent with the findings of Wiggins (1998), who stated that teachers used assessment information to aim for improvement in student achievement; Hattie (2009), who showed that assessment information was a critical outcome of an investment by students and teachers in the assessment process; and Pellegrino (2012) who commented that students needed feedback for understanding what they had done. Howard said that he considered the feedback process as an opportunity for students to be inducted as co-markers, experiencing an assessor perspective. Collette suggested that feedback helped students to see that answers were relative with regard to complexity and could be compared along a continuum.

The roles of the teacher in assessment were highlighted by changes in teacher voice during interviews. Four teachers changed from discussing answers as an assessor/judge to assuming the role of teacher/mentor/advisor to students. Sadler (1998) spoke about the idea of teacher-as-assessor. Philip raised the idea of the teacher needing to be confident in their knowledge when they were in a feedback role with students. Sadler (1998), in describing his teacher-as-assessor role, emphasised the superior knowledge held by highly competent teachers. These roles and the knowledge and versatility associated with them could be viewed with an expert/novice lens, as characteristic of highly competent teachers. Discussions with these teachers demonstrated their recognition of feedback as an essential process among their teaching and assessment strategies, contained within their personal repertoire of effective practices and that these are important aspects of their interpretational framework.

Frameworks for biology thinking

Research Question 5 *What do teachers consider are their own and their students' frameworks for organising biology?* provided the focus for Chapter 7, *Frameworks for biology thinking*. The category *Frameworks for biology thinking* emerged from the teacher interviews and highlighted the teachers' views about the need to order, organise and understand the biology domain and assessment. They saw their own thinking in biology as three-dimensional, using words such as multi-level, multi-directional, relational, dynamic, holistic, system-based and problem solving. They predominantly thought visually and also linked their thinking to their positive feelings about biology. They exhibited strong professional concern for developing their students' thinking in these ways. The teachers asserted that most students did not yet have adequate experience of organising and understanding biology and that they thought in a range of two-dimensional, pigeon-hole, recall and concrete ways, although the teachers also said that their students were progressing along a continuum towards big-picture, three-dimensional, complex, abstract and higher-level thinking about biology. Assertions 5 and 6 were developed from the data in providing evidence regarding *Frameworks for biology thinking* and highlighted the differences between the frameworks that teachers had in the biology area and their perception of students' frameworks, thus providing a response to Research Question 5. The findings and discussion of the *Frameworks for biology thinking* category were provided in Chapter 7.

The first assertion within the category of *Frameworks for biology thinking* with implications for teachers' interpretational frameworks is Assertion 5. *These biology* *teachers have a big picture, three-dimensional understanding of biology and prefer visual models.* Teachers spoke in detail about the thinking required for organising and understanding biology. They described multiple ways of conceiving the biology domain along with the need for a holistic, big-picture understanding.

All the interviewed teachers were in accord with the multi-level views of biology, alternating between macroscopic and biochemical, in thinking about ecosystems, organisms and cells and prevalent in biology curriculum and texts (Australian Academy of Science, 1981b; Biological Sciences Curriculum Study, 1993; Department of Education and Skills, 2013; Shulman, 1986; Treagust & Tsui, 2013). Teachers described the levels in biology as hierarchical and compared them to chemistry. The teachers added the need to interrelate aspects of organisms, processes and levels and then understand the consequences of dynamic changes to any of these aspects. This has engendered a three-dimensional view of biology. Treagust and Tsui (2013) referred to a cube model, as did BSCS (Biological Sciences Curriculum Study, 1993) in their models in biology teaching, with both recognising the three dimensional character of biology.

Wendy and Collette referred to problem solving in biology being necessary to reason through the different contexts of organisms and their survival. Erickson (1986) commented that causal relations were more complicated in biology than physics or chemistry. In considering biology from a systems-thinking approach, Riess and Mischo (2010) stated that complex systems included non-linearity or numerous interactions and Ossimitz (2000) described an internal model of reality incorporating multiple and relational aspects, dynamic and network thinking, models and action as parts of the system but not independent of each other. Biology has been described as having qualitative differences depending on the area of biology, with genetics requiring abstraction and evolution being very analytical (Schonborn & Bogeholz, 2009). These ideas on the innate complexity and multiple dimensions of biology referred to by the teachers and researchers could indicate particular challenges in teaching and assessing biology.

Teachers discussed their thinking in biology as visual, providing evidence about using models, pictures, diagrams and other visual representations in their thinking, teaching, learning and assessing in biology. The work of Eilam (2013) and Treagust and Tsui (2013) showed extensive visual representations as appropriate in biology education.

Sweller's (1994) research demonstrated that cognitive load could be reduced by using a self-contained, fully labelled diagram. Visual thinking formed a part of these teachers' interpretational frameworks. The multiple frameworks and associated disposition of wonder and engagement that teachers demonstrate in order to help them organise and understand biology form a valuable contribution to understanding these teachers' interpretational frameworks.

The second assertion within the category of *Frameworks for biology thinking*, with implications for teachers' interpretational frameworks is Assertion 6 *These biology teachers consider that students differ from each other in their thinking, with most being linear thinkers that progress through shifts in learning.* Teachers in this study indicated they knew their students well enough to hypothesise about the frameworks their students used. They placed students along continua of variation in thinking, understanding and organising knowledge and described the continua for each using a variety of terms. Essentially, teachers determined between the extremes of pigeon-hole and big picture thinking, two-dimensional and three-dimensional thinking, single-idea and complex thinking, weaker and top student thinking, recall and higher-level thinking and concrete and abstract thinking. This was congruent with Pellegrino et al. (2001) who suggested that in a subject domain, students' intermediary states of understanding could be identified in an assessment context. The continua are indicative of expert/novice approaches to knowledge and its organisation. Bransford et al. (2000), Sweller (1994), Sadler (1998) and Mislevy (1996) commented about expert/novice approaches, where experts are more likely to group related ideas and integrate knowledge for easier processing.

Based on student answers the teachers determined the frameworks of organisation and understanding in biology that their students had, including the ways that students related a new, unseen structure to its function, successfully explained the action of an enzyme using a linked set of ideas and models and could see a number of related processes, structures and biological levels when explaining a photosynthesis equation. Teachers used this knowledge of the different frameworks held by students to plan teaching, learning and assessment. The teachers, for example Howard, provided scaffolding in assessment for students who demonstrated two-dimensional thinking or who had partial knowledge. Teachers predicted that students with this approach to thinking would obtain fewer marks in assessments because they could not explain principles, relate knowledge or cope with writing coherent, extended answers. Anthea discussed selecting and targeting different teaching strategies as a result of her perception of accomplished thinkers, those students who struggled with literacy and those who lacked motivation. Howard spoke of his efforts to change particular students' English or literacy frameworks into science frameworks for writing answers. These teachers commented about their perception of student learning preferences as factors involved in the students' frameworks. Three teachers commented about a significant visual preference amongst their biology students while a fourth teacher commented on a collaborative style amongst his students.

Collette described that most students experienced a moment of learning and there was a perception by Philip of a blockage in some students when presented with content of higher levels of difficulty or complexity. Teachers suggested that their students made incremental shifts in their understanding in biology and that the shift may be a discrete step or a shift along a continuum.

Taken together, these biology teachers have demonstrated that their interpretational frameworks in the assessment and biology contexts are dynamic, adjust for context, account for differences in students, new knowledge and processes and are appropriately applied. The study findings indicate that these teachers' interpretational frameworks:

- are complex, relational, multi-level, three-dimensional and experiential (Sections 4.2 and 7.2),
- show significant expert characterisation (Section 7.2),
- are used in specific and integrated ways to interpret the quality and complexity of biology assessment responses (Sections 4.2 and 5.2)
- are used to make assessment judgments (Section 5.2) and
- take account of students' interpretational frameworks (7.3)

Section 8.2 has summarised the individual teacher cases and findings based in assertions, which address the research questions.

The explication of six assertions, the summary of five elements above and the more expansive evidence presented in this study of biology teachers' interpretational frameworks contributes to the field of science education research.

8.3 Recommendations and Limitations of the Study

8.3.1 Recommendations for further research

As a result of this study the following recommendations are made for further research that it would be useful to conduct. These 14 recommendations are presented as research topics or research questions and are organised in order of results and discussions chapters and assertions. Each set of recommendations is followed by an explanation, rationale or possible implications for research.

1. Determine and confirm key aspects of subject-specific interpretational frameworks used by individual teachers for assessment.

2. What are specific origins and influences on teachers' ideas and perceptions forming their interpretational frameworks?

These two recommendations arise from Chapter 4, which provides evidence that teachers have specific subject understanding, their ideas, perceptions, strategies and responses to assessment are complex and they are influenced by past and contemporary research, current curriculum and experiences.

3. To what extent do teachers' expectations of content complexity and their own standards affect their judgments of student answers?

In *Making judgments of student achievement*, Chapter 5, teachers' comments on assessments show influences from their expectations and perceptions and these have been highlighted in Assertion 1. The experienced teachers' judgments were predominantly based on expectations regarding specific biological detail in questions, with flexibility depending on context, perceptions of different student interpretations of the question and their own interpretations of the knowledge or accuracy of the student answer (Section 5.2). There are implications for the role of expectations and contexts in the assessment process.

4. Investigate the prevalence, application, opportunity and desirability of using a jigsaw analogy within teachers' assessment processes for both class tests and system-wide examinations.

5. Investigate factors influencing teachers' final judgments, including impacts of teachers' rationales, marking keys and marking processes.

6. What are implications of the influences and impacts in Recommendation 5 for comparability of students' results in examinations and common assessment tasks?

7. Investigate effective strategies to enable consistency and comparability in teachers' assessments.

Recommendations 4 - 7 are related to aspects of teachers' assessment practices and would provide useful results for pre-service and in-service professional development. Teachers drew a spectrum of relevant knowledge and experience from their interpretational frameworks in order to use a dynamic marking process leading to decisions and judgment-making, as has been highlighted in Assertion 2. Howard (Section 5.3.3) used the analogy of a jigsaw to describe the assessment process. This implied that tests produced partial excerpts of knowledge that the teacher interpreted and fit into a holistic understanding in order to assess a student's achievement. The teachers interviewed commented on inferences they made about student achievement in tests. The implication is that the teachers understood that making judgments involved interpretation.

The marking process described by teachers was dynamic, limited by time and influenced by teachers' attributes and also by dispositions, discretionary decisions and rationales. The teachers were idiosyncratic in their approaches, analyses and conclusions regarding a common test question. One teacher's expectations of a common Student Answer led her to give a significantly different assessment from the others, but all the teachers varied in their marking keys and judgments (Section 5.3). There are implications for consistency and comparability between teachers in the marking process and for the current comparative assessment focus within systems and sectors for ranking and determining the futures of students.

8. What are relationships between PCK and teachers' assessment design and judgment processes?

In Chapter 6 *Teachers' strategies for assessment* the teachers commented in detail on their strategic thinking and practices in planning and implementing assessments as part of their interpretational frameworks. The findings regarding these experienced teachers' strategies, purposes, choices and practices in assessment, reflected in Assertion 3, have implications for the importance of pedagogical understandings and effective implementation within assessment, similar to research about PCK. The teachers' range and depth of pedagogical explanations in biology assessments provide an indication of the complexity and pragmatism in this difficult area. There are implications for pre-service and in-service education, including focusing on the understanding of *whole strategy* (Wendy, Section 6.2.2) understanding brought to each question and test by experienced teachers. *Whole strategy* understanding was a term constructed by Wendy as an approach to questions including reading for meaning, accurate interpretation, identification of focus concepts, understanding content in context and developing an appropriate answer. Research that emerged in investigating teachers' interpretational frameworks in the *Making judgments of student achievement* category had implications for further research in the PCK paradigm and a PCK perspective has provided a helpful way of viewing teachers' interpretational frameworks.

9. What are effects on student achievement of allocating time in teaching and learning programs for feedback after summative class tests, when the student learning environment and dispositions to learning are highlighted?

The teachers identified different purposes for feedback and multiple outcomes were highlighted by Assertion 4. The teachers had recognised the benefits of feedback to students and these were predominant within their discussions. They also mentioned the benefits to themselves. An implication of this study is that the feedback at the conclusion of tests may hold more importance than the teachers had previously considered. Post-test feedback may be underrated and rushed by the teachers, whereas according to their own statements and the research by Pellegrino (2012) and Siegler and Araya (2005) the students appear to be at their optimal learning capacity and motivation as a result of their engagement in the testing process. The teachers identified benefits for themselves and it could be useful for them to focus more on those possible benefits. The summative assessment feedback aspects of *Teachers' strategies for assessment* emerged from the teachers' comments and formed a part of their interpretational frameworks.

10. Investigate the benefits of biology teachers using a problem solving approach as a predominant way of teaching and assessing biology.

When discussing assessment, the teachers described multiple ways of organising and understanding biology within their interpretational frameworks, presented in Chapter 7 as Assertion 5. The hierarchical levels of complexity in biology from biochemical to ecosystem were common points within the teachers' comments and concurred with system-wide approaches and texts used during their teaching careers. An implication is that consistent and long-standing approaches within the state education system allowed teachers to form continuing networks of knowledge within an interpretational framework. An alternative direction given by BSCS (Biological Sciences Curriculum Study, 1993) to unify the content of biology using the theory of evolution was not evident amongst these teachers nor in the curriculum materials they were using.

The biology teachers' multi-level understanding and rich networks of concepts and relationships and their ability to change within and between the levels provided evidence for their three-dimensional, relational, dynamic interpretational frameworks. As well as having implications for expert/novice research, these results could add to the richness of understanding PCK. There are implications for curriculum and teaching when considering the complexities and possible difficulties in developing students' interpretational frameworks in the biology domain. The teachers' comments about their own and students' feelings of passion and motivation for the subject may be an indication of a disposition present in their own biology framework. An implication of this could be the link between emotional dispositions and levels of expertise in the domain. Problem solving was suggested by teachers as an approach for thinking, understanding and organising their biology frameworks (Section 7.2).

11. Investigate teachers' perceptions of students' shifts in understanding, compared with their perceptions of student interpretational frameworks, including contexts and factors involved in the shifts.

Teachers' perceptions of their students' interpretational frameworks and placement of students' thinking along continua were characteristic of Assertion 6. The teachers' use of continua has implications for expert/novice theory and research on the intersection between teachers' views of student expert/novice continua, with teachers' conceptualisation of students' frameworks. Depending on whether a teacher's view is that students have discrete or continuous shifts in learning and their positioning of students on continua, there could be implications for teaching, learning and assessing.

12. Investigate the effectiveness and propensity of visual conceptualisation in biology assessments in comparison with other science subjects.

13. Determine what similarities and differences are found among students' domain frameworks and to what extent students' domain and assessment frameworks are influenced by teachers' interpretational frameworks.

In the *Frameworks for biology thinking* section of this study (Assertions 5 and 6) teachers commented that students' and their own preferences for visual explanations in biology are strong. Visual representations appear consistent with network, relational and three-dimensional thinking within interpretational frameworks. Implications of these findings are that these teachers' observations and understanding of their students when discussing questions and tests suggest that visual preferences are strong in biology. This could have implications for possible increases in the accommodation of visual representations in assessment materials. These teachers considered that students used different frameworks for different domain areas, which is worth further investigation.

14. Study teachers' interpretational frameworks used in planning, implementing and achieving assessment in their domain within the explicit area of PCaK.

Teachers' understanding of student frameworks in biology and assessment contexts could inform PCK with more targeted research undertaken in this area. In identifying its own footprint within PCK, assessment could be represented by use of an additional notation, for example *Pedagogical Content assessment Knowledge* (*PCaK*). An analysis of the place of the *nature of science (nos)* in PCK by van Dijk (2014) presented a similar situation and could be identified as PCnosK. There are implications for PCK research in the identification of PCaK with its own character.

Section 8.3.1 has outlined 14 recommendations for research and explained how these have arisen from the data and analysis presented in this study.

8.3.2 Limitations and concluding comments

The limitations within the study have resulted in the recommendations in Section 8.3.1 for further research. A corpus of research could provide reliable evidence to inform teachers, educators and policy and curriculum authorities about the influence of teachers' interpretational frameworks in assessment. The accounts of six teachers in this study, though interviews and discussions of a limited number of test questions and answers, could be seen as a partial view of each teacher's whole thinking and interpretational frameworks. The explication of teachers' perceptions and interpretational frameworks forming the research captured a meaningful part of their experience at a particular time. The findings of the research point in worthwhile directions and provide rich scope for further research.

This study has provided an understanding of the complexity and the nature of biology teachers' interpretational frameworks in assessment contexts. The level of organisation, mastery and achievement in assessments in biology depends on the dynamism and comprehensiveness of the frameworks used by the teachers. The teachers' responsiveness and awareness is critical in recognising questions and answers and the thinking of students within the classroom and test environments. Their understandings of the complexity of knowledge required in the assessment process and assessment frameworks held by their students are significant. Pedagogical Content assessment Knowledge is proposed as a major organising feature within teachers' interpretational frameworks in the context of assessment.

References

Abell, S. K. (2007). Research on science teacher knowledge. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education*. Mahwah, NJ: Lawrence Erlbaum Associates.

Abell, S. K. (2008). Twenty years later: Does pedagogical content knowledge remain a useful idea? *International Journal of Science Education, 30*(10), 1405-1416. doi: 10.1080/09500690802187041

Andersson, B. (1986). The experiential gestalt of causation: A common core to pupils' preconceptions in science. *European Journal of Science Education, 8*(2), 155-171.

Atkinson, P., & Delamont, S. (2005). Analytic perspectives. In N. K. Denzin & Y. S. Lincoln (Eds.), *The SAGE handbook of qualitative research* (3rd ed., pp. 821-840). Thousand Oaks, CA: Sage.

Australian Academy of Science. (1981a). *Biological Science: The web of life (Part One and Part Two)* (3rd ed.). Canberra, Australia: Author.

Australian Academy of Science. (1981b). *Biological Science: The web of life (Teachers Guide Part 2)*. Canberra, Australia: Author.

Australian Academy of Science. (1990). *Biology: The common threads (Part 1 Teachers resource book)*. Canberra, Australia: Author.

Berliner, D. C. (1986). In pursuit of the expert pedagogue. *Educational Researcher, 15*(1), 5-13.

Berry, A., Loughran, J., & van Driel, J. H. (2008). Revisiting the roots of pedagogical content knowledge. *International Journal of Science Education, 30*(10), 1271-1279. doi: 10.1080/09500690801998885

Biggs, J. B., & Collis, K. F. (1982). *Evaluating the quality of learning: the SOLO taxonomy*. New York, NY: Academic Press.

Biological Sciences Curriculum Study. (1959). Biological Sciences Curriculum Study formed. *Science, 130*(3385), 1328.

Biological Sciences Curriculum Study. (1963). *High school biology: BSCS green version*. Chicago, IL: Rand McNally.

Biological Sciences Curriculum Study. (1993). *Developing biological literacy: A guide to developing secondary and post-secondary biology curricula*. Colorado Springs, CO: Author.

Biological Sciences Curriculum Study. (2006). *BSCS Biology: A human approach (teacher guide)* (3rd ed.). Dubuque, IA: Kendall/Hunt.

Blackmore, J. (1988). *Assessment and accountability*. Geelong, Australia: Deakin University.

Bloom, B. S. (Ed.). (1956). *Taxonomy of educational objectives: The classification of educational goals. Handbook 1, Cognitive domain*. London, UK: Longman.

Blumer, H. (1969). *Symbolic interactionism: Perspective and method*. Englewood Cliffs, NJ: Prentice Hall.

BouJaoude, S. B. (1991). A study of the nature of students' understanding about the concept of burning. *Journal of Research in Science Teaching, 28*(8), 689-704.

Bowen, G. M., Roth, W. -M., & McGinn, M. K. (1999). Interpretations of graphs by university biology students and practicing scientists: Towards a social practice view of scientific representational practices. *Journal of Research in Science Teaching, 36*(9), 1020-1043.

Brady, L., & Kennedy, K. (2001). *Celebrating student achievement: Assessment and reporting*. Frenchs Forest, Australia: Pearson.
Bramley, T. (2008, September). *Mark scheme features associated with different levels of marker agreement.* Paper presented at the annual conference of the British Educational Research Association (BERA), Herriot-Watt University, Edinburgh, UK.
Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2000). *How people learn: Brain, mind, experience and school (Expanded edition)*. Washington, DC: National Academy Press.
Brehmer, B. (1992). Dynamic decision making: Human of complex systems. *Acta Psychologica, 81*(3), 211-241.
Briscoe, C. (1993). Using cognitive referents in making sense of teaching: A chemistry teacher's struggle to change assessment practices. *Journal of Research in Science Teaching, 30*(8), 971-987.
Broadfoot, P., & Black, P. (2004). Redefining assessment? The first ten years of assessment in education. *Assessment in Education, 11*(1), 7-26.
Bronson, P., & Merryman, A. (2009). *Nurtureshock: New thinking about children*. New York, NY: Hachette Book Group.
Bryman, A. (2001). *Social research methods*. New York, NY: Oxford University Press.
Campbell, D. T. (1978). Qualitative knowing in action research. In M. Brenner, P. Marsh & M. Brenner (Eds.), *The social context of method*. New York, NY: St. Martin's.
Campbell, N. A., & Reece, J. B. (2003). *Biology*. San Francisco, CA: Addison Wesley.
Carlsen, W. S. (1999). Domains of teacher knowledge. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 133-144). Dordrecht, The Netherlands: Kluwer Academic.
Charmaz, K. (2000). Grounded theory: Objectives and constructivist methods. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 509-535). Thousand Oaks, CA: Sage.
Claxton, G. (1993). Minitheories: A preliminary model for teaching science. In P. J. Black & A. M. Lucas (Eds.), *Children's informal ideas in science* (pp. 45-61). London, UK: Routledge.
Cohen, L., Manion, L., & Morrison, K. (2000). *Research methods in education* (5 ed.). New York, NY: RoutledgeFalmer.
Cresswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (4th ed.). Boston, MA: Pearson Education.
Cresswell, J. W., & Miller, D. M. (2000). Determining validity in qualitative inquiry. *Theory into Practice, 39*(3), 124-130.
Cresswell, M. J. (1997). *Examining judgements: Theory and practice of awarding public examination grades.* (Thesis submitted for the degree of Doctor of Philosophy), Institute of Education, University of London, London, UK.
Crisp, V. (2013). Criteria, comparison and past experiences: How do teachers make judgements when marking coursework? *Assessment in Education: Principles, Policy and Practice, 20*(1), 127-144.
Cronbach, L. J. (1975). Beyond the two disciplines of scientific psychology. *American Psychologist, 30*(2), 116-127.

Cronbach, L. J., & Gleser, G. C. (1965). *Psychological tests and personnel decisions* (2nd ed.). Urbana, IL: University of Illinois Press.

Crotty, M. (1998). *The foundations of social research: Meaning and perspective in the research process.* Crows Nest, Australia: Allen & Unwin.

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. New York, NY: HarperCollins.

Curriculum Council of Western Australia. (1998). *Curriculum framework for kindergarten to year 12 education in Western Australia*. Osborne Park, Australia: Author.

Curriculum Council of Western Australia. (2001). *Making Progress*. Perth, Australia: Author.

Curriculum Council of Western Australia. (2005). *Science Progress Maps*. Perth, Australia: Author.

Darling-Hammond, L., Bransford, J. D., & LePage, P. (2005). Introduction. In L. Darling-Hammond & J. D. Bransford (Eds.), *Preparing teachers for a changing world* (pp. 1-39). San Francisco, CA: John Wiley & Sons.

Dennis, L., Newstead, S. E., & Wright, D. E. (1996). A new approach to exploring biases in educational assessment. *British Journal of Psychology, 87*(4), 515-534.

Denzin, N. K. (1971). The logic of naturalistic inquiry. *Social Forces, 50*(2), 166-181.

Denzin, N. K. (1989). *The research act: A theoretical introduction to sociological methods* (3rd ed.). Englewood Cliffs, NJ: Prentice Hall.

Denzin, N. K., & Lincoln, Y. S. (2005). Introduction. In N. K. Denzin & Y. S. Lincoln (Eds.), *The SAGE handbook on qualitative research* (3rd ed.). Thousand Oaks, CA: Sage.

Denzin, N. K., & Lincoln, Y. S. (Eds.). (1994). *Handbook of qualitative research*. Thousand Oaks, CA: Sage.

Department of Education and Science. (1989). *Science at age 13: A review of APU findings*. London, UK: HMSO.

Department of Education and Skills. (2013). Curriculum and syllabus information: Senior cycle. Retrieved from http://www.education.ie/en/Schools-Colleges/Information/Curriculum-and-Syllabus/Senior-Cycle-/

diSessa, A.A., Gillespie, N.M., & Esterly, J.B. (2004). Coherence versus fragmentation in the development of the concept of force. *Cognitive Science, 28*(6), 843-900.

Donmoyer, R. (1990). Generalisability and the single-case study. In E. W. Eisner & A. Peshkin (Eds.), *Qualitative inquiry in education: The continuing debate*. New York, NY: Teachers College Press.

Donovan, M. S., Bransford, J. D., & Pellegrino, J. W. (1999). *How people learn: Bridging research and practice*. Washington, DC: National Academies Press.

Dorner, D. (1996). On the difficulties of decision making in complex and uncertain domains of reality. *Journal of the European Society for Opinion and Marketing Research (ESOMAR), 24*(1), 51-60.

Dowd, A, & Dekkers, J. (1980). Class and teacher opinions of the Web of Life biology course. *Journal of Biological Education, 14*(3), 237-244.

Duffee, L., & Aikenhead, G. (1992). Curriculum change, student evaluation, and teacher practical knowledge. *Science Education, 76*(5), 493-506.

Education Department of Western Australia. (1998). *Science: Outcomes and standards framework*. East Perth, Australia: Author.

Edwards, W. (1962). Dynamic decision theory and probabilistic information processing. *Human Factors, 4*, 59-73.
Eilam, B. (2013). Possible constraints of visualization in biology: Challenges in learning with multiple representations. In D. F. Treagust & C.-Y. Tsui (Eds.), *Multiple representations in biological education* (pp. 55-73): SpringerLink (Online service).
Einhorn, H. J. (2000). Expert judgement: Some necessary conditions and an example. In T. Connolly, H. R. Arkes & K. R. Hammond (Eds.), *Judgement and decision making: An interdisciplinary reader* (2nd ed., pp. 324-335). Cambridge, UK: Cambridge University Press.
Eisner, E.W. (1979). *The educational imagination: On the design and evaluation of school programs*. New York, NY: Macmillan.
Elander, J., & Hardman, D. (2002). An application of judgment analysis to examination marking in psychology. *British Journal of Psychology, 90*(3), 303-326.
Erickson, F. (1986). Qualitative methods in research on teaching. In M. C. Wittrock (Ed.), *Handbook of research on teaching*. New York, NY: Macmillan.
Falk, A. (2012). Teachers learning from professional development in elementary science: Reciprocal relations between formative assessment and pedagogical content knowledge. *Science Education, 96*(2), 265-290. doi: 10.1002/sce.20473
Flyvberg, B. (2011). Case study. In N. K. Denzin & Y. S. Lincoln (Eds.), *The SAGE handbook of qualitative research* (4th ed., pp. 301-316). Thousand Oaks, CA: Sage.
Foddy, W. (1993). *Constructing questions for interviews and questionnaires: Theory and practice in social research*. Cambridge, UK: University of Cambridge.
Geertz, C. (1973). *The interpretation of cultures*. New York, NY: Basic Books.
Genishi, C. (1997). Assessing against the grain: A conceptual framework for alternative assessments. In L. Goodwin (Ed.), *Assessment for equity and inclusion: Embracing all our children* (pp. 35-50). New York, NY: Routledge.
Gess-Newsome, J. (1999). Pedagogical content knowledge: An introduction and orientation. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 3-17). Dordrecht, The Netherlands: Kluwer Academic.
Gilbert, J. K. (2008). Visualization: An emergent field of practice and enquiry in science education. In J. K. Gilbert, M. Reiner & M. Nakhleh (Eds.), *Visualization: Theory and practice in science education* (pp. 3-24). New York, NY: Springer.
Gilbert, J. K., Reiner, M., & Nakhleh, M. (Eds.). (2008). *Visualization: Theory and practice in science education*. New York, NY: Springer.
Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Chicago, IL: Aldine.
Gonzales, C., Lerch, J. F., & Lebiere, C. (2003). Instance-based learning in dynamic decision making. *Cognitive Science, 27*(4), 591-635.
Grainger, P., Purnell, K., & Kipf, R. (2008). Judging quality through substantaive conversations between markers. *Assessment and Evaluation in Higher Education, 33*(2), 133-142.
Guba, E. G. (1990). *The paradigm dialog*. Newbury Park, CA: Sage.

Guba, E. G., & Lincoln, Y. S. (1989). *Fourth generation evaluation*. Newbury Park, CA: Sage.

Hamlyn, D. W. (1995). Epistomology, history of. In T. Honderich (Ed.), *The Oxford companion to philosophy* (pp. 242-245). Oxford, UK: Oxford University Press.

Hattie, J. A. C. (2009). *Visible learning: A synthesis of over 800 meta-analyses relating to achievements*. Abingdon, UK: Routledge.

Hauslein, P. L., Good, R. G., & Cummins, C. L. (1992). Biology content cognitive structure: From science student to science teacher. *Journal of Research in Science Teaching, 29*(9), 939-964.

Hitchcock, G., & Hughes, D. (1995). *Research and the teacher* (2nd ed.). London, UK: Routledge.

Johnson-Laird, P. N. (1983). *Mental models: Towards a cognitive science of language, inference, and consciousness*. Cambridge, MA: Harvard University Press.

Kahneman, D., & Frederick, S. (2002). Representativeness revisited: attribute substitution in intuitive judgment. In T. Gilovich, D. Griffin & D. Kahneman (Eds.), *Heuristics and biases: The psychology of intuitive judgment*. Cambridge, UK: Cambridge University Press.

Kamen, M. (1996). A teacher's implementation of authentic assessment in an elementary science classroom. *Journal of Research in Science Teaching, 33*(8), 859-877.

Kapyla, M., Heikkinen, J.-P., & Asunta, T. (2009). Influence of content knowledge on pedagogical content knowledge: The case of teaching photosynthesis and plant growth. *International Journal of Science Education, 31*(10), 1395-1415. doi: 10.1080/09500690802082168

Kokkotas, P., Vlachos, I., & Koulaidis, V. (1998). Teaching the topic of the particulate nature of matter in prospective teachers' training courses. *International Journal of Science Education, 20*(3), 291-303.

Laming, D. (2004). *Human judgment: The eye of the beholder*. London, UK: Thompson Learning.

LeCompte, M. D., & Preissle, J. (1993). *Ethnography and qualitative design in educational research* (2nd ed.). San Diego, CA: Academic Press.

Lincoln, Y. S. (1995). Emerging criteria for quality in qualitative and interpretive research. *Qualitative inquiry, 1*(3), 275-289.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Thousand Oaks, CA: Sage.

Lopez, A., Atran, S., Coley, J. D., & Medin, D. L. (1997). The tree of life: Universal and cultural features of folkbiological taxonomies and inductions. *Cognitive Psychology, 32*(3), 251-295.

Loughran, J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching, 41*(4), 370-391.

Lucas, A. M. (1980). The development of a curriculum monopoly in Australian secondary schools: Biological Science: The Web of Life 1 Origins and spread. *Journal of Biological Education, 14*(1), 15-28.

Macquarie University. (2001). *Macquarie Dictionary* (Revised 3rd ed.). Sydney, Australia: The Macquarie Library.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 95-132). Dordrecht, The Netherlands: Kluwer Academic.

Marton, F., & Booth, S. (1997). *Learning and awareness*. Mahwah, NJ: Lawrence Erlbaum Associates.

Masters, G. N. (2014). Assessment: Getting to the essence. *Designing the Future*, Issue 1. Retrieved from http://www.acer.edu.au/files/uploads/Assessment_Getting_to_the_essence.pdf

Maxwell, J. A. (2005). *Qualitative research design: An interactive approach.* (2nd ed.). Thousand Oaks, CA: Sage.

McClelland, J. L. (1995). Toward a pragmatic connectionism. In P. Baumgartner & S. Payr (Eds.), *Speaking minds: Interviews with twenty eminent cognitive scientists* (pp. 131-144). Princeton, NJ: Princeton University Press.

Merriam, S. B. (1998). *Qualitative research and case study applications in education* (Rev. ed.). San Francisco, CA: Jossey-Bass.

Merriam-Webster. (2014). Dictionary. Retrieved from http://www.merriam-webster.com/dictionary

Messick, S. (1989). Validity. In R. L. Linn (Ed.), *Educational measurement:* (3rd ed., pp. 13-103). New York, NY: American Council on Education/Macmillan.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd ed.). Thousand Oaks, CA: Sage.

Minichiello, V., Aroni, R., Timewell, E., & Alexander, L. (1990). *In-depth interviewing: Researching people*. Melbourne, Australia: Longman Cheshire.

Minsky, M. (1975). A framework for representing knowledge. In P. H. Winston (Ed.), *The psychology of computer vision* (pp. 211-277). New York, NY: McGraw-Hill.

Mislevy, R. J. (1994). Evidence and inference in educational assessment. *Psychometrika, 59*(3), 439-483.

Mislevy, R. J. (1996). Test theory reconceived. *Journal of Educational Measurement, 33*(4), 379-416.

Morgan, D. G. (Ed.). (1967). *Biological science: The web of life*. Canberra, Australia: Australian Academy of Science.

Morrison, J. A., & Lederman, N. G. (2003). Science teachers' diagnosis and understanding of students' preconceptions. *Science Education, 87*(6), 849-867.

Mulhall, P., Berry, A., & Loughran, J. (2003). Frameworks for representing science teachers' pedagogical content knowledge. *Asia-Pacific Forum on Science Learning and Teaching, 4*(2), Article 2. Retrieved from http://www.ied.edu.hk/apfsit/

National Academy of Sciences. (2012). *A framework for K-12 science education: Practices, crosscutting concepts and core ideas*. Washington, DC: National Academies Press.

OCR. (2013). AS/A Level GCE Biology - H021, H421 Specification. Retrieved from http://www.ocr.org.uk/qualifications/as-a-level-gce-biology-h021-h421/

Ossimitz, G. (2000). *Entwicklung systemischen Denkens. Theoretische Konzepte und empirische Untersuchungen [Development of systems thinking: Theoretical concepts and empirical studies]*. Munich, Germany: Profil-Verlag.

Patton, M. Q. (1990). *Qualitative evaluation and research methods* (2nd ed.). Newbury Park, CA: Sage.

Pellegrino, J. W. (2012). The design of an assessment system focused on student achievement: A learning sciences perspective on issues of competence, growth, and measurement. In B. S., K. Neumann & P. Nentwig (Eds.), *Making it tangible: Learning outcomes in science education* (pp. 63-93).

Pellegrino, J. W., Chudowsky, N., & Glaser, R. (Eds.). (2001). *Knowing what students know: The science and design of educational assessment*. Washington, DC: National Academy Press.

Piaget, J. (1960). *The child's conception of the world*. Atlantic Highlands, NJ: Humanities Press.

Pozzer, L. L., & Roth, W. -M. (2003). Prevalence, structure, and functions of photographs in high school biology textbooks. *Journal of Research in Science Teaching, 40*(10), 1089-1114.

Preissle, J. (2011). Qualitative futures: Where we migfht go from where we've been. In N. K. Denzin & Y. S. Lincoln (Eds.), *The SAGE handbook of qualitative research* (4th ed., pp. 685-698). Thousand Oaks, CA: Sage.

Raikes, N., & Massey, A. (2007). Item-level examiner agreement. *Research Matters: A Cambridge Assessment Publication, 4*, 34-38.

Reason, P. (1988). Introduction. In P. Reason (Ed.), *Human inquiry in action: Developments in new paradigm research*. Newbury Park, CA: Sage.

Riess, W., & Mischo, C. (2010). Promoting systems thinking through biology lessons. *International Journal of Science Education, 32*(6), 705-725.

Roth, K. J. (2007). Science teachers as researchers. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 1203-1259). Mahwah, NJ: Lawrence Erlbaum Associates.

Rumelhart, D. A. (1980). Schemata: The building blocks of cognition. In R. Spiro, B. Bruce & W. Brewer (Eds.), *Theoretical issues in reading comprehension* (pp. 33-58). Hillsdale, NJ: Erlbaum.

Sadler, D. R. (1989). Formative assessment and the design of instructional systems. *Instructional Science, 18*(2), 119-144.

Sadler, D. R. (1998). Formative assessment: Revisiting the territory. *Assessment in Education: Principles, Policy & Practive, 5*(1), 77-84.

Sadler, D. R. (2005). Interpretations of criteria-based assessment and grading in higher education. *Assessment & Evaluation in Higher Education, 30*(2), 175-194.

Sanders, M. (1993). Erroneous ideas about respiration: The teacher factor. *Journal of Research in Science Teaching, 30*(8), 919-934.

Schauble, L. (1996). The development of scientific reasoning in knowledge-rich contexts. *Developmental Psychology, 32*(1), 102-119.

Schon, D. A. (1983). *The reflective practitioner: How professionals think in action*. New York, NY: Basic Books.

Schonborn, K. J., & Bogeholz, S. (2009). Knowledge transfer in biology and translation across external representations: Experts' views and challenges for learning. *International Journal of Science and Mathematics Education, 7*(5), 931-955.

Schonborn, K. J., & Bogeholz, S. (2013). Experts' views on translation across multiple external representations in acquiring biological knowledge about ecology, genetics, and evolution. In D. F. Treagust & C.-Y. Tsui (Eds.),

Multiple representatiions in biological education (pp. 111-128): SpringerLink (Online service).
Schum, D. A. (1987). *Evidence and inference for the intelligence analyst*. Lanham, MD: University Press of America.
SCSA. (2009). Senior Secondary Biological Sciences course. Retrieved from http://www.scsa.wa.edu.au/internet/Senior_Secondary/Courses/WACE_Courses/Biological_Sciences
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).
Siegler, R. S. (2005). Children's learning. *American Psychologist, 60*(8), 767-778. doi: 10 1037/0003-066X.60.8.767
Siegler, R. S., & Araya, R. (2005). A computational model of unconscious and conscious strategy development. In A. Kail (Ed.), *Advances in child development: Vol 33* (pp. 1-42). Oxford, UK: Elsevier.
Siegler, R. S., & McGilly, K. (1989). Strategy choices in children's time-telling. In I. Levin & D. Zakay (Eds.), *Time and human cognition: A life span perspective* (pp. 185-218). Amsterdam, The Netherlands: Elsevier Science.
St.Pierre, E. A. (2011). Post qualitative research: The critique and the coming after. In N. K. Denzin & Y. S. Lincoln (Eds.), *The SAGE handbook of qualitative research* (4th ed., pp. 611-626). Thousand Oaks, CA: Sage.
Stake, R. E. (1978). The case study method in social inquiry. *Educational Researcher, 7*(1), 5-8.
Stanovich, K., & West, R. (2002). Individual differences in reasoning. In T. Gilovich, D. Griffin & D. Kahneman (Eds.), *Heuristics and biases: The psychology of intuitive judgment*. Cambridge, UK: Cambridge University Press.
Strauss, A. (1995). Notes on the nature and development af general theories. *Qualitative inquiry, 1*(1), 7-18. doi: 10.1177/107780049500100102
Suto, W. M. I., & Greatorex, J. (2008). What goes through an examiner's mind? Using verbal protocols to gain insights into the GCSE marking process. *British Educational Research Journal, 34*(2), 213-233.
Suto, W. M. I., & Nadas, R. (2008). What determines GCSE marking accurcy? An exploration of expertise among maths and physics markers. *Research Papers in Education, 23*(4), 477-497.
Suto, W. M. I., Nadas, R., & Bell, J. (2011). Who should mark what? A study of factors affecting marking accuracy in a biology examination. *Research Papers in Education, 26*(1), 21-51.
Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction, 4*(4), 295-312.
Taber, K. S. (2000). Multiple frameworks?: Evidence of manifold conceptions in individual cognitive structure. *International Journal of Science Education, 22*(4), 399-417. doi: 10.1080/095006900289813
Tomlinson, C. A., & Moon, T. R. (2013). *Assessment and student success in a differentiated classroom*. Alexandria, VA: ASCD.
Townsend, C., Begon, M., & Harper, J. L. (2008). *Essentials of ecology*. Oxford, UK: Blackwell.
Treagust, D. F., & Tsui, C.-Y. (2013). Contributions of multiple representations to biological education. In D. F. Treagust & C.-Y. Tsui (Eds.), *Multiple*

representations in biological education (pp. 349-367): SpringerLink (Online service).

Tsui, C.-Y., & Treagust, D. F. (2013). Introduction to multiple representations: Their importance in Biology and biological education. In D. F. Treagust & C.-Y. Tsui (Eds.), *Multiple representations in biological education* (pp. 3-18): SpringerLink (Online service).

van Dijk, E. M. (2014). Understanding the heterogegeous nature of science: A comprehensive notion of PCK for scientific literacy. *Science Education, 98*(3), 397-411. doi: 10.1002/sce21110

Vosniadou, S. (1992). Knowledge acquisition and conceptual change. *Applied Psychologist, 41*(4), 347-357.

Walker, R. (1980). The conduct of educational case studies: Ethics, theory and procedures. In W. B. Dockerell & D. Hamilton (Eds.), *Rethinking educational research*. London, UK: Hodder & Stoughton.

Wallace, J., & Louden, W. (2000). *Teachers' learning: Stories of science education*. Dordrecht, The Netherlands: Kluwer Academic.

Walster, P. (1997). *TEE Study Guide: Biology* (2nd ed.). Perth, Australia: Academic Associates.

Welman, J. C., & Kruger, S. J. (1999). *Research methodology for the business and administrative sciences*. Johannesburg, South Africa: International Thompson.

Wiggins, G. (1998). *Educative assessment: Designing assessments to inform and improve student performance*. San Francisco, CA: Jossey-Bass.

Wiliam, D. (2003). Validity: All you need in assessment. *School Science Review, 86*(315), 79-82.

Wilson, S. (1979). Exploration of the usefulness of case study evaluations. *Educational Quarterly, 3*, 446-459.

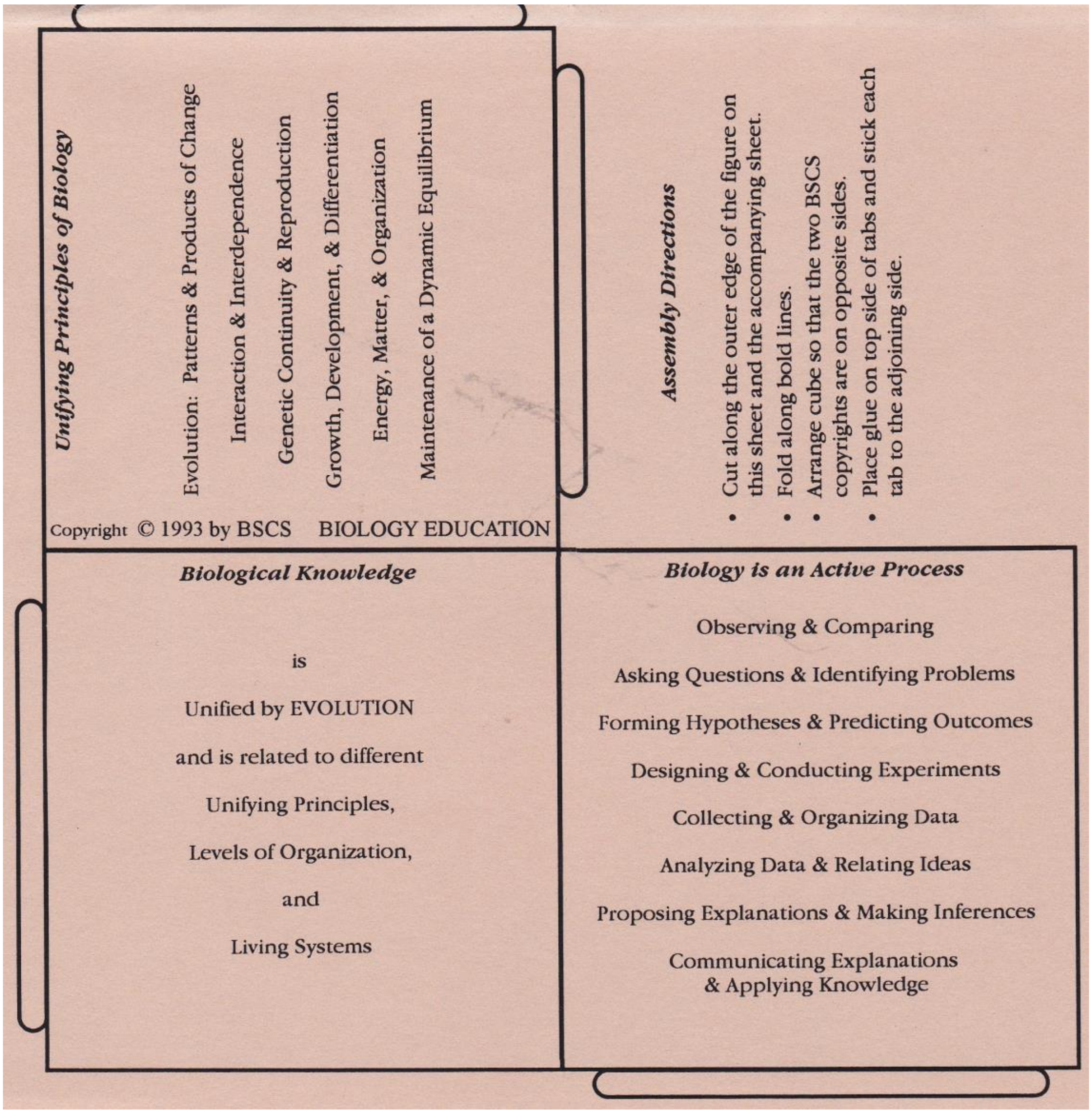
Yin, R. K. (1994). *Case study research: Design and methods*. Thousand Oaks, CA: Sage.

Yore, L. D., & Treagust, D. F. (2006). Current realities and future possibilities: Language and science literacy-empowering research and informing instruction. *International Journal of Science Education, 28*(2-3), 291-314.

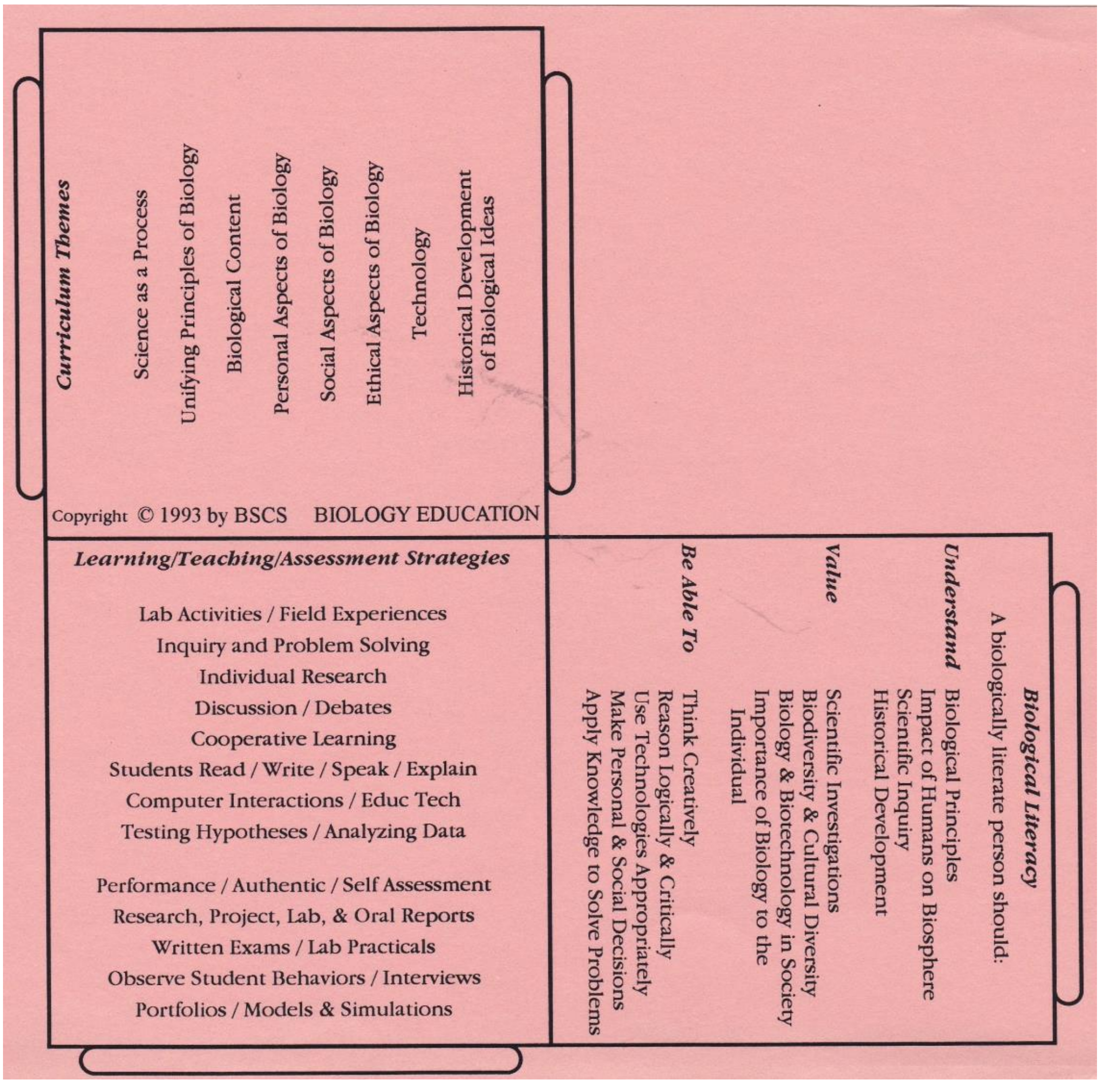
Appendices

Appendix 1 BSCS biology cube, 1993

Part 1 of cube



Part 2 of cube



Appendix 2 The interview Schedule

Questions used in teacher interviews

Why did you ask this question?

What is the body of knowledge expected in the question?

What did you expect in an answer?

What did the student answer that indicated depth of understanding?

What was your thinking when you rated/answered the question?

How did you rate/mark/level it? Why?

What did the student need to do to achieve a higher rating?

Could you have interpreted the student's answer in a different way?

Were there clues in the answer that would lead you to believe the student understands more than they wrote down, or alternatively that they have written a pre-prepared answer?

Do you think this was a good question (now that you have read the student's answer)?

Did it achieve your purpose?

Which questions do you feel most comfortable with? Why?

Which questions allow students to demonstrate their learning/achievement best? Why?

Appendix 3 Data from marked tests and teacher and student answers

Anthea

The following questions were selected for response analysis in consultation with the teacher.

Question 32d (Short answer, 4 marks)

A cell biologist obtained the following images when examining a cell with an electron microscope. (This is followed by two micrograph images, image A with arrow pointing to the grana of a chloroplast and image B pointing to the internal structure of a mitochondrion.)

Describe and explain the effect of a slow increase in temperature on the metabolism of these cells.

The teacher's answer to 32d was

"A slow temperature rise will increase metabolism (1)

Because according to kinetic theory particles move more quickly (1)

As temperature increases metabolism will peak then fall (1)

As enzymes become denatured (1)."

Question 32e(ii) (Short answer, 2 marks)

A cell biologist obtained the following images when examining a cell with an electron microscope. (This is followed by two micrograph images, image A with arrow pointing to the grana of a chloroplast and image B pointing to the internal structure of a mitochondrion.)

The biologist treated the cells with a detergent and was surprised to observe that the cytoplasm leaked into the surrounding fluid. Explain why this occurred."

The teacher's answer was:

“Cell membranes consist of a bi-lipid layer (1)

Detergents dissolve lipids hence cell contents leak out (1).”

Question 33a(i) (Short answer, 2 marks)

Water is an essential component of life. Many organisms expend much energy in maintaining a constant level of water in their bodies.

Provide two reasons why water is kept under homeostatic control in vertebrates. (S

The teacher’s answer was:

“Water levels affect the concentration of solutes and hence metabolism (1)

Water levels affect the concentration of solutes and hence osmotic balance (1).”

***Question 35c** (Short answer, 4 marks)*

Cell division is a process carried out by all cells and is illustrated in the diagram below. (The diagram shows three stages of a simple division, one ‘parent cell’ with arrow to one cell showing ‘DNA replicates’ in the nucleus of the cell, then the final stage showing two arrows to ‘2 daughter cells’.

Describe the circumstances in which carbon dioxide and lactic acid are produced.

The teacher’s answer was:

“In the absence of O2, pyruvic acid cannot enter the mitochondrion. It is converted to ethanol and CO2 in plants and lactic acid in animals / muscle tissue. Carbon dioxide is also produced during aerobic respiration in both plants and animals.”

Question 36a (Essay, 10 marks)

Describe the structure and importance of enzymes to the body. Include in your answer an explanation of the factors which affect enzyme activity.

The teacher’s answer was:

- “Enzymes are organic catalysts, ie some enzymes are protein in nature and can speed up a chemical reaction.
- Enzymes are specific to the reaction they can catalyse
- Each enzyme has a particular shape
- On the surface of the enzyme is the active site onto which another molecule, the substrate can fit
- Lock (substrate) and key (enzyme) mechanism
- The enzyme will hold the substrate which the chemical reaction occurs
- The changed molecule, the product is released, leaving the enzyme unchanged and able to catalyse more reactions. (6 marks for 6 points)

Factors which affect enzyme activity:

- Temperature-high temperatures will permanently denature enzymes while low temperatures will temporarily inactivate them
- Enzymes are sensitive to changes in pH – they work best at an optimum pH
- Their activity is affected by the concentration of both reactants and products. Increase in concentration leads to increase in activity until other factors become limiting
- Heavy metals and inhibitors can restrict their functioning. (max 4 marks)”

Students of Anthea (Students 1-4)

Four students were from a country senior high school and in Year 12. They all completed responses to a Semester exam written by their teacher, Teacher A.

Student 1 (AD)

AD is a male, 17 year old, Year 12 student. AD received 68% for his Semester 1 exam paper from the teacher.

Question 32d (Short answer, 4 marks)

AD’s response to Question 32d - “A product of respiration is heat. When external heat is increased, the metabolism of these cells would decrease so less heat is produced and therefore homeostasis is maintained. Too much heat can de-nature enzymes and therefore chemical reactions decrease.”

The teacher ticked “denature enzymes” and “chemical reactions decrease” and gave AD two marks out of a possible four marks.

Question 32e(ii) (Short answer, 2 marks)

AD’s response to Question 32e(ii)- “Detergent is used to break down lipids which are hydrophobic. The cell’s double membrane consists of a phosphate head with two fatty acid tails. The detergent broke down these fats, therefore the membrane dissolved and the cytoplasm leaked into surrounding fluid.”

The teacher ticked the sentence finishing with hydrophobic and the reference to the membrane dissolving with subsequent leakage, awarding two marks out of a possible two marks.

Question 33a(i) (Short answer, 2 marks)

AD’s response to Question 33a(i) - “water is an ideal medium for chemical reactions (because of cohesion) and therefore is used as a medium in organisms. Water level needs to be controlled so that chemical reaction can occur in a cell/organism (ie metabolism).”

The teacher gave one mark for “chemical reactions”.

Question 35c (Short answer, 4 marks)

AD’s response to Question 35c - “Carbon dioxide is a waste product of respiration. It comes from the oxidisation of carbon in glucose and is diffused from the blood to our lungs, then breathed out into the air. Lactic acid is produced in anaerobic respiration. Instead of pyruvic acid, lactic acid is produced so that small amounts of energy can be produced without oxygen (2 ATP). The build up of lactic acid in our muscles which we exercise causes fatigue.”

The teacher ticked the oxidisation of carbon in glucose point and the lactic acid, anaerobic connection, resulting in two marks out of a possible four marks.

Question 36a (Essay, 10 marks)

AD's response to Question 36a – "Enzymes are catalysts that decrease the initial energy requirements for chemical actions to take place. Enzymes are proteins and are polymers made from smaller sub-units called amino acids. Enzymes can be anabolic (building) or catabolic (breaking down). Enzymes have an active site which either breaks down large molecules into smaller, simpler molecules or make small molecules into large ones. The active site only acts on particular substrates which is referred to as the 'Lock and Key' method. [Diagram of 3 stages of the Lock and Key model are shown with substrate, enzyme and products labelled].

Because enzymes decrease the initial energy requirements for chemical reactions they are important if the body is to respirate fast enough and are therefore essential for survival. Enzymes can be re-used which means very few are needed but factors such as heat and pH can permanently denature the active site. If it is too high or low the enzymes get denatured and chemical reaction can no longer take place."

The teacher ticked "decrease the initial temperature requirements", "Enzymes have an active site", the sentence with "break down" and "making small molecules into large ones", the diagram, "enzymes can be reused", "denatured", and gave a score of 6 marks out of a possible 10 marks.

Student 2 (AJ)

AJ is a male, 17 year old, Year 12 student. AJ received 45% for his Semester 1 exam paper from the teacher.

Question 32d (Short answer, 4 marks)

"AJ's response to Question 32 d was "The cells would start to increase respiration till they hit their peak then start to slow down again until the cell denatures due to such high temperatures."

The teacher ticked “increase respiration” and gave a total of one mark out of a possible four marks.

Question 32e(ii) (Short answer, 2 marks)

AJ’s response to Question32e(ii) was “This is most likely due to osmosis. Because the detergent and cytoplasm are both water based; due to osmosis the salts present in detergent move from a high concentration (the detergent) to a low concentration (the cell) and therefore the cell shrinks and the cytoplasm expelled into the excess detergent.”

The teacher crossed the answer and gave zero out of a possible two marks.

Question 33a(i) (Short answer, 2 marks)

AJ’s response to Question 33a(i) was “Due to it being a vital part of respiration for vertebrates. Needed to expel nitrogenous wastes.”

The teacher crossed the answer and gave zero out of a possible two marks.

Question 35c (Short answer, 4 marks)

AJ’s response to 35c was “Carbon dioxide is produced in every process of respiration. Lactic acid though is made when all other energy sources have been used.”

The teacher ticked the end of the first sentence and crossed the second sentence and gave one out of a possible four marks.

Question 36a (Essay, 10 marks)

AJ’s response to 36a was “Enzymes are proteins. They are made / synthesised in ribosomes, they are also produced by the rough endoplasmic reticulum. Enzymes are used as catalysts to break down complicated molecules. These catalysts reduce the activation energy of cells and therefore make it easier to break down molecules such as sugar. Factors which affect enzyme activity though include respiration and heat. Respiration affects enzymes through energy. If there is not enough energy then there is no enzymes. Like most parts of cells and the cell itself heat affects enzymes. It causes the enzymes to work faster then eventually denature. A sketch can be used to explain this.

[Sketch shows a graph of cell/enzyme activity vs temperature – two parabolic graphs are compared, one showing activation energy needed for the reaction and the lower graph showing the reaction with an enzyme. The point of denaturing is shown].

Also with enzymes they follow a Lock and Key rule with breaking down or building molecules, example [diagram drawn showing 3 stages of Lock and Key model]. This process is also reversed to create simple molecules. But water may also be needed."

The teacher ticked "enzymes are used", "breakdown complicated molecules", "the molecules such as sugar" and "denature" and the diagram and gave a score of 4 marks out of a possible 10 marks.

Student 3 (AE)

AE is a female, 17 year old, Year 12 student in a large country town rural Catholic school. AE received 74% for her Semester 1 exam paper from the teacher.

Question 32d (Short answer, 4 marks)

AE's response to question 32d was – As a general rule metabolic activity would increase as temperature does however other factors may hinder this such as: pH and availability of the required reactants (ie; O2 etc). Also if the temp increases too much the enzymes may become denatured causing a decrease in metabolic activities and possible death.

The teacher ticked 'increase as temperature does, "(ie; O2 etc)" and "may become denatured" and gave four out of four marks.

Question 32e(ii) (Short answer, 2 marks)

AE's response to question 32e(ii) was – 1. The detergent has altered the concentration of the surrounding fluid, therefore water/slats etc., move out of the cytoplasm into the surrounding fluidly diffusion. 2. The detergent may have reacted with the cellular membrane causing it to break. This is very possible as the membrane is made up of a layer of lipids which are extremely soluble in detergent as shown below. [Diagram structure of detergent molecule with non-polar tail and polar head]. The hydrophobic tail digs into the membrane and wraps around it, much like when washing dishes i.e.[Diagram].

The teacher ticked “layer of lipids which are extremely soluble in detergent” and gave two out of four marks.

Question 33a(i) (Short answer, 2 marks)

AE’s response to question 33a(i) was - 1. Needed for cellular respiration. 2. Used as a solvent, within and outside of cells to allow particles to diffuse into and out of cell. 3. Also used for temp regulation in some organisms (i.e., sweat).

The teacher ticked “Needed for cellular respiration.” and “temp regulation in some organisms” and gave two out of two marks.

Question 35c (Short answer, 4 marks)

AE’s response to question 35c was – Aerobic respiration – 1. C6H12O6 -> pyruvic acid +2ATP. 2(a). Pyruvic acid + O2 -> CO2 + H2 + 36ATP. 2(b). Pyruvic acid -> 4 + lactic acid + 2ATP. Lactic acid is produced during anaerobic respiration due to a lack of available oxygen. CO2 is produced during aerobic respiration.

The teacher ticked “2(a). Pyruvic acid + O2 -> CO2 + H2 + 36ATP” “2(b). Pyruvic acid -> 4 + lactic acid + 2ATP” and “CO2 is produced during aerobic respiration” and gave three out of four marks.

Question 36a (Essay, 10 marks)

AE’s response to question 36a was – Enzymes are essential to all chemical reactions within a cell and/or organism. - They act as <u>organic catalysts</u> for the reactions in the body, therefore, they can be used over and over again. – The substance that an enzyme acts upon is called the <u>substrate</u> and the final products of the reaction are called the <u>products</u>. – Enzymes are termed <u>substrate specific</u>, as they are created to catalyse specific reactions. This can be further seen in the <u>“lock and key” model</u> of an enzyme at work. An example of this is seen below [Diagram of lock and key model for enzyme and substrate, showing products]. Note: the enzyme has not been altered, changed or used up, again supporting the fact that it is a catalyst and not a reactant in the reaction. Note: notice how the active site and the substrate match, this is why the enzyme is called substrate specific. The active site of the enzyme matches only one type of substrate.

Factors that affect enzyme activity are as follows: 1. Temperature: 2. Concentration of substrate and enzyme: 3. pH: 4. Competition with other molecules (inhibition). Let's look at these in more detail.

1. As a general rule, an increase in temperature generally means an increase in all cellular activity including enzyme activity. This is due to the fact that an increase in temp gives the particles enough energy (kinetic) to react, therefore increasing the rates of reaction. However if the temperature becomes too high, the active site of the enzyme can become denatured hence causing the enzyme to no longer work and leading to a decrease in the rate of that particular reaction and can eventually lead to death. This is why it is a problem if someones fever becomes too high or carries on for too long. 2. The concentration of the substrate and enzyme also affects the rate of enzyme activity. Generally a high concentration os substrate means an increased rate of reaction, however, once all the enzymes are in use, the rate of reaction can no longer increase any further. Likewise if the conc of the enzyme is greater than that of the substrate. Therefore from this we can conclude that the maximum rate of enzyme activity occurs when the amount of enzyme = the amount of substrate. 4. pH like temperature can again denature the active site of the enzymes . Most enzymes have an optimum pH and temperature in which they react, with generally a margin of about 3 (ph scale). [Diagram showing graph of 'rate of reaction' against 'pH', with tolerance range marked.] 4. In some cases, other molecules compete with the substrate for the active site. When this happens the molecule can bond permanently with the enzyme (inhibition). This is a serious problem as it interferes with the normal substrate-enzyme reaction and can lead to death. But what does an enzyme actually do? All reactions have a certain amount of energy required for the reaction to take place. This is called the activation energy and is denoted (Ea). What an enzyme does is lower the Ea required by providing and alternative path, ie: [Diagram, graph of Ea vs time]. Overall, the work of enzymes is essential to all life and a huge part of the world around us.

The teacher marked seventeen ticks on the answer sheet for “they can be used over and over again”, “final products of the reaction are called the products”, “substrate specific”, “lock and key model of an enzyme at work”, diagram of lock and key model, “enzyme has not been altered, changed or used up”, ‘temperature”, “concentration of substrate and enzyme”, “ pH”, “competition with other molecules” “denatured”, “fever becomes too high or carries on for too long”, “an increased rate of reaction”, “amount of enzyme = amount of substrate”, graph of rate of reaction vs pH, “interferes with the normal substrate-enzyme reaction and can lead to death” and “overall, the work of enzymes is essential to all life and a huge part of the world around us” and gave ten out of ten marks.

Student 4 (AK)

AK is a female, 17 year old, Year 12 student in a large country town rural Catholic school. AK received 84% for her Semester 1 exam paper from the teacher.

Question 32d (Short answer, 4 marks)

The student underlined “Describe”, “explain”, “slow increase in temperature” and “the metabolism of these cells” on the question paper.

AK’s response to question 32d was - Metabolism is the sum total of all the chemical reactions that occur in a cell. Many biological reactions are catalysed by enzymes. Hence increasing the temperature of the cells would increase their metabolic rates. This is because, at higher temperatures, enzymes are more effective and hence chemical reactions are able to occur more rapidly. If the temperature becomes too high – metabolic rate will dramatically drop, as enzymes will become denatured. But in general, an increase in temperature causes an increase in metabolic activity.

The teacher ticked “increase the metabolic rates”, “hence chemical reactions are able to occur more rapidly”, “If the temperature becomes too high – metabolic rate will dramatically drop” and “in general, an increase in temperature causes an increase in metabolic activity” and gave four out of four marks.

Question 32e(ii) (Short answer, 2 marks)

AK's response to question 32e(ii) was - The cell membrane of animal cells is composed of a phospholipid bilayer – with the hydrophobic (non-polar) tails pointing inwards and the hydrophilic (polar) heads pointing outwards. Hence the membrane is composed mainly of fats. Detergent is designed to break down fats by interacting and disrupting the bonding between lipid molecules. Therefore the detergent disrupted the cell membrane's structure. This caused the cell's contents (cytoplasm) to leak away. [Diagram included, showing cell membrane structure with phospholipid bilayer]

The teacher ticked "The cell membrane of animal cells is composed of a phospholipid bilayer" and "Detergent is designed to break down fats" and gave two out of two marks.

Question 33a(i) (Short answer, 2 marks)

The student underlined "kept under homeostatic control" on the question paper.

AK's response to question 33a(i) was - 1. Water levels must be kept constant, because water is needed for all metabolic reactions in cells (therefore must have enough of it). 2. Water also prevents cells from drying out and becoming dehydrated, therefore must stay constant.

The teacher ticked "water is needed for all metabolic reactions in cells" and "therefore must stay constant" and gave two out of two marks.

Question 35c (Short answer, 4 marks)

The student underlined "circumstances" "carbon dioxide" and "lactic acid" on the question paper.

AK's response to question 35c was – Carbon dioxide and lactic acid are products of anaerobic respiration in humans. Anaerobic respiration occurs in the absence of oxygen, hence these products would be produced in condition when oxygen was scarce (i.e., there is not enough oxygen available to supply all cells with aerobic respiration). This may occur when the person is carrying out strenuous muscle activity and the cells require large amounts of oxygen.

The teacher ticked “carbon dioxide” and “anaerobic respiration” and gave two out of four marks.

Question 36a (Essay, 10 marks)

AK’s response to question 36a was – Enzymes are essentially molecules of protein, hence they consist of amino acids (monomers). An enzyme is a biological catalyst, a catalyst being any substance that has the ability to increase the rate of a chemical reaction, without being permanently consumed in the reaction. Enzymes increase the rate of chemical reactions by lowering the activation energy required for the reaction to succeed.

Enzymes are therefore of enormous importance to the body of any organism. All organisms have thousands of essential reactions occurring in their cells. Most of these reactions would require very large amounts of energy, if a catalyst was not present. Hence enzymes allow many essential reactions (such as photosynthesis – plant cells – respiration – animal cells) to proceed at relatively low temperatures. Enzymes are therefore essential to life.

The ‘lock and key’ theory of enzymes states that each enzyme has an ‘active site’, which <u>specific</u> substrates attach to. The enzyme is the ‘key’ that allows the substrate (‘lock’) to break apart or combine. [Diagram included showing lock and key mechanism]. The enzyme itself is unchanged after the reaction. Hence enzymes are highly specific, and their active site must be exactly the right shape to fit the substrate.

If the active site is altered in any way the enzyme can no longer function effectively. Hence several factors can affect enzyme activity. 1. Temperature – every enzyme has an ‘optimum’ temperature, at which it works best. If the temperature becomes too high, the enzyme’s active site begins to be altered, and the enzyme is <u>denatured.</u> It is no longer effective as the active site cannot bond with the substrate. Denaturation is irreversible. If the temperature is too <u>low</u>, the enzyme may become also inactive, although this is reversible. 2. pH – every enzyme also has an optimum pH. If the enzyme’s environment becomes too acidic or basic, the active site may again be altered (shape changed) and the enzyme will not function as effectively.

The teacher marked eleven ticks on the answer sheet for "molecules of protein", "biological catalyst", "lowering the activation energy required for the reaction to succeed", "an 'active site', which specific substrates attach to", the diagram, "unchanged after the reaction", 'right shape to fit the substrate", "1. Temperature", "temperature is too low", "optimum pH" and "not function as effectively" and gave ten out of ten marks.

Howard

The following questions were selected for response analysis in consultation with the teacher.

Question 32c (Short answer, 3 marks)

Describe three (3) ways organisms may GAIN or LOSE heat.

The teacher's answer was:

- radiation
- conduction
- evaporation

Question 32f (Short answer, 4 marks)

Explain the advantages of hibernation to an animal like a bat, when ambient temperature drops significantly below that of body temperature.

The teacher's answer was:

- activity goes down
- metabolism goes down
- heat loss goes down
- conserve energy

Question 36a (Short answer, 4 marks)

Many animals have a range of strategies to keep themselves warm in winter and cool in summer. Scientists have studied two different marsupials in Western Australia, the red-tailed phascogale and the quokka wallaby, and compared their structure, characteristics and behaviour. [Data for characteristics related to surface area and heat loss in the two mammals were given in a table.]

Using the information in the table discuss the relationship between body size and metabolic rate.

The teacher's answer was:

- Phascogale: metabolic rate goes up, small body mass
- Quokka: metabolism goes down, heat production goes down – large body mass

Question 37ii (Short answer, 3 marks)

In most cells, genetic information is stored in a code in large molecules in the nucleus. This is transferred to smaller molecules which pass out of the nucleus and become attached to structures labelled 'Ribosomes' in the diagram below. (Note that the organelles in this diagram are not drawn to scale.) [A diagram of a cell follows, with nucleus and ribosomes labelled.]

Briefly describe how these molecules store information.

The teacher's answer was:

- 4 nucleotides
- paired specifically
- triplets of pairs in many formations

Question 38a (Essay, 10 marks)

Compare the processes of aerobic and anaerobic respiration in terms of sites where they occur in the cell, requirements, products (including wastes) and the circumstances under which each occurs.

Question 38b (Essay, 10 marks)

Describe and explain the processes of diffusion and osmosis, highlighting the differences between them. Give reasons for the importance of osmosis to living cells.

Question 38c (Essay, 10 marks)

Compare the Pygmy Mulga Monitor lizard and the Kultarr (a small marsupial mouse) in regards to

(i) How the internal body temperature of each are affected by extremes of environmental temperature

(ii) How each maintains internal temperature within certain limits.

Both live in the same region of Central Australia, where extreme temperature differences occur between day and night.

Question 38d (Essay, 10 marks)

Homeostasis is the maintenance of a relatively constant internal environment within a living organism. In order to survive, living cells must be baths in a fluid whose properties are not allowed to vary beyond certain limits.

Make a list of the internal conditions that an organism must regulate in order to survive and give a reason for the regulation of each.

Question 39b (Essay, 10 marks)

Cloning of organisms is a common practice in our society. For example, genetically engineered bacterial cells are cloned to produce large quantities of human hormones, which are used to treat individuals with hormone deficiencies. Commercially important plants such as cabbage, citrus fruits, carrots, tomatoes and *potatoes can be grown from a single cell taken from an adult plant. Recently, animals such as mice and sheep have been cloned from their parents.*

It is clear from experiments such as these that all the genetic information required to produce a complete organism is contained in a single body cell.

Describe the structure and location of the substances involved in the stotage of this information, and show how it is possible for a single cell to give rise to a complete organism in which every cell contains identical genetic information.

Question 39c (Essay, 10 marks)

A polar bear is a large thickly furred mammal, which inhabits arctic environments in Canada, Alaska and Russia. Polar bears used to be kept in Perth Zoo, but a few years ago the zoo decided not to replace the polar bears after they died.

Describe the problems that an arctic mammal like the polar bear would experience in a warm climate like Perth's and explain the biological reasons for those problems.

Question 39d (Essay, 10 marks)

Cartilaginous fish such as sharks, which live in the oceans, produce the nitrogenous waste urea. The y maintain this urea in high concentrations in their body tissues and fluids. These animals are thereby able to maintain a body osmotic concentration greater than that of seawater. Bony fish such as tuna, which also live in the oceans, produce ammonia as their main nitrogenous waste and do not retain it in their tissues. Their body osmotic concentration is below that of seawater.

Discuss the advantages and disadvantages of these two different strategies of nitrogenous waste production and osmotic concentration in the marine environment.

Students of Howard

Four students were from a city senior high school and in Year 12. They all completed responses to a Semester exam written by their teacher, Howard.

Student 5 (HA)

HA is a male, 17 year old, Year 12 student in a large city privately run co-ed high school. HA received 62% on the short answer and written sections for his Semester 1 exam paper from the teacher.

Question 32c (Short answer, 3 marks)

HA's response to Question 32c - "An organism may gain heat by raising its metabolic rate and it may also gain heat through heat radiation. It may also gain heat through raised activity (e.g. exercising in humans)."

The teacher wrote "how?" next to "raising its metabolism", ticked "radiation" and gave HA two marks out of a possible three marks.

Question 32f (Short answer, 4 marks)

HA's response to Question 32f- "It allows the organism to keep its oxygen consumption down which helps it not require energy so most of the energy is used to keep a optimal body temperature. It also allows the organism to have a low metabolic rate so it keeps heat production going and allows the organism to survive."

The teacher ticked "not require energy", "low metabolic rate" and heat production going" awarding three marks out of a possible four marks.

Question 36a (Short answer, 4 marks)

HA's response to Question 36a - "The red-tailed phascogale had a small body size but a large SA:volume ratio. This increased its heat loss so its metabolic rate increases to increase the rate of heat production. The quokka wallaby has a larger body size so it has a smaller SA:volume ratio. It doesn't lose much heat so its metabolic rate is relatively low. The smaller the organism the higher its metabolic rate is and the larger the animal the lower its metabolic rate is."

The teacher ticked "large SA:volume ratio", "its metabolic rate increases", "increase the rate of heat production", "smaller SA:volume ratio" and "its metabolic rate is relatively low" and awarded four out of four marks.

Question 37ii (Short answer, 3 marks)

HA’s response to Question 37ii - “They store it in long double strands called DNA. DNA is made of 2 strands of acids pairing with each other. This contains all the genetic information of the cell.”

The teacher awarded one mark out of a possible three marks.

Question 39c (Essay, 10 marks)

HA’s response to Question 39c – “Polar bears cannot survive in a warm climate like Perth because they have adapted to freezing temperatures not warm temperatures.

The polar bear wouldn’t be able to stand the heat because it has adapted to have a thick fur coat to conserve heat. But in a warm environment the polar bear wouldn’t want to conserve heat and would eventually over heat and die. Polar bears also have a thick layer of fat which allows them to swim in water with temperatures below freezing. In Perth the water is warm compared to the artic waters so again the polar bear would overheat and result in its death.

The polar bear has also adapted to hibernate through the artic winter (which last about half a year). The polar bear would not be able to survive if it hibernated in Perth because the temperature is too great and the polar bear would end up dieing from exposure to hot temperature.

Basically the polar bear cannot survive in Perth’s warm climate because it has adapted to the freezing environment of the Arctic circle which makes it almost impossible for a polar bear to survive in Australia.”

The teacher ticked “thick fur coat”, “wouldn’t want to conserve heat”, “thick layer of fat” and “below freezing” and gave a score of 4 marks out of a possible 10 marks.

Student 6 (HL)

HL is a female, 17 year old, Year 12 student in a large city privately run co-ed high school. HL received 71% for her short answer and written sections of the Semester 1 exam paper from the teacher.

Question 32c (Short answer, 3 marks)

HL's response to Question 32c - "One way is radiation which is an indirect energy transfer in which the organism gains heat. Another way is conduction which is a direct energy transfer to or from an organism. One other way is evaporation in which organisms lose heat."

The teacher gave HL three marks out of a possible three marks.

Question 32f (Short answer, 4 marks)

HL's response to Question 32f- "Hibernation allows animals to retain body heat easier. As they are curled in a ball, this reduces the surface area over which heat can be lost. As the bat is not out in the cold weather, this also reduces heat loss and the body isn't as exposed to the cold. The bat being inactive during hibernation means less energy and heat need to be generated for usual activities such as walking and eating."

The teacher ticked "means less energy" awarding one mark out of a possible four marks.

Question 36a (Short answer, 4 marks)

HL's response to Question 36a - "As body size increases, metabolic rate decreases. The Quokka Wallaby has a greater mass (4000g) but has a lower metabolic rate (rate of heat production - 4J/g/h). This occurs because larger animals have a smaller surface area: mass ratio (0.5 cm2/g). Therefore they lose less heat and don't need a greater metabolism to generate the heat lost. Smaller animals have a greater surface area: mass, so they lose more heat and need a faster metabolism to regenerate heat."

The teacher ticked "greater mass", "lower metabolic rate", "greater surface area: mass" and "lose more heat" and awarded four out of four marks.

Question 37ii (Short answer, 3 marks)

HL's response to Question 37ii - "Chromosomes store information in the DNA, which is present in the genes which are in the chromosomes. Genetic information is stored in the DNA which is required for the cell to function."

The teacher awarded zero marks out of a possible three marks.

Question 38a (Essay, 10 marks)

HL's response to Question 38a – "Aerobic respiration is respiration involving the oxidation reaction of glucose. Oxygen is required. Aerobic respiration has slow ATP production, unlimited use time and efficient energy transfer. Aerobic respiration produces 36 ATP and occurs in the mitochondria.

Anaerobic respiration involves the breakdown of glucose in the absence of oxygen. Oxygen is not required. Anaerobic respiration has rapid ATP production, limited use time and inefficient energy transfer. Anaerobic respiration produces 2 ATP.

The diagram below shows the process of respiration, both aerobic and anaerobic, products produced and the requirements: [Diagram follows].

When aerobic respiration occurs without oxygen, either ethanol and CO2 are produced or lactic acid and H2O. When aerobic respiration occurs with oxygen CO2 and H2O are produced, long with 36 ATP.

In anaerobic respiration the process for the production for 2ATP and CO2 is called glycolysis. It's where glucose is broken down into pyruvate. In aerobic respiration there are two processes. The krebs' cycle occurs in the matrix of the mitochondria and sees the pyruvate diffuse into the mitochondria from the cytoplasm. Electron transport occurs in the inner membrane of the mitochondria."

The teacher ticked "Oxygen is required", "Aerobic respiration has slow ATP production", "produces 36 ATP", "in the absence of oxygen", "rapid ATP production", "produces 2 ATP", "either ethanol and CO2", "in the matrix of the mitochondria" and "in the inner membrane of the mitochondria" and gave a score of 9 marks out of a possible 10 marks.

Question 39c (Essay, 10 marks)

HL's response to Question 39c – "An arctic mammal, such as a polar bear, would have many of the adaptations to survive cold weather, but none of the adaptations to survive hotter weather.

The polar bear has thick fur to retain heat in the cold Arctic weather. However, in the heat, this fur will retain heat where heat needs to be lost. The body temperature of the polar bear will rise too high.

The polar bear may curl in a ball or huddle in the cold in order to make the surface area of its body smaller so it loses less heat. In hot weather though the polar bear needs to spread its limbs out to increase the surface area of its body and hence heat loss. Once again the bear will become overheated.

The polar bear may not have the appropriate body mechanism to retain water. While in the Arctic there is plenty of water, in Australia there is not as much. The polar bear may not use mechanisms to retain its water such as: - efficient kidneys producing concentrating concentrated urine – extract water from many seeds – metabolise fat reserve to produce water. If the polar bear doesn't use these mechanisms, this may result in it becoming dehydrated.

As the polar bear is from cold weather it may have a high metabolism to generate heat and the animal may undergo vasoconstriction to restrict blood flow to the skin. These mechanisms need to be reduced in warmer weather. The metabolic rate needs to slow and the blood supply to the skin needs to increase. If the polar bear doesn't have these adaptations then it may have trouble controlling is body temperature.

The teacher ticked "thick fur", "retain heat in the cold Arctic weather", "increase the surface area of its body", "hence heat loss", "concentrated urine" and "metabolise fat reserves to produce water" and gave a score of 6 marks out of a possible 10 marks.

Student 7 (HR)

HR is a male, 17 year old, Year 12 student in a large city privately run co-ed high school. HR received 58.5% for his short answer and written sections of the Semester 1 exam paper from the teacher.

Question 32c (Short answer, 3 marks)

HR's response to Question 32e - "An organism can lose heat through respiration, through their bodies externalities and through waste products excreted."

The teacher gave HR one mark out of a possible three marks.

Question 32f (Short answer, 4 marks)

HR's response to Question 32f- "It does not have to hunt for food, which would involve being exposed to the cold weather and losing heat. If it is inactive it will require less food, hence being able to maintain a low metabolism, yet maintaining its core temperature."

The teacher ticked "low metabolism" awarding one mark out of a possible four marks.

Question 36a (Short answer, 4 marks)

HR's response to Question 36a - "The smaller the body size the faster the metabolism, this is because of the increased surface area to the mass of the body. More heat is able to escape and is lost from the body of a smaller animal in proportion to that of a larger animal. Thus the smaller phascogale has larger oxygen requirements and less the larger quokka."

The teacher ticked "smaller the body size" and "faster the metabolism" and awarded four out of four marks.

Question 37ii (Short answer, 3 marks)

HR's response to Question 37ii - "The information is stored in a strand of DNA, Deoxyribonuclaic Acid, which is a string of 4 different kinds of proteins. These proteins are stored in the form of a double helix to give maximum length, as they are very long, but still able to be stored. These different proteins are then read by the cell like a kind of instruction manual to replicate or create organelles and reproduce itself."

The teacher wrote "general idea but not in terminology" and awarded one mark out of a possible three marks.

Question 39c (Essay, 10 marks)

HR's response to Question 39c – "An Arctic Mammal like the polar Bear would have many problems adjusting to the climate in Perth.

The Polar Bear has many different adaptations to its environment in order to survive. Such adaptations include its thick fur coat, that is used to trap air in pockets close to the skin to retain warmth. The storing of fat to keep internal organs warm and at a constant temperature.

These adaptations to the Arctic were conditions are freezing all year round become hinderance in climate were conditions never fall below freezing, and usually remain at 20 degrees or higher and at some time in summer above 30 degrees.

The polar Bear is unable to adapt to these conditions in such a small period of time, as some structural and physiological adaptations take thousands of years to occur.

The Polar Bears Behavioural adaptations are ???? warm, and in Australias climate even though it is warm it has never experienced the kind of conditions "naturally" in which it must cool down.

So by keeping Polar Bears at Perth Zoo it is cruel looking at it from a Biological point of view, as it is unfair of Humans to keep such an Animal in conditions it is clearly unfamiliar with and finds impossible to survive in.

However from Al Gores perspective we may be saving them, as global warming will soon have an affect on their adaptations."

The teacher ticked "thick fur coat", "pockets close to the skin", "storing of fat" and "it must cool down" and gave a score of five marks out of a possible ten marks.

Student 8 (HC)

HC is a female, 17 year old, Year 12 student in a large city privately run co-ed high school. HC received 47% for her short answer and written sections of the Semester 1 exam paper from the teacher.

Question 32c (Short answer, 3 marks)

HC’s response to Question 32c - “3 ways an organism may gain heat is through movement and muscle activity, through eating (gaining heat and energy from food) and exposing self to warm external temperature.”

The teacher gave HC three marks out of a possible three marks.

Question 32f (Short answer, 4 marks)

HC’s response to Question 32f- “When there is a low external temperature, it is an advantage for a bat to hibernate as they are not losing heat through activity and they have a constant oxygen consumption through very low temperatures and very high temperatures.”

The teacher ticked “activity” awarding one mark out of a possible four marks.

Question 36a (Short answer, 4 marks)

HC’s response to Question 36a - “The smaller the body size, the higher the metabolic rate. The Red-tailed phascogale weights 20 grams and its rate of heat production is (J/g/h) 25 while the quokka wallaby weights 4000 grams and its rate of heat production (J/g/h) is 4 showing it having a lower metabolic rate due to its larger size.”

The teacher ticked “body size”, “higher the metabolic rate”, “lower metabolic rate” and “larger size” and awarded four out of four marks.

Question 37ii (Short answer, 3 marks)

HC’s response to Question 37ii - “The chromosomes build p the strands of DNA that have the genetic information.”

The teacher awarded zero marks out of a possible three marks.

Question 39c (Essay, 10 marks)

HC’s response to Question 39c – “Polar Bears are adapted to the very cold climates of Canada, Alaska and Russia. There are many problems in attempting to obtain these bears in Perth, with such a hot Australian climate. Polar bears would be very expensive to keep as an area must be kept as cold as an arctic climate. Without this happening, the bears would not survive for a number of biological reasons.

The polar bears are structurally adapted to live in the cold, as is seen in their thick fur and thickly padded paws. They are physiologically adapted to the cold as their internal temperature adjusting is designed to preserve their heat. They are also behaviourally adapted to a cold climate as they eat a lot in order to gain energy and heat, they use this energy in staying warm. In a warm climate this extra eating will turn to even more fat which may cause the polar bear to over heat and may cause death."

The teacher ticked "thick fur", "thickly padded paws", "preserve their heat" and "cause the polar bear to over heat" and gave a score of four marks out of a possible ten marks.

Collette

The following questions were selected for response analysis in consultation with the teacher.

Year 12 Question (Short answer, 12 marks)

An experiment was conducted in which the digestion of polypeptides by trypsin was investigated. Six test tubes were placed in the water bath that was set at 35°C. Each test tube contained 5mL of peptide solution and 1mL of trypsin solution. The pH of the test tubes was altered as indicated below. The reaction was tested for the percentage breakdown of polypeptide into amino acid at the end of 30 minutes.

pH of test tube	***% breakdown of peptide***
6	*32*
7	*65*
8	*100*
9	*95*
10	*35*
11	*20*

(g) Plot a graph of % breakdown of peptide against the pH. (4 marks)

(h) *Write a hypothesis that was possibly being tested in this experiment. (1 mark)*

(i) *Name the independent and dependent variables. (2 marks)*

(j) *Name two factors that should have been kept constant in conducting the experiment. (2 marks)*

(k) *Explain why it is important to keep each of these constant. (2 marks)*

(l) *From this data what is the optimum pH for the activity of the enzyme trypsin. (1 mark)*

Year 11 Question (Short answer, 7 marks)

6. *What is classification? (1 mark)*
7. *Why is classification an important life skill? (2 marks)*
8. *Give one example of how classification is or can be used in your daily life. (1 mark)*
9. *What is a classification key? (1 mark)*
10. *If someone makes an error while using the key, what did they probably do wrong? (2 marks)*

Students of Collette

Four students were from a city senior high school, two from Year 11 and two from Year 12. They all completed responses to a Semester exam written by their teacher, Collette.

Student 9 (CE)

CE is a female, 17 year old, Year 12 student in a large city privately run girls' high school. CE received 82% for her Semester exam paper from the teacher.

Question 26 (Short answer, 12 marks)

CE’s response to question 26(b) – “Enzymes have an optimum pH, below or above this they will denature and stop functioning.” The teacher wrote “What is the optimum? Not a hypothesis” and gave CE zero out of 1 marks.

CE’s response to question 26(c) – “Independent – pH. Dependent - % breakdown of peptide.” The teacher gave 2 marks out of 2.

CE’s response to question 26(d) – “Amount of light. Type of peptide solution.” The teacher gave CE 2 out of 2 marks.

CE’s response to question 26(e) – “Differing amounts of light could cause a change in temp -> effecting the % breakdown. The type of peptide solution would effect how well the enzymes can break it down.” The teacher awarded 1 mark out of 2.

CE’s response to question 26(f) – “pH of 8.” The teacher awarded 1 mark out of 1.

Student 10 (CC)

CC is a female, 16 year old, Year 11 student in a large city privately run girls’ high school. CC received 50% for her short answer section of the Semester exam paper from the teacher.

Questions 1 – 5 (7 marks)

CC’s response to question 1 – “Classification is the separation of all living things, dividing things into groups on factors such as structure and physical characteristics.” The teacher gave CC 1 mark out of 1.

CC’s response to question 2 – “Classification is an important life skill because it distinguishes all living things into groups which help to determine the species etc. of a living thing.” The teacher wrote “Allows us to study and communicate about them, make sense” and gave CC 1 mark out of 2.

CC’s response to question 3 – “Classification can be used when determining whether the food you eat is a fruit or a vegetable.” The teacher gave 1 mark out of 1.

CC’s response to question 4 – “A classification key is a guide that helps the reader determine the classification of each thing in the dichotomous diagram.” The teacher wrote “A method to identify an organism by using observation of traits or a checklist to pinpoint the organism’s identity” and gave CC zero mark out of 1 mark.

CC’s response to question 5 – “The person who did the diagram might have put the wrong number classification e.g. (4a) with the wrong separation explanation or particular thing, e.g. shell.” The teacher wrote “Interpreted key incorrectly. Using organism that key wasn’t constructed for. Used juvenile, key made for adult.” and awarded 1 mark out of 2.

Student 11 (CM)

CM is a female, 16 year old, Year 11 student in a large city privately run girls’ high school. CM received 90% for her short answer section of the Semester exam paper from the teacher.

Questions 1 – 5 (7 marks)

CM’s response to question 1 – “Classification is to simplify a group of objects or things using structure, genetics, biochemistry & behaviour by picking characteristics and grouping the objects into smaller groups according to these characteristics, so that the group or a single object can be more easily interpreted or separated.” The teacher ticked the answer on the left hand side and gave CM 1 mark out of 1.

CM’s response to question 2 – “It is important to be able to classify things so that you can organise work and objects and to be able to communicate with others what object you are talking about. It allows us to simplify complex groups or situations.” The teacher ticked the answer on the left hand side, ticked above “complex groups” and gave CM 2 marks out of 2.

CM’s response to question 3 – “When choosing a movie to watch as a family, we classify a selection of movies by the number of votes that they get. (Largest no. votes win).” The teacher ticked the answer on the left hand side and gave 1 mark out of 1.

CM’s response to question 4 – “A classification key is a list of the characteristics that have been used to classify the objects alongside numbers and letters which are used to illustrate the relationships between these characteristics & objects. It can be followed through systematically in order to classify an object or see why it is classified there in that group." The teacher ticked the answer on the left hand side and gave CM 1 mark out of 1. The teacher given answer written afterwards by the student was "Method to identify organism using observable traits to pinpoint organism's identity."

CM's response to question 5 – "They may have misread the key or interpreted the words used differently to the person who made the key and therefore classified the object differently to the key." The teacher ticked the answer on the left hand side and awarded 1 mark out of 2. The teacher given answer written afterwards by the student was "- or use organism not on key or juvenile animal or lines and arrows."

Student 12 (CL)

CL is a female, 17 year old, Year 12 student in a large city privately run girls' high school. CL received 84% for the Semester exam paper from the teacher.

Question 26 (Short answer, 12 marks)

CL's response to question 26(b) – "The % breakdown of peptide is greatest at a pH around 8, and the amount of peptide broken down decreases as the pH is increased or decreased." The teacher gave CL 1 out of 1 marks.

CL's response to question 26(c) – "Independent variable – the pH of test tube. Dependent variable – the % breakdown of peptide." The teacher gave 2 marks out of 2.

CL's response to question 26(d) – "- the temperature. – concentration of solutions (trypsin and peptide)." The teacher gave CE 2 out of 2 marks.

CL's response to question 26(e) – "The temperature needs to be constant – too low the reaction rate will decrease, too high, the enzymes will denature. Concentration of solutions needs to be constant throughout mixture, so then everything will react and the only limiting factor to the reaction is the pH, rather than the amount of trypsin or peptide to make results valid, so then the results of the experiment are caused by independent variable." The teacher awarded 1 mark out of 2.

CL's response to question 26(f) – "optimum pH = 8." The teacher awarded 1 mark out of 1.

Michelle

The following question from a term exam paper that was given as a homework assignment was selected for response analysis in consultation with the teacher.

11b vi

In aerobic respiration, the product of the first stage moves to the mitochondrion. Outline subsequent events in the total breakdown of this product. (5 marks)

Students of Michelle

Six students were from a city senior high school in Ireland, all undertaking their A-Levels year and 18 years of age. They all completed responses to a Semester exam written by their teacher, Michelle.

Student 13 (MK)

MK is a female, 18 year old, A-Level student in a large city privately run girls' high school in Ireland. She was awarded 5 marks out of 5 possible marks for this question.

2007 Q 11

a) i) ATP = Adenosine Tri Phosphate

ii) ATP provides energy to cells

b) i) glycolysis

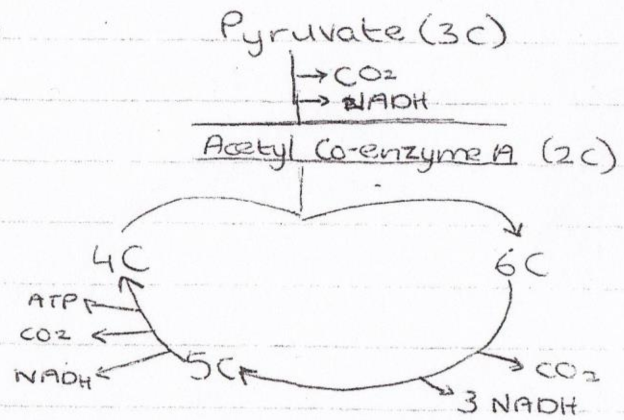
ii) cytosol

iii) pyruvate

iv) Oxygen is not required, it is anaerobic.

v) lactic acid in bacteria or animals

vi)



Electron carrier system

NADH $\rightarrow$ CARRIER 1 $\rightarrow$ ATP

$\rightarrow$ CARRIER 2 $\rightarrow$ ATP

NADH $\xrightarrow{3ATP}$ H_2O

$\rightarrow$ CARRIER 3 $\rightarrow$ ATP

$\rightarrow 2H^+ + \frac{1}{2}O_2 \rightarrow H_2O$

Student 14 (MN)

MN is a female, 18 year old, A-Level student in a large city privately-run girls' high school in Ireland. She was awarded 5 marks out of 5 possible marks.

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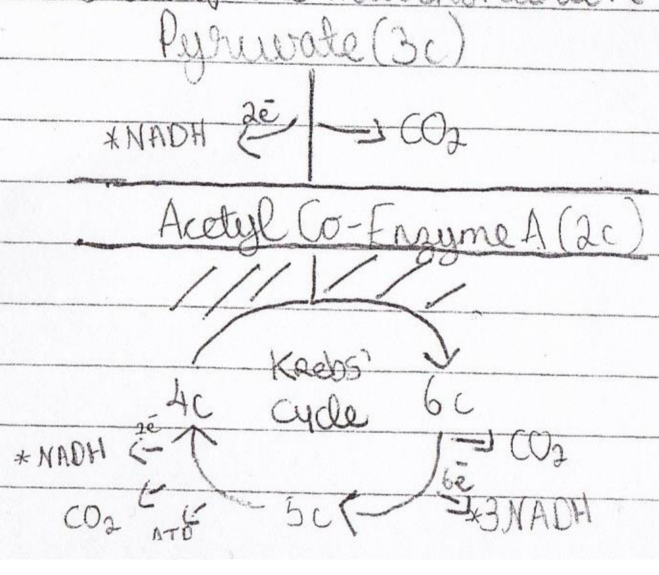
11(a)(i) Adenosine Tri Phosphate
(ii) ATP is used in the dark stage to produce $C_6H_{12}O_6$ and a 5 carbon acceptor.

(b)(i) Glycolysis
(ii) lumen of the mitochondrion
(iii) Pyruvate
(iv) No.
(v) Ethanol and CO_2
Lactic Acid
(vi) - lumen of the mitochondrion



Page 1

Electron / Hydrogen Carrier System
Oxidative Phosphorylation
(+ oxygen) (+ phosphate + energy)
- cristae of the mitochondrion

NADH

$\searrow 2\bar{e}$

CARRIER 1 $\xrightarrow{ADP + P}$ ATP

$\searrow$

CARRIER 2 $\xrightarrow{ADP + P}$ ATP

$\searrow$

CARRIER 3 $\xrightarrow{ADP + P}$ ATP

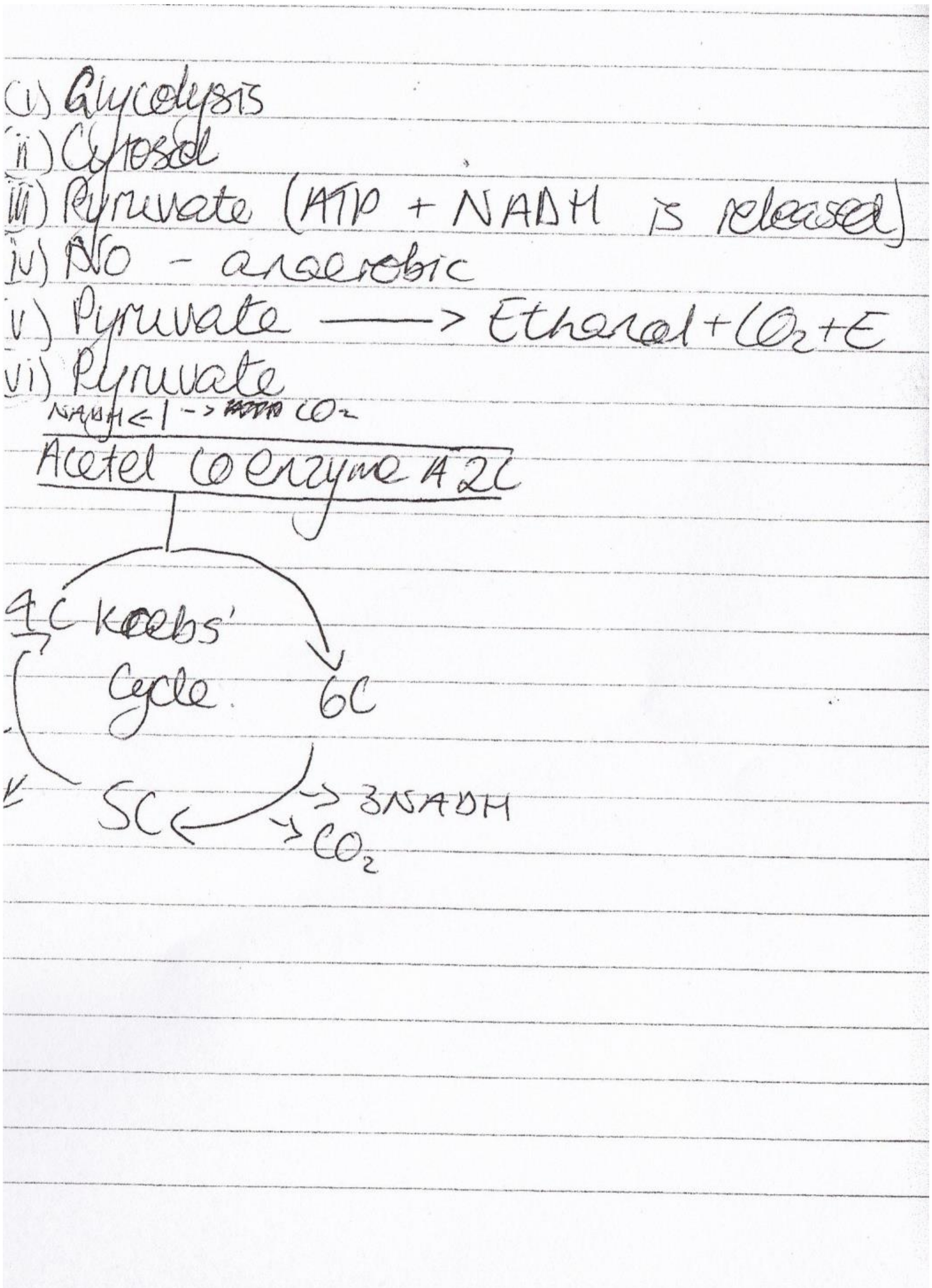
$\searrow 2\bar{e}$

$2H^+ + \frac{1}{2}O_2 \rightarrow H_2O$

Page 2

Student 15 (MC)

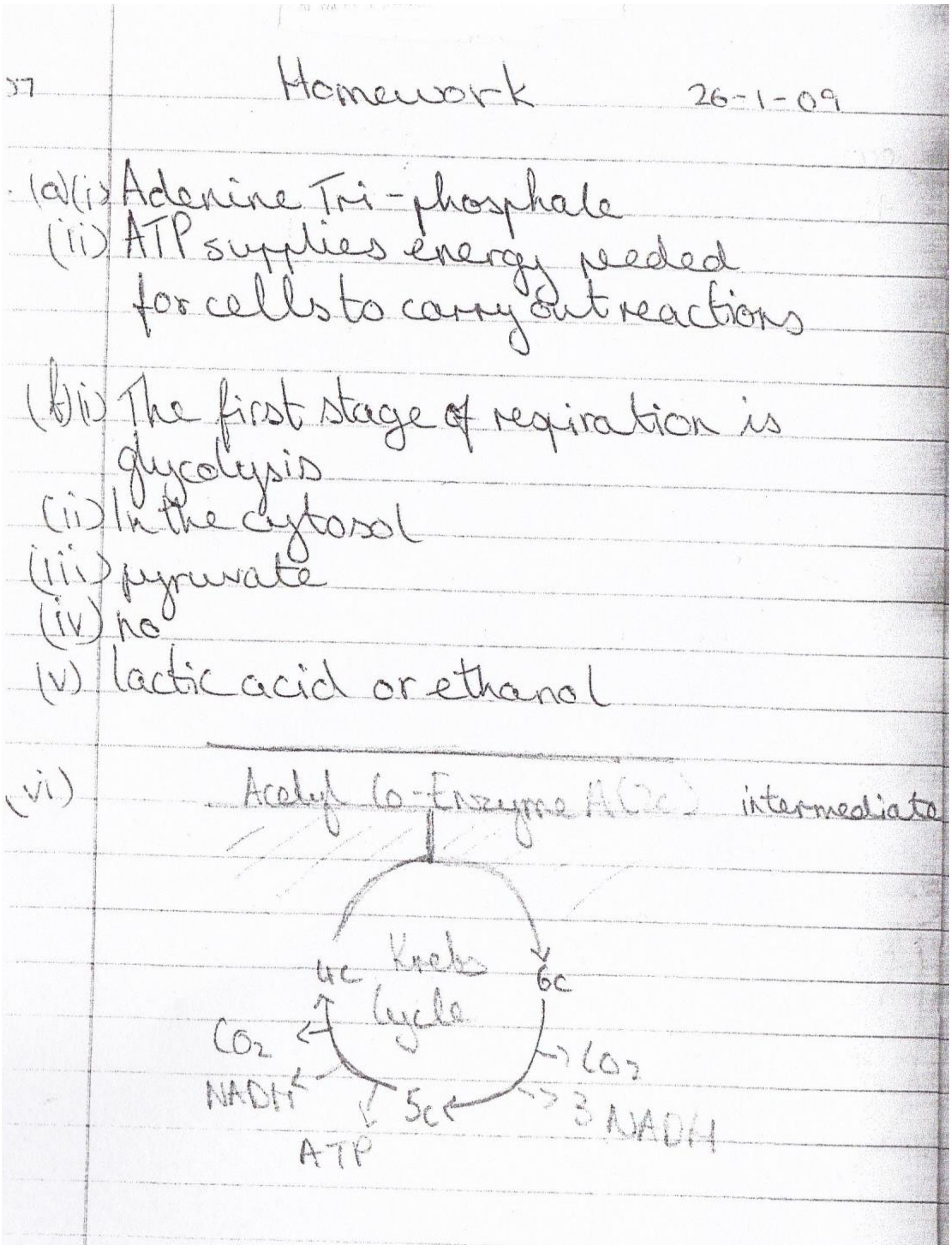
MC is a female, 18 year old, A-Level student in a large city privately run girls' high school in Ireland. She was awarded 4 marks out of 5 possible marks.



(i) Glycolysis
(ii) Cytosol
(iii) Pyruvate (ATP + NADH is released)
(iv) NO - anaerobic
(v) Pyruvate ——> Ethanol + CO_2 + E
(vi) Pyruvate
NADH ←| -> CO_2
Acetel coenzyme A 2C

Student 16 (MG)

MG is a female, 18 year old, A-Level student in a large city privately run girls' high school in Ireland. She was awarded 4 marks out of 5 possible marks.



Homework 26-1-09

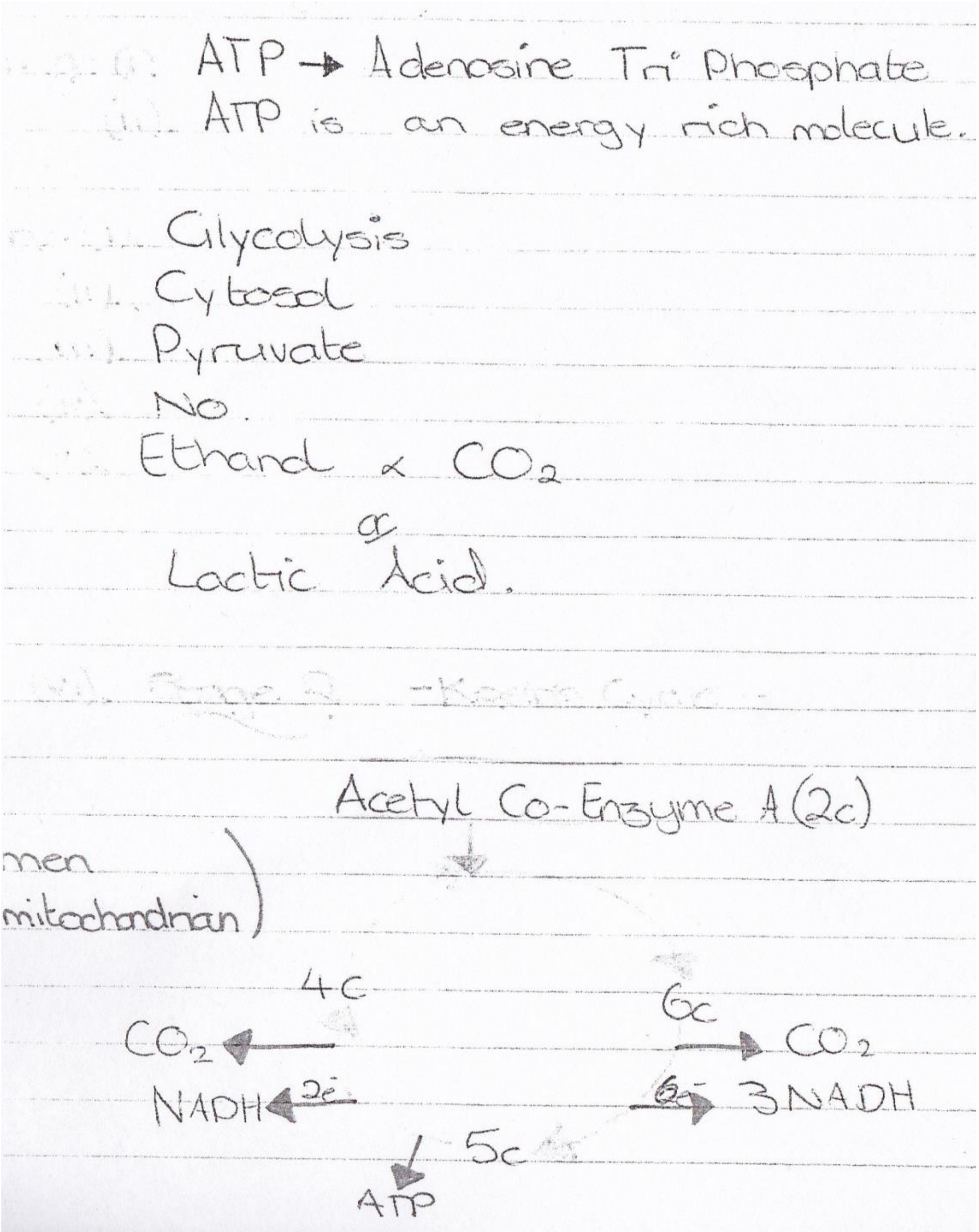
(a)(i) Adenine Tri-phosphate
(ii) ATP supplies energy needed for cells to carry out reactions

(b)(i) The first stage of respiration is glycolysis
(ii) In the cytosol
(iii) pyruvate
(iv) no
(v) lactic acid or ethanol

(vi)

Student 17 (ME)

ME is a female, 18 year old, A-Level student in a large city privately run girls' high school in Ireland. She was awarded 5 marks out of 5 possible marks.



Page 1

NADH

Carrier ① → ATP

Carrier ② → ATP

(Cristae → Mitochondrian)

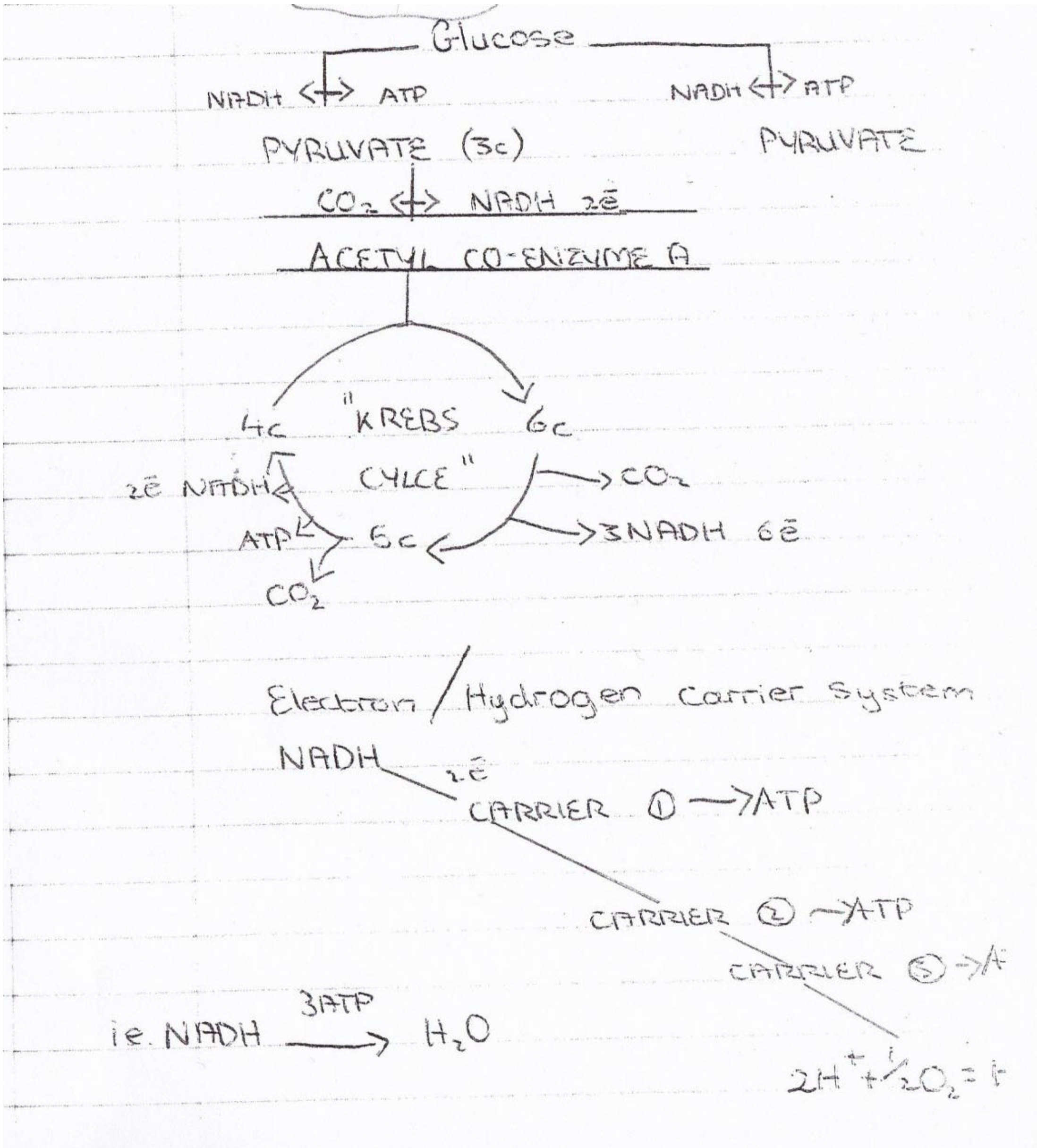
Carrier ③ → ATP

$2H_2^+ + \frac{1}{2}O_2 \rightarrow H_2$

Page 2

Student 18 (MV)

MV is a female, 18 year old, A-Level student in a large city privately run girls' high school in Ireland. She was awarded 5 marks out of 5 possible marks.



Teachers Wendy and Philip had no self-selected questions or student responses.

Philip's interview and answers to the Test Question and Student Answer

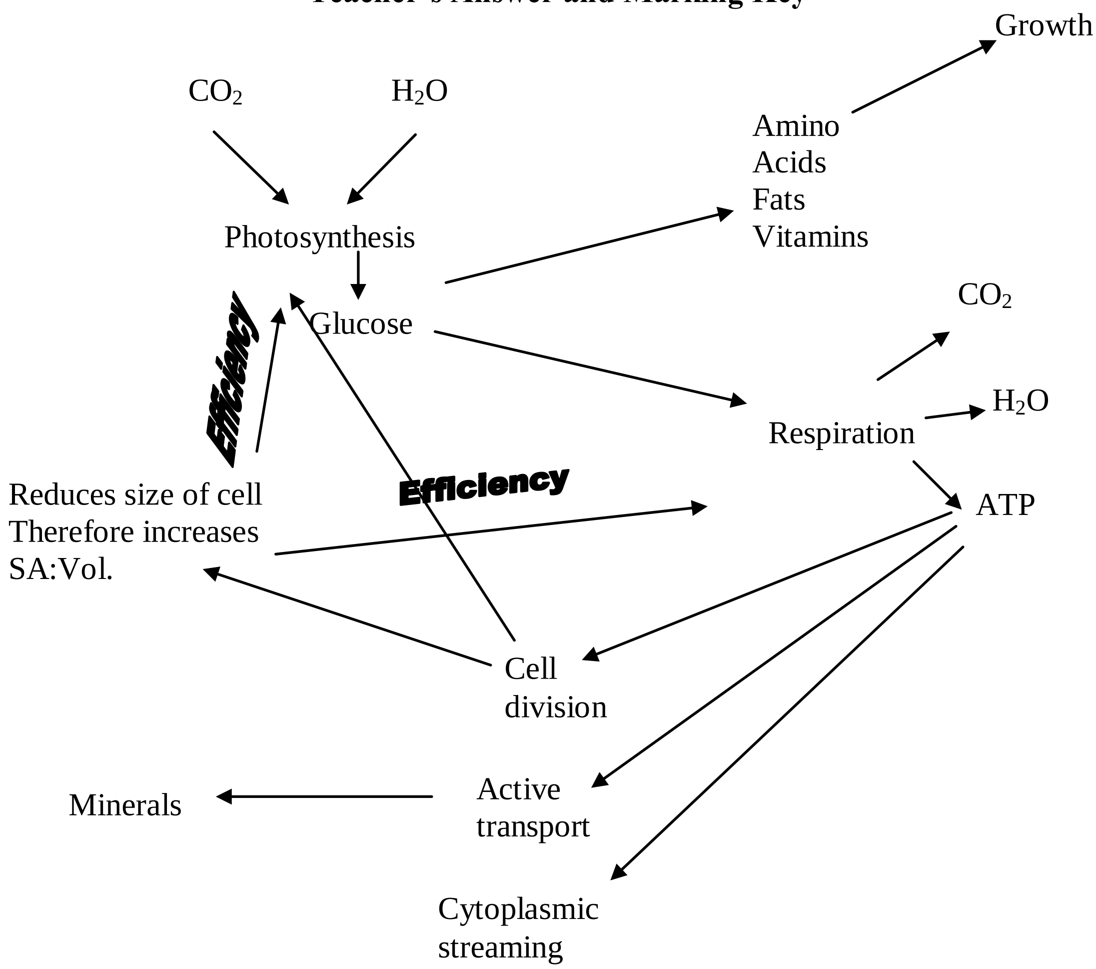
Test Question

38. (Written Question) 10 marks

Describe a series of four (4) processes that occur in a plant cell and how they are related to enable the cell to work efficiently.

(Marks will be allocated for the relationships between the processes and how they benefit the cell, not just for the names of the processes).

Teacher's Answer and Marking Key



Total = 10

Each process clearly explained 1 x 4 = 4 marks

Links between processes 1 x 6 links = 6 marks

Interview with Biology teacher Philip

P is the teacher. R is the interviewer.

P I would have set out with a marking key to do this. I see you had a bit of a marking key. You didn't indicate on that marking key where marks were allocated.

R What would you have done?

P I would have started off with something like this flow diagram… (I was shown his diagrammatic representation of an answer with mark allocation explained in two sentences at the base)…link up whatever these particular processes were, like photosynthesis is linked to respiration, it (photosynthesis) produces glucose which is needed in respiration and getting ATP for active processes, cytoplasmic streaming and so on. Cell division tends to reduce the size of the cell and therefore maintains a higher surface area to volume ratio which impacts on other process, such as making photosynthesis more efficient, enabling the uptake of carbon dioxide and water more efficiently. With a flow diagram I would try to relate all these processes.

And that's what I would be talking to them about when going back over the exam - showing how they can relate all of these, because they are interrelated.

In marking this you have to appreciate that a lot of people could not develop something like this until they have years of contact with the subject. For a good student they would need to be able to explain each of the processes that they talked about. I think they need to mention photosynthesis, discussion of the equation would be required and they would get one mark, and similarly for cell division, active transport, cytoplasmic streaming, respiration. Each of these together could add to a total of 4 marks, that's without showing any interrelationship, then the students a bit stronger than that would go on to show some links. Most of them are able to link photosynthesis and respiration. They will say that because we teach them photosynthesis and respiration are almost opposite reactions that therefore without photosynthesis you can't have respiration, without respiration you can't have photosynthesis, because that produces the carbon dioxide which inevitably gets back to the photosynthesis. So that would get the medium type student 6-8 marks or 6 marks is probably the maximum they would get. Then the better students would say respiration is related to all these other processes by ATP so they would be discussing how ATP is used in cell division, not in detail, but just saying ATP breaks down to ADP releasing energy which makes cell division possible, because cell division requires movement of tiny molecules and organelles and the like and active transport is an energy requiring process so all those things have to show that ATP breaks down to produce the energy needed for these endothermic type reactions so they are getting marks for relating ATP to those sort of things, so possibly 9 marks.

Then to get a full 10 marks they would have to explain how all of these processes make up the whole organism - without one you can't have the other.

R If you had a student who explained a lot more detail, say with photosynthesis and respiration and still putting a bit of the linkage that is important, but showed their understanding of photosynthesis, talked about the equation and maybe even light and dark reactions, would you consider giving them more marks in this section?

Analysis

Philip constructed an answer model in the form of a flow diagram/concept map and had a clear concise representation of the concepts and the relationships between them.

He is using his content knowledge to describe a good answer.

He makes plans about the concepts and issues within the question that he will raise with the students after the exam.

He plans for learning experiences as a result of

He identifies an expert/novice problem.

He identifies the parts of the answer (which he allocates marks).

Then he describes the relationships the students generally make between the concepts and identifies a mark that he would give them.

He uses his experiences of students, teaching and assessing to predict answers that students would give. This is linked to Pedagogical Content Knowledge.

He identifies ranges of answers that increasingly more expert students would give.

He recognises complex responses in that the answers both require more microscopic knowledge, more parts to each concept and the beginnings of integration of chemistry concepts within the biology field.

As well as patterns of student responses and their alignment with complexity of concepts, Philip has identified a progression to more expert student knowledge. Philip exhibits knowledge of concepts/content and is experienced with how students respond to assessment.

P No. Not necessarily, because, the question doesn't ask them to discuss in detail any of those particular processes. A wonderful essay on photosynthesis, indicating the light and dark stage, and all those sort of things won't necessarily get them any more marks.

He has views about too much information in an answer. He would not give extra marks for a detailed answer that wasn't asked for.

R What if they did a very good one on say respiration, photosynthesis, cell division, and production of ATP which is also a process in itself, very well and just related them briefly. What sort of mark would they get?

He has a justification for not awarding extra marks, based on the students' responsibility to read the question correctly. He does admit that a teacher judgement is needed.

This could be a point of difference between teachers.

P Somewhere of that order. We've tried to teach them to read the question carefully and that does ask them to talk about 4 processes and how those 4 processes are related and they have only done a couple of them in detail. It is a bit of discretion here, If they have done the top half of the thing very well, then they might get 6 or 7 marks I suppose.

R When you're marking do you have any considerations in your head apart from the marking key? Exam time?

The teacher takes account of other factors affecting the student's performance of the assessment.

P You generally try to make accommodation so they have plenty of time to do it, If you give them a task that is unreasonable in the time given, you can say I'm sorry I didn't give you enough time, but I'm not going to adjust the marking key because they have run out of time, just make sure they have enough time. Sometimes I have split these tests and from past experience seen they are a bit long and done the written part on a separate day. In retrospect, this test could have been given on a different day to give them enough time to do it, because I know that some of them might have done a better job if given more time. It's hard to say because I've not used this one before (the written question) but you get used to it.

R Are there any other factors that you might take into account?

The teacher reasons about and is sensitive to the role of the learning process in assessment. He recognises the importance of student reflection and accurate teacher feedback in student learning.

P You might also take into account just how much exposure they have had to the whole area and you might mark it harder if they have had more time to digest the material they have been given. Like, in a few weeks, they can absorb all this information and then suddenly given a question, they might have not have time to mentally process all this stuff yet and when you go over this thing, they might appreciate the question a lot better, having done it and gone over the answer.

R How much effect do you think the feedback will have on them in the future?

The teacher discussed difficulties of feedback with different question types. He reflected on lengthy multiple choice questions and the time factor. He also emphasises the importance his content knowledge in order to engage and help his students.

The teacher understands through his experiences student learning, and thinking and their application to assessment. He understands the importance of content knowledge. He acknowledges trade-offs that occur, such as the time needed for feedback on multiple choice questions. This could be indicative of good PCK in assessment.

P Quite a lot actually, but it's important to go through the written questions particularly. You don't have time to go over all the multiple choice questions. This test had a lot of longer multiple choice questions with long preambles, which involves a lot of reading and thinking and sometimes in class you don't have time to go over every one of those multiple choice. Sometimes you might go over the key ones you think are really good questions and just give them the answer for a lot of the other ones, say the answer is A, and if you want to discuss that with just come and see me. But not many of them would. Some like to argue about them, that is good, because it gets them thinking about it. But you need to be very confident about the answer yourself if you're going to engage in a discussion with them. Multiple choice is good to discuss. They learn a lot from actually doing the test and going over it. It's all part of the learning really. It has a very important role in gathering all the information you have to on the kids, but it is also very important for their learning to go over the test.

R So if you gave them a similar question, but different, in a weeks time after you have gone over this?

P You would expect them to get a lot better at it, than if they didn't. But finding a similar question might be difficult to do because you can't really compare them. You give them a watered down version of it where they discuss only two processes, and not photosynthesis and respiration and see how they go, but if they can't produce a fairly good answer, then either they are not thinking about it or something's failed.

R Have you thought about it according to levels?

P No

R Shall I show you some levels?

P Yes

R Just looking at Level 8…

P. used the Western Australian Progress Maps in Life and Living in order to assess a level for a student's work. He shows flexibility in his use of different assessment frameworks.

P I think that this kid, knowing this kid as well as I do, I would say she's very bright, she's got a 9 for this question (out of 10), and she'd probably be a level 7 or 8, probably an 8. Yep.

R If you look at 'describe the role of respiration in cell survival', 'compare energy production and transfer and use in cells' …

He has identified students at the highest level.

P She's quite capable of doing that. Yes. We're working on that further, but the better ones are able to do this pretty well at this stage. When you look at this particular level as it's described here, these top kids are definitely at Level 8. Whether or not that's a problem with this description. I don't know whether you want them to be level 8 at this stage.

R Yes. The good ones. They should be up at Level 8 and getting the breadth of the level now.

He described the historical student standard in Biology at the school.

P applies external curriculum such as Progress Maps and internal school and personal standards in his outlook of assessment in Biology.

P We probably now have 4 or 5 kids in that group, at least, but this is not uncommon with a good Biology class. At our school. you know that when we look back over the years we have some very bright kids in Year 12 doing Biology, particularly.

R Thinking about the level 7 that you read, now the level 8, do you think that it is a useful tool to help you work out what the child knows and what to do to move them on?

P Um.

R Or how would you be using this.

P. undertook a critique of the progress Maps using his experience of depth of knowledge in both the subject and in his understanding of the range of student 'thought processes' and understanding.

P I would be using this description here to try to ascertain to what level the student is at. I'm not sure whether it would be much help, because you already have the underlying understandings of their thought processes, You already know that without reading that description here to know what they can and can't understand. I know what they are capable of doing. They are at a stage where they could move beyond this. Unfortunately in the scheme of things, they are probably going to have to leave it and move onto something else which is prescribed. They have (?) this and now have to move onto the organism as a whole. It's time constraints, which are necessary, because you've got a course and a course structure and you need to move on. Some students are probably not going to be at this stage and it's no point keeping them and trying to press on with the same thing. You've got 23 kids in the class you've got to move onto something different that these kids can cope with.

He recognises the practicality of teaching and learning, such as needing to continue with new material, time constraints and allowing for the interests of the whole class.

He recognises trade-offs and a pragmatic approach to teaching.

R So this is a not a course, just an example, so if you look at the big idea that the students understand the relationship between structures, processes and dynamic change within sophisticated biological models of their body, and that the kids have to understand that at a broad level of experiences and have to demonstrate that at level 8, do you think they are helpful statements to aim for kids or…

P Maybe for the inexperienced teacher – they can look at these things and think that these are things that a child could be aiming for if at least some of students are level 8, these could be used as a guideline for determining, what a teacher is doing in the classroom. That's right.

He comments on the usefulness of the Progress Maps for a novice teacher.

R What's you're preferred way of thinking as far as student's mental processes in Biology

P I will carry students as far as they can go within limits, from here you need to go into tertiary institution stuff, like Kreb's Cycle, but you can't do that with you're very top kids because you've got the other students in the class to consider, and they are not required to go beyond that are they. They will be struggling to cope with all the material in all the other modules in the other part of the course and their other subjects, so you can't really say let's go off and do something beyond this, although they are quite probably capable of doing it.

When asked about students' mental processes, his immediate response was in terms of Biology content.

He recognises the range of student understanding and their commitment to other subjects.

R If I say level 5 or 6 that level 5s are really not comfortable with science, but level 6 are just becoming confident with science and you have all those types of kids in your class as well, and you have the choice of something like this where this is one way of putting down general ideas of student progression, so what are your ideas about student progression, without having a syllabus, what are your ideas about how you progress them and get them to understand the area.

P Without having a syllabus, that doesn't occur. You always have a syllabus.

R OK. Given a syllabus or some kind of syllabus, what's your preferred way of getting kids to progress.

P You immerse them in the area, do experiments and discuss all of these things with them but there comes a point where the weaker students are not really going to understand the concepts and detail to the depth that the brighter kids do, and you have to move on to something else. Every student is not going to be level 8. Some students will end up as level 6 doing Biology and they will not progress on from that level so you move onto something else in Biology that interesting and different area that they are interested in.

The teacher describes limitations of student achievement and plans for learning in different contexts or accommodating students' different interests.

R How do you know if they do progress? What are you looking for?

P The level of understanding they demonstrate in their answers, that's reflective of their marks.

R That to do with their understanding of facts in Biology?

P And the concepts and link those facts.

R So talking more about that – the facts and linking facts and concepts, what is involved in Biology then - in moving on with your thinking. What are some of the things you'd be looking for in kids?

P. identifies the best assessment strategies for his purpose, such as creative open-ended questions or application questions for teasing out the students' understanding.

P If you're reading their answers, particularly extended answers, that gives you a clues to what to whether or not they really understand what they are doing, so you give them obviously open-ended questions, or tease out the like trying to level kids so we gave them a scenario which a flower was to be pollinated by an insect which can't fly or climb – design this flower. So here's a new thing that they haven't encountered before unless they are interested in Botany, so you might get the odd kid whose father is a curator of a herbarium, who might know all about prostrate flowers, But those really creative open-ended things separate them and also enable us to decide where they are in terms of their understanding.

R If you could generalise with kids' thinking, is there any steps they go through as they think in more detail about Biology and in more complex ways. What are some thinking processes they need to go through?

P Like the ability to relate a new structure that we haven't discussed before with its function. It's a very important indication of the level at which students (?), but that's a clear division. You present a working organ to a student and ask them to discuss its function. Some of them will have no idea, so the student who can move straight away to its function has reached a higher level. That's the sort of thing you might look for.

Application of knowledge in unfamiliar contexts is proposed by P. as an indication of higher order thinking.

R Are there any other steps that come to mind – they could be lower school students - steps in their thinking?

P Looking at this question, you hope that they are going to learn what all these processes mean and that's the first level, they are able to explain how photosynthesis differs from respiration, for example, so when they move on is where they understand the relationship between the two, - interrelating these two with a whole lot of other processes, I don't know whether it's a continuum or whether were getting 2 or 3 discrete groups of people.

P. explains steps in student thinking in terms of a content continuum, but hypothesises that it may not be a continuum so much as discrete groups.

What P. demonstrates here is an explanation based on concepts interrelating together in dynamic ways. He thinks his students don't understand these dynamic aspects.

R What about the detail. If you just ask for 1 process, what are the steps in understanding the detail of the process/processes?

P I f you looked at photosynthesis, the first step is getting all the reactants and the products in the right places in an equation and some students don't even understand what an equation is, that they really don't understand that those things on the LHS are partly used up in produced on the RHS. They don't really understand that. And they don't understand that if you keep taking something away on the RHS of an equation that the reaction will proceed more rapidly or continue to proceed more rapidly towards those products. They don't understand those basic principles of chemistry do they? Even if you're not dealing with balanced equations, you're dealing with processes that aren't understood by a lot of students. And then some students are prepared to learn those and others I suspect, reach a stage where they don't understand, and decide not to proceed any further. There's a bit of a block. That illustrates an attitude.

He comments on students reaching a level of understanding and for their own reasons, not proceeding any further.

The discussion of student mental blocks in further achievement could be a part of an assessment PCK.

R What about the model of the cell, we have a leaf model with cells and we ask them to explain from the Sun to the food, what happens? What steps are in students' understanding there?

P If they understand each one of the processes first of all, they can begin to interrelate everything – the Sun's energy is absorbed by the chlorophyll passes that energy onto carbon dioxide and water to create a more complex molecule and go through all of those steps that need to be understood fairly well if they are going to link the whole thing together in an understanding – gets back to what I said before that each one of these processes needs to be fairly well understood before they understand the whole.

P. states that each of a number of steps need to be understood before the whole process is understood.

P's ideas on steps and understanding the contributing processes to a bigger concept could be a target of a purposeful assessment design.

R Is there anything else, any questions that you think I could have asked you?

P It's difficult. I don't know whether we could have looked at a more structured question to more clearly, open questions are great because they

P. speculated about advantaging lateral or creative thinkers with open ended questions and offering a range of question types to students.

are interesting and see how creative people can get, but we have also got people who are lateral thinkers, and I don't know whether being a lateral thinker necessarily puts you higher up in the levels or at the same level of understanding but more creative. So you have that level of difficulty with an open-ended question, but maybe quite often we structure extended answer so we can tease more out a student than we might otherwise get. They're not a bad idea. There's a place for those questions. And I think there's a place for Multiple Choice questions, because Multiple Choice can be very interesting.

R If you're thinking about teachers making judgements about students work, are there any other questions I could have asked you that could have given me some more information about that?

P It's very difficult. You have a pretty good idea about what kids will get in tests and exams by just talking to them, so have a discussion with them, and that those who know the answers will come out with them and those same students will do well on all the written tests. It's not 100% reliable, because some people are fairly quiet and prefer to have other people answer questions they know the answers to, so it's not really in itself enough. It really needs to be written. Gives the opportunity for everyone to be able to say something.

He acknowledges the place of talking and discussion with students as a way of predicting or judging their level of understanding. He also recognises different styles of expressing their understanding.

Appendix 4 Permission letters

Student letter and consent form

Curtin University of Technology

Curtin University of Technology
Science and Mathematics Education Centre

STUDENT Information Sheet

My name is Elaine Horne. I am currently completing a piece of research for my Doctor of Philosophy at Curtin University of Technology.

Purpose of Research
I am investigating the research topic of biology assessment.

Your Role
I will conduct research by asking you to discuss in an interview a question/s that you answered in an exam this year and take part in answering one common test question on biology that will complement your learning. Your teachers and the College principal have already been contacted and have agreed in principle to the project. Feedback about answering these specific biology questions will be given to you after the completion of the activities.

Consent to Participate
Your involvement in the research is entirely voluntary. You have the right to withdraw at any stage without it affecting your rights or my responsibilities. When you have signed the consent form I will assume that you have agreed to participate and allow me to use your data in this research.

Confidentiality
The information you provide will be kept separate from your personal details, and only myself and my supervisor will only have access to this. The interview transcript will not have your name or any other identifying information on it and in adherence to university policy, the interview tapes and transcribed information will be kept in a locked cabinet for at least five years, before a decision is made as to whether it should be destroyed.

Further Information
This research has been reviewed and given approval by Curtin University of Technology Human Research Ethics Committee. If you would like further information about the study, please feel free to contact me on 9334 0387- or by email elaine.horne@dec.wa.gov.au Alternatively, you can contact my supervisor Dr. David Treagust on 9266 7924 or email David Treagust [d.f.treagust@curtin.edu.au]

Thank you very much for your involvement in this research.
Your participation is greatly appreciated.

Curtin
University of Technology

STUDENT CONSENT FORM

• I understand the purpose and procedures of the study.

• I have been provided with the participation information sheet.

• I understand that the procedure itself may not benefit me.

• I understand that my involvement is voluntary and I can withdraw at any time without problem.

• I understand that no personal identifying information like my name and address will be used in any published materials.

• I understand that all information will be securely stored for at least 5 years before a decision is made as to whether it should be destroyed.

• I have been given the opportunity to ask questions about this research.

• I agree to participate in the study outlined to me.

Name: ______________________________

Signature: ___________________________

Date: ______________

Parent letter and consent form

Curtin University of Technology

Curtin University of Technology
Science and Mathematics Education Centre

PARENT Information Sheet

My name is Elaine Horne. I am currently completing a piece of research for my Doctor of Philosophy at Curtin University of Technology.

Purpose of Research
I am investigating the research topic on *biology assessment*

Your Role
I will conduct research by asking for your child to discuss in an interview a question/s that they answered in an exam this year and take part in answering one common test question on biology that will complement their learning. Your child's teachers and the College principal have already been contacted and have agreed in principle to the project. Feedback about answering these specific biology questions will be given to the students after the completion of the activities.

Consent to Participate
Your child's involvement in the research is entirely voluntary. You have the right to withdraw at any stage without it affecting your rights or my responsibilities. When you have signed the consent form I will assume that you have agreed to participate and allow me to use your data in this research.

Confidentiality
The information your child provides will be kept separate from their personal details, and only myself and my supervisor will only have access to this. The interview transcript will not have your child's name or any other identifying information on it and in adherence to university policy, the interview tapes and transcribed information will be kept in a locked cabinet for at least five years, before a decision is made as to whether it should be destroyed.

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Thank you very much for your involvement in this research.
Your participation is greatly appreciated.

Curtin
University of Technology

PARENT CONSENT FORM

- I understand the purpose and procedures of the study.
- I have been provided with the participation information sheet.
- I understand that the procedure itself may not benefit my child.
- I understand that my and my child's involvement is voluntary and I can withdraw at any time without problem.
- I understand that no personal identifying information like my name and address will be used in any published materials.
- I understand that all information will be securely stored for at least 5 years before a decision is made as to whether it should be destroyed.
- I have been given the opportunity to ask questions about this research.
- I agree to allow my child to participate in the study outlined to me.

Name: ______________________________

Student Name: ______________________________

Signature: ______________________________

Date: ______________

Appendix 5 Examination technique guide from Ireland

EXAMINATION TECHNIQUE

INTRODUCTION

Sometimes an exam paper contains those very questions which you have anticipated and specially prepared for. Such good fortune is a rare event and wonderful when it happens. To perform well and regularly demands more than good luck. Unfortunately, there is only one road to success and that is by **hard work**. By hard work you will get to know and understand all relevant subject matter laid down in the syllabus. If this hard work is completed, then on the day of the exam you have to display your command of the subject to your best possible advantage.

TECHNIQUE GUIDE

A problem you will face on the day of the exam may not be lack of information. If you have been conscientious and have desired to perform well, you will have studied. Your problem may be lack of exam technique. The inability to apply knowledge you have to the question asked will cost you many marks. It is a shame that, having worked so hard, a simple thing like technique should let you down.

There is a 15% gap between the different grades. If for example 4 marks (1%) are lost due to a badly drawn diagram, then one in every fifteen students will drop a grade.

What follows are suggestions for improving your answering technique so that you may gain maximum value for the **many hours of study you have endured or enjoyed.**

Time for Biology exam paper: 3 hours ~ 9.30-12.30

.

SECTIONS A & B….

1. Answer all parts of these sections.
2. Answer in pencil, as this will allow you to alter your answers without destroying the neat presentation of your work.
3. Do not use liquid eraser; it takes time to dry, is messy and you may forget to go back and answer that erased section.

4. Make sure you have completed Section A within 30 minutes and Section B within 20 minutes. The instructions on the exam paper advise this so you will have sufficient time to complete Section C.

5. ****LEAVE NO BLANK SPACES IN SECTIONS A & B.**

SECTION A – advised time 30 minutes.

1. This has a value of 100 marks (25%). You must score high here to ensure that you gain a high grade.

2. There are 6 questions, each worth 20 marks (5%); you are awarded your best five.

SECTION B – advised time 20 minutes.

1. This has a value of 60 marks (15%).

2. There are 3 questions, each worth 30 marks (7.5%); you are awarded your best two.

SECTION C – advised time 120 minutes. *Start this section at 10.30 am!*

1. This has a value of 240 marks (60%).

2. There are 6 long-answer questions, each worth 60 marks (15%). You are marked out of your best four but it is strongly advised that you only do four so that you will give sufficiently detailed answers to gain full marks.

3. In order to allocate sufficient time to each subsection of the questions in this section, it is suggested that you **<u>divide the number of marks</u>** for each subsection **<u>by two</u>** and allow this many minutes for each subsection.

4. It is essential that you take CARE and TIME at choosing your four questions from Section C, as a poor choice may spell disaster.

5. After choosing your questions, divide the remaining time by four. You should have 30 minutes per question, having given yourself at least 10 minutes to read and choose your questions.

6. Your best question should be answered first and completed within 30 minutes.

   Your second best should be answered next.

   Your third best should follow then.

   Your fourth best should come last.

7. Your fourth question is the most important because it is the question you think will score the lowest mark, (i.e. lose most marks) and so it is the question on which you are most likely to drop a grade. Therefore you must give it full time (**30 minutes**) and work on it with great thoroughness.

8. **** YOU MUST GIVE 30 MINUTES TO EACH QUESTION.**

DO NOT CUT THE LAST QUESTION SHORT.

Poor timing is your own fault and you do not deserve any sympathy. Don't offer it as an excuse.

9. Good layout helps you to quickly recheck your work and also makes the examiner's job easier (we have to keep this individual happy!)

10. It is essential that you only supply information on what you have been asked. Irrelevant information, no matter how interesting, gains you no marks and so is a waste of valuable time.

To avoid irrelevant information you must carefully analyse the question i.e. break it up into parts. To do this accurately and swiftly, use the **underlining technique.** *Select and underline all significant parts; be aware why these parts are important; and promise faithfully to obey them without the slightest alteration.*

If you follow this technique all the information you supply will be relevant and valuable, and wasteful waffle will be avoided.

WRITING STYLE

Try to avoid long paragraphs and essay-type answering. Try to give information in short clearly-distinct points. Leave a gap of one line between points so that you can add in extra points in their correct position.

POST-EXAM ACTIVITY

"What's done is done". Discussing your answers with others often leaves you depressed as you discover mistakes you were not aware of. Therefore talk about anything else but not yours or any other person's answers.

Worrying about your exam is a waste of time and energy as it has no effect on your result. It only makes you and your family less happy. Get on with enjoying life.

The very best of luck with your Biology exam on Thursday (9.30am), June 12th, 2008.