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# EDUCATIONAL ISSUES IN INTRODUCTORY TERTIARY BIOLOGY

A thesis

submitted in the fulfilment

of the requirements for the degree of

**Doctor of Philosophy**

by

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**The University of Waikato, 2006**

## **ABSTRACT**

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The work presented in this thesis focuses on educational issues in first-year biology courses at university. First-year courses are important because they have the potential to influence student retention and subsequent subject selection choices, as well as learning at higher levels. Further, biology is considered to be an important enabling subject in New Zealand because of the Government's drive towards a biotechnology-based knowledge economy.

Specifically, the work in this thesis explores the educational implications of the increasingly diverse academic backgrounds of students entering first-year biology courses on teaching and learning in these courses. A social constructivist view of learning is adopted, in which prior knowledge of the learners is considered to have a significant influence on their learning. The social context of learning interactions also is considered to be important. The research involved three phases: identification of prior knowledge assumed by faculty; identification of actual prior knowledge of students; and the implementation and evaluation of an intervention programme based on concept mapping.

In order to investigate faculty assumptions of student prior knowledge, 35 faculty from six New Zealand universities were interviewed. Document analysis and classroom observations provided data triangulation. The findings for this phase of the research suggest that faculty were aware of the diverse prior knowledge of students, and reported a tension between teaching "from scratch" in order to accommodate those with very limited prior knowledge; and the risk of boring those with more extensive relevant backgrounds. A range of concepts that are not explained during teaching (i.e., concepts it is assumed students understand) were identified, including biology-specific concepts and relevant chemical and mathematical concepts.

In the second phase, research findings from phase one were used to develop a prior knowledge questionnaire administered in two successive years to all students enrolled in first-year biology courses at one New Zealand university. Data analysis for this phase suggests that although students with more extensive prior biology study were more likely to have a scientifically acceptable understanding of some key concepts, this was not true of all the concepts that were investigated, including chemical and mathematical concepts. The data also point to differences between what faculty expect students to know, and what students actually know. Furthermore, few students, regardless of the extent of prior biology study, were able to demonstrate understanding of the relationships between important biological concepts.

In the third phase of the research, an intervention based on concept mapping was implemented and evaluated. Two of the six weekly tutorial classes associated with two first-year biology courses were used for the purposes of the intervention. The intervention differed from the other concept mapping studies reported in the literature in that its implementation was of long duration, viz., a period of 11 weeks.

Students who participated in the intervention reported in 'tutorial experience questionnaires' and subsequent interviews that concept mapping helped them to learn the biology content covered during lectures, and to identify links between concepts. A large proportion of participants indicated that they used concept mapping for biology study outside of the intervention tutorial classes, and in some cases in other courses of study. Classroom management strategies appeared to contribute to the positive views about the use of concept mapping during tutorials. Specifically, the tutor modelled the use of concept mapping, but students were also given opportunities to construct their own maps. The role of the tutor in guiding discussions with students and providing feedback was also viewed as being important. Detailed analysis of course assessment tasks suggests that concept mapping enhanced learning for test questions that require understanding of links between concepts. Where tasks require only the recall of facts, concept mapping does not appear to make a statistically significant difference to student performance.

The findings from the concept mapping intervention thus suggest that although concept mapping is a strategy that can be used effectively in tertiary biology tutorial classes, it is more worthwhile if the type of deep learning that is encouraged by the use of concept mapping is also the type of learning required to successfully complete assessment tasks. This raises the issue of whether the type of learning faculty specify in course objectives is the type of learning they actually seek to develop in course delivery and associated assessment regimes.

Effective science instruction is an art involving creativity, imagination, and innovation, along with planning, practice, decision making, and evaluation. Teaching is a scholarly activity, benefiting from research, collective experience, and critical thinking throughout. Yet with all the demands on our time we seldom have an opportunity to think through the entire process.

(Committee on Undergraduate Science Education, 1997, p. vii)

## **PUBLICATIONS ARISING FROM THIS THESIS**

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### **Refereed Journal Articles**

Buntting, C.M., Coll, R.K., & Campbell, A. (2006, in press). Student views of concept mapping use in introductory tertiary biology classes. *International Journal of Science and Mathematics Education*.

Buntting, C.M., Campbell, A., & Coll, R.K. (2003). But I didn't do biology at high school. In R.K. Coll (Ed.), *Science and technology education research (STER) Papers* (pp. 2-32). Hamilton, New Zealand: University of Waikato.

### **Conference Proceedings**

Buntting, C.M., Coll, R.K., & Campbell, A. (2004). Faculty assumptions and student prior knowledge for entrant level tertiary biology. In D.B. Zandvliet (Ed.), *Proceedings of the Annual Meeting of the National Association for Research in Science Teaching* (pp. 1-11). Vancouver, BC.

Buntting, C.M., Campbell, A., & Coll, R.K. (2003). Does concept mapping enhance learning by first-year biology students? In V. Young & M. Brown (Eds.), *Proceedings of the Annual Meeting of the Association of Tertiary Learning Advisors of Aotearoa, New Zealand* (pp. 109-118). Hamilton, New Zealand.

Buntting, C.M., Campbell, A., & Coll, R.K. (2003). Designing curricula for bridging courses: A case study in biology. In H. Anderson (Ed.), *Proceedings of the Third Conference of the New Zealand Association of Bridging Educators* (pp. 92-105). Auckland, New Zealand.

### **Conference Papers**

Buntting, C., Coll, R., & Campbell, A. (2005, July). *Using concept mapping to enhance conceptual understanding of diverse students in an introductory-level university biology course*. Paper presented at the 36th annual conference of the Australasian Science Education Research Association. Hamilton, New Zealand.

Buntting, C.M., & Campbell, A. (2003, November). *Using concept mapping in tutorials: A teacher's perspective*. Paper presented at the annual meeting of Tertiary Education Research New Zealand. Palmerston North, New Zealand.

Buntting, C.M., Coll, R.K., & Campbell, A. (2003, November). *The use of concept mapping in tertiary biology education*. Paper presented at the fourth annual New Zealand Science Education Research symposium. Christchurch, New Zealand.

- Buntting, C.M., Campbell, A., Coll, R.K., & Jones, A. (2003, July). *But I didn't do biology at high school*. Paper presented at the 34th annual conference of the Australasian Science Education Research Association. Melbourne, Australia.
- Buntting, C.M., Campbell, A., & Coll, R. (2003, July). *What do students need to know to study first year biology at university?* Paper presented at the Biolive Conference for New Zealand secondary school biology teachers. Hamilton, New Zealand.
- Buntting, C.M., Campbell, A., Coll, R., & Jones, A. (2002, November). *Improving biology education for a biotechnology-related knowledge economy*. Paper presented at the third annual New Zealand Science Education Research Symposium. Wellington, New Zealand.



## **ACKNOWLEDGEMENTS**

---

I am deeply grateful to all those who have provided encouragement and support during the completion of this project.

Associate Professor Richard Coll introduced me to the world of science education research and provided expert guidance and support as I journeyed from being a researcher in science to a researcher in science education.

Professor Alister Jones helped me to see the importance of ‘the big picture’ and has been a valued mentor in the early stages of my career.

Dr. Alison Campbell was enthusiastic about the project from the start, and her enduring interest helped me to remember why I was doing it.

Other experienced researchers, whose interest in my work provided me with tremendous encouragement, include Dr. Bev France, Rose Hipkins, Dr. Allan Harrison, Dr. Billy McClune, and Professor Michael Reiss.

The Centre for Science and Technology Education Research is a stimulating place to work, and I thank the staff and students for the many conversations and laughs over the years. Each person has made a valued contribution to my experience, and it is too difficult to single out individuals.

I am also grateful to many other friends for the enduring interest they have shown in my progress, and I especially thank Ashlie for the roads we have journeyed together.

My parents and sister are thanked for their interest, support and love, especially over the final few months. My husband Keith is my rock, and I cannot imagine having a better person by my side.

As I learned very early in the project, research in education is also entirely dependent on the good will of the research participants, and I am extremely grateful to all the students and faculty who willingly agreed to be a part of this work. Many have become good friends, and continue to enrich my life.

Finally, I feel honoured to have been awarded a Top Achiever Doctoral Scholarship (administered by the Tertiary Education Commission), a University of Waikato Doctoral Scholarship, a merit study award (administered by the Federation of Graduate Women, Waikato Branch), and a Freemasons Postgraduate Scholarship. These organisations are thanked not only for the financial assistance that their awards provided, but also for the faith that they placed in the research project, and in me as an emerging researcher.

For Megan Catalina, whom we loved and love

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# Chapter 1

## Introduction and Overview

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### 1.1 INTRODUCTION

In its first report to the New Zealand government, the Science and Innovation Advisory Council [SIAC] emphasised the need to educate for a ‘knowledge economy’ (SIAC, 2000) with a particular focus on biotechnology as an area for accelerated growth and development (Growing an Innovative New Zealand, 2002). This report included a call for tertiary institutions to prepare students to participate in and contribute to the biotechnology industry.

Despite its multidisciplinary nature, biotechnology is still strongly dependent on the enabling sciences, particularly biology (Bozeman, 2005). Hence, effective training of biotechnologists relies on students developing a sound knowledge of traditional topics in the biological sciences.

The work undertaken in this thesis seeks to contribute to human capital development for the biotechnology and bioscience industries by informing the practice of biology education, with particular emphasis on introductory biology courses at university. Although science education research has traditionally been dominated by studies at the elementary and secondary school level, tertiary-level courses have received increasing attention over recent years (Coll, 2005; James, 2001; Laws, 1996; Mervis, 2001; Stokstad, 2001). In particular, first-year courses have been recognised as having a significant influence on student retention and subject selection choices (Daempfle, 2003; Dalgety & Coll, 2005; James, 2001; Yorke, 2001), as well as learning at higher levels (Tyson, Venville, Harrison, & Treagust, 1997; Stokstad 2001).

This thesis focuses on educational issues in first-year biology courses. Specifically, it concentrates on the increasing diversity in the academic backgrounds and qualifications of students entering tertiary biology courses, and the impact this may have on teaching and learning. As part of the work, a teaching intervention based on concept mapping is developed and evaluated. The work is based on a social-constructivist view of learning, that is, learning is considered to occur in social settings, and learners construct understandings of concepts by relating new concepts to relevant prior knowledge that they already possess (Tobin & Tippins, 1993; Guba & Lincoln, 1994).

This chapter sets out to contextualise the research. First, the increasing diversity of students entering tertiary courses will be described. Second, the current research will be outlined, followed by a description of the way this thesis is organised.

## **1.2 STUDENT HETEROGENEITY IN INTRODUCTORY-LEVEL COURSES**

In the middle of the twentieth century access to, and participation in, tertiary education was limited to certain segments of the population. Since then, an

increasing requirement for a more highly skilled workforce in most Western countries (and many developing countries) has led to increased demand for post-compulsory training and education (Jorgensen, 2001; Leder & Forgasz, 2004). As a result, higher education has undergone a period of massive expansion, with a greater number of school-leavers entering tertiary study, and a marked increase in the number of 'mature' students<sup>1</sup> (Hoskins & Newstead, 1997; Zepke et al., 2005). This expansion in tertiary enrolments has been aided in New Zealand by the country's lifelong approach to tertiary learning, its relatively open access to enrolment, and the availability of a student loan scheme (Scott, 2005). In addition to increased uptake of tertiary study, recent technological advances and the globalisation of technology mean that industry demand for tertiary graduates has been particularly heavy in science, engineering and technology-related fields (Daempfle, 2003; Dalgety, Coll, & Jones, 2003; Robottom & Hart, 1993; Rowarth, 2005).

As access to higher education has widened, large groups of students from heterogeneous backgrounds have become the norm (Scott, 2005; Sneddon, Settle, & Triggs, 2001). In particular, an increased proportion of enrolling students do not hold traditional entry qualifications. For example, fewer than 60% of students entered tertiary studies in the UK in 1995 having completed their 'A' levels (Hoskins & Newstead, 1997). The means of entry of mature students appear to be particularly varied. Some have appropriate high school qualifications or may have already completed a degree, polytechnic qualification or other professional qualification. Others have completed an access or bridging course or gained special permission to enter on some other grounds, for example, industry-based experience (Blaxter, Dodd, & Tight, 1996). The subject combinations completed by school-leavers also are varied. For example, the broadening of school curricula, including the introduction of technology as a separate subject in New Zealand and other countries (see Sade & Coll, 2003) means that school students now have greater choice in school subjects, and their high school qualifications reflect this.

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<sup>1</sup> The age at which students are classified as 'mature' varies, although classifications such as "21 and over" or "over 25" are commonly used (see Hoskins & Newstead, 1997).

Diversity in ethnicity and other demographic groups (e.g., females) in introductory science classes is not seen negatively. Indeed the opposite seems to apply, with increasing calls for science participation from non-traditional backgrounds (e.g., Dearing, 1997; Justiz, Wilson, & Björk, 1994). What is of concern is the increasing diversity in content knowledge of entry-level, or freshman, science students. For example, Ramsden (2003) argues that:

The continually growing numbers of students entering higher education from non-traditional backgrounds imply that increasing attention will have to be paid to studying the variety of understandings and skills with which students begin a course of higher education. (p. 131)

However, as Hoskins and Newstead (1997) point out, few published research studies have examined the impacts of traditional versus non-traditional entrance qualifications on student achievement. An exception appears to be literature reporting on the academic success of mature students, although the majority of these studies investigate performance across all disciplines rather than specifically in the sciences. In studies where analysis is separated out for different disciplines, findings for mature students participating in science programmes have been ambiguous. For example, a study by Bourner and Hamed (1987) reported no difference in performance between mature students compared with those of traditional entry age participating in science courses, but Woodley (1984) reported that mature students did worse. In contrast, Hoskins and Newstead (1997) reported that mature students did better. Other studies (e.g., Archer, Cantwell, & Bourke, 1999) point to the benefits of access or bridging courses. However, it is important to note that mature students cannot be considered to represent a homogenous group (Sneddon, Settle, & Triggs, 2001). Some may be nervous about university study after many years away from the classroom, or be concerned that they lack the required background knowledge and skills; others, particularly those who may not have completed high school, may be worried that their attempt at university will end in failure (Archer, Cantwell, & Bourke, 1999; Dalgety & Coll, 2005; Leder & Forgasz, 2004).

Not all students entering university via non-traditional pathways are mature students. However, few studies have examined the academic success of this other,

younger cohort of students who do not have traditional university entrance qualifications, other than research investigating the success of particular minority groups (e.g., Lamont & Ernest, 2003; Mullen, 2001). Hoskins and Newstead (1997) reported in a British-based study that traditional (non-mature age students) did worse when they had non-traditional qualifications (i.e., no 'A' levels) when compared with mature students with non-traditional qualifications across all disciplines. The authors suggest that the younger students may be less able or less highly motivated than either mature students or those of similar age who have entered university by more conventional means. Yager, Snider, and Krajcik (1988) reported in a small-scale study at one North American university that students with and without prior study of high school chemistry showed similar achievement in an introductory college chemistry course, although further investigation revealed differences in the amount of time and effort that students expended studying. In particular, students without a high school chemistry background sought out many more hours of tutoring than their peers. In contrast, Tai, Sadler, and Loehr (2005) reported a correlation between high school chemistry instruction and college chemistry performance, based on a survey across 12 universities in the United States. In another small-scale study at a British university, students who failed a first-year biology module were most likely to be those who had not completed A-level biology (Phoenix, 2001). Hazel, Prosser, and Trigwell (2002), investigating first-year biology students in Australia, report that students with more extensive prior knowledge are more likely to adopt 'deep' approaches to learning<sup>2</sup> than those with more limited prior knowledge.

Zeegers (1994) argues that students entering science at university who do not have a traditional high school mathematics and science background are not necessarily as well prepared for their first year science courses as those who enter by the traditional route. This can exacerbate the inherent difficulties associated with the transition to tertiary study - particularly when assumptions are made by the teaching staff as to the level of preparedness of their students. A key aspect of this is the

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<sup>2</sup> Students adopting 'deep' approaches to learning tend to seek meaning and understanding, whereas 'shallow' approaches tend to be associated with rote memorisation of isolated facts (see Section 2.4 of this thesis).



notion that students' prior knowledge may affect their understanding of newly-learned scientific concepts, as well as the learning approaches that students adopt.

### **1.3 PRIOR KNOWLEDGE AND STUDENT LEARNING**

The importance of students' prior knowledge is emphasised in a variety of current theories of learning, including constructivism and its variants such as social and contextual constructivism (see Good, Wandersee, & St. Julien, 1993). Constructivist-based views of learning consider that learners construct knowledge by relating new knowledge to relevant concepts that they already possess (Douvdevany, Dreyfus, & Jungwirth, 1997; Millar, 1989; Wandersee & Fisher, 2000). During the learning process, students may form understandings that are inconsistent with consensual scientific views (Driver, 1989; Duit, 2004; Pfundt & Duit, 2000), particularly if the prerequisite knowledge necessary for the construction of a new concept is absent from their cognitive structure (Garnett, Garnett, & Hackling, 1995). Prior knowledge is thus considered to be important because it interacts with knowledge presented during formal instruction, sometimes resulting in undesirable outcomes such as alternative understandings of important scientific concepts (Pfundt & Duit, 2000; Wandersee, Mintzes, & Novak, 1994). Social constructivism posits that the internal construction of knowledge is driven by social interaction with the outside world (Wertsch, 1985), and students aim to make sense of new input by relating it to their prior knowledge and by collaborating in dialogue with others to co-construct shared understandings (Good & Brophy, 2000).

The impact of prior knowledge on student learning will be explored more fully in Chapter 2 of this thesis.

### **1.4 THE CURRENT RESEARCH**

The current research focuses on introductory-level biology courses at New Zealand universities. Specifically, it investigates the diversity of academic

backgrounds of students (and consequent diversity in prior knowledge), and the potential impact of this diversity on teaching and learning.

Two broad aims frame the research. The first is to develop an understanding of any matches and mismatches between faculty assumptions regarding student prior knowledge, and actual student prior knowledge. The second is to develop and evaluate an appropriate teaching intervention to enhance learning in first-year biology courses by taking into account the diverse prior knowledge of students. As Sneddon, Settle, and Triggs (2001) have argued, “Traditional teaching methods do not suit what has become, in reality, mixed ability teaching” (p. 6).

## **1.5 OVERVIEW OF THE THESIS**

The research presented in this thesis contributes to an understanding of educational issues in introductory-level biology courses at New Zealand universities. These courses are important because of their potential to affect student retention, subject selection choices, and subsequent learning at higher levels. Student retention and learning is significant in the current political climate, not only because of the financial pressure on departments to retain student numbers, but also because of the current emphasis by the New Zealand Government on the need for graduates able to contribute to the biotechnology and bioscience-related industries.

Specifically, the work in this thesis focuses on the increasingly diverse academic backgrounds of students, and the potential impacts this has on teaching and learning. From a social constructivist view of learning, prior knowledge is considered to be an important factor influencing student learning. However, taking students’ diverse prior knowledge into account can be problematic for faculty, particularly when some students have very little prior understanding of specific concepts (which they need to be taught in order for subsequent learning to successfully occur), and other students have a scientifically acceptable understanding

of these same concepts, and resent the time spent 're-teaching' them. Time constraints further impact the number of concepts that can be taught 'from scratch'.

An overview of current understanding of the role of prior knowledge in learning, particularly from a social constructivist view of learning is explored in more detail in Chapter 2, as are teaching strategies that can be used to accommodate and incorporate students' prior knowledge. The chapter concludes with the three research questions underpinning the work:

1. What are faculty assumptions about the prior knowledge of students entering first-year biology courses?
2. What is the actual prior knowledge of students entering first-year biology courses?
3. How useful is concept mapping as a teaching and learning strategy within a first-year biology course at university?

The research was conducted within an interpretive paradigm, which is described in Chapter 3. Chapter 3 also outlines the specific methods that were used to gather and interpret data.

The findings from the research are presented in the subsequent chapters. Chapter 4 presents an extensive survey of faculty views of students' prior knowledge, and includes a list of concepts (biological, chemical and mathematical) that they assume students understand prior to participating in first-year biology courses. Faculty from six different New Zealand universities participated in this part of the study.

Chapter 5 details the prior knowledge of students, based on a prior knowledge questionnaire administered to two different cohorts of students at the start of a first-year biology course. The concepts included in the questionnaire were ones faculty identified as being important for students to understand prior to participating in these courses.

In Chapter 6, an intervention programme based on concept mapping is developed and evaluated. A description of the concept mapping classes and the conventional classes is presented, as well as justification for using concept mapping as the basis for the intervention. Students' views of concept mapping, as well as the tutor's views, are also presented, as are quantitative data evaluating the effect of on student learning.

Finally, Chapter 7 places the findings from the research in the context of the broader science education literature, and details implications for teaching and learning in first-year biology courses. Recommendations for further research are also provided.

# Chapter 2

## A Review of the Literature

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### 2.1 INTRODUCTION

Chapter 1 highlighted the increasing diversity in academic backgrounds of students entering university courses, including science courses. Laws (1996), in a broad evaluation of research in undergraduate science education, claims that such diversity “must have a profound effect on the kind of science education which is offered” (p. 67). Laws goes on to stress the need for strategies in which a teacher’s planning and implementation can take into account a broad range of students’ prior learning and conceptions. It is this theme that forms the focus of the current study, viz., how can teaching staff take into consideration students’ conceptions and learning processes, particularly in the context of increased student diversity?

The literature reviewed in this chapter focuses on an analysis of current understandings about student learning processes and the role of prior knowledge and

experiences in student learning. Teaching strategies that are reported to facilitate effective student learning are also considered.

## **2.2 LEARNING THEORIES**

Behaviourism and constructivism are two learning theories that seem to sit on opposite ends of an epistemological continuum, and are often presented as contrasting viewpoints (Fosnot, 1996a). Duit and Treagust (1998), in an historical overview of trends in science education, note that behaviourism theories of the first part of the 20<sup>th</sup> century have now largely given way to cognitive theories, in particular constructivism. Both behaviourism and constructivism will be discussed in the next sections. Some of the impacts that these theories have had on research in science education will also be explored.

### ***2.2.1 Behaviourism***

Behaviourism is often aligned with a positivist view of knowledge, that is, that reliable, stable knowledge of the world exists and can be known. The purpose of the mind, according to a behaviourist view of learning, is to ‘mirror’ this reality (Jonassen, 1991). The goal of the learner is to gain knowledge and the goal of the teacher is transmit it (Davis, McCarty, Shaw, & Sidam-Tabbaa, 1993). Further, learning is considered to occur primarily as the result of conditioning, where positive or negative consequences to an action influence the likelihood of the action being repeated, or learned (Calder, Faire, & McGougan, 1994). Typically, knowledge is broken down into skills and subskills which are presented in curricula as behavioural objectives (Wheatley, 1991), with an emphasis on performance (what students can do) as opposed to competence (what students know) (Bruner, 1986).

Science education research in the context of behaviourism is based on the view that human behaviour is governed by universal, and motivations and intentions of the participants tend to be ignored (Cohen, Manion, & Morrison, 2000). There is

also a strong emphasis on objectivity and the control of experimental variables (Holloway, 1997).

Science education research with a theoretical underpinning based on behaviourism therefore tends to focus on discovering whether or not changes in teaching procedures or the curriculum lead to changes in students' performances, rather than why or how these changes come about (Duit & Treagust, 1998). Thus, although behaviourist learning theory can be used to explain behavioural change, it appears to offer little in the way of an explanation for conceptual change (Fosnot, 1996a). In contrast, cognitive learning theories like constructivism place emphasis on the internal processes that constitute learning.

### ***2.2.2 Constructivism***

Interest in cognitive theories of learning was initiated at least in part by Piaget's (1954, 1964) ideas of the development of cognitive structures at different stages of development. For example, Piaget described a 'concrete operations stage' of learning where symbols can be used and manipulated within the context of concrete (real) situations. The 'formal operations stage' generally occurs in older children and allows for logical investigation and problem solving in abstract (imaginary) contexts. Reference to these stages were first incorporated into research that was still influenced by behaviourism, such as research focusing on creating conditions that could move students from concrete to formal thinking (Duit & Treagust, 1998). Emphasis also was placed on general cognitive functions, rather than the structure of domain-specific knowledge (e.g., biological and chemical knowledge) (Mintzes & Wandersee, 1998), and limited attention was paid to the effects of contextual variables and prior experiences on learning (Lawson, 1991).

Novak (1977, 1978) suggests that the primary limitation to learning is not 'cognitive operational capacity' as emphasised by the work of Piaget, but rather the quality of relevant knowledge structures that allow the learner to make sense of an

experience. Novak's ideas are based largely on an interpretation of Ausubel's (1968) theory of meaningful learning, called cognitive assimilation theory. 'Meaningful learning' is defined by Ausubel (1968, pp. 37-38) as the "nonarbitrary and substantive" incorporation of new ideas into a learner's existing knowledge structure. In contrast, 'rote learning' results in the "discrete and relatively isolated entities that are relatable to cognitive structure only in an arbitrary, verbatim fashion" (Ausubel, 1968, p. 108). This isolation of propositions can result in poor retention and retrieval of new ideas, potential interference with subsequent learning of related concepts, and the inability to use new knowledge to solve novel problems (Mintzes & Wandersee, 1998).

In contrast to the behaviourist view of knowledge as an external reality, constructivists consider knowledge to be a constructed entity constructed by each learner during the learning process (von Glasersfeld, 1993). However, constructivism does not deny the existence of reality as is argued by some critics (e.g., Matthews, 1992). Rather, a constructivist-based view of reality is that it can only be known in a personal and subjective way (Tobin & Tippins, 1993). In other words, the existence of an external reality is acknowledged, but the focus shifts from 'truth' to 'viability' (von Glasersfeld, 1995) and the ways in which learners construct viable knowledge (Tobin & Tippins, 1993).

Constructivism has many variants (Good, Wandersee, & St. Julien, 1993) but all have as a central tenet the principle that human beings construct knowledge for themselves (Ausubel, Novak, & Hanesian, 1978). This mental construction, or meaning-making, occurs when connections are formed between new concepts and those that are part of an existing framework of prior knowledge (Novak, 1993). An underlying principle of constructivism is that concepts are conceptually grouped together in hierarchies and the more a person knows about a subject, the more substantial and accurate the cognitive hierarchy becomes (Calder, Faire, & McGougan, 1994).



The construction of knowledge is embodied in a complex set of language and symbol systems (Mintzes & Wandersee, 1998). It is also affected by a person's experiences – their subjective interactions with the world, including other people (Tobin & Tippins, 1993). In other words, even the personal construction of knowledge by an individual is socially and culturally mediated. The social dimension of knowledge construction also enables negotiation about the viability of the constructed knowledge (von Glasersfeld, 1993). The constructed knowledge must therefore be viable, not only personally, but also in the social context in which it is used.

Because no two human beings construct precisely the same meanings, even when presented with identical objects or events (Mintzes & Wandersee, 1998), knowledge is not seen by constructivists as a product that can be faithfully conveyed from one person to another, for example, from a teacher to a student (von Glasersfeld, 1993). According to a constructivist view of learning, the goal of education is the construction of shared meanings (Novak, 1993). Teaching in this context becomes a process of discovering what the learner knows and using this knowledge to help the learner build further constructions that are considered to be accurate (to the best of our current knowledge) and stable (Calder, Faire, & McGougan, 1994). Thus, the teacher's role is to provide students with opportunities and incentives to build their own knowledge constructs (von Glasersfeld, 1992), introducing new ideas where necessary, and providing support and guidance for students to make sense of these for themselves (Fosnot, 1996a).

'Learning' is therefore viewed from a constructivist perspective as a self-regulatory process of "struggling with the conflict between existing personal models of the world and discrepant new insights ... and constructing new representations and models of reality as a human meaning-making venture" (Fosnot, 1996b, p. xi). The learner is actively engaged in constructing meaning and, if the purpose is considered to be worthwhile, prior knowledge is adjusted to accommodate new concepts and ideas (Driver, 1995). In constructivist-based teaching the teacher's role is to orient

students' constructions in "a fruitful direction," but he or she cannot "force" the construction (von Glasersfeld, 1993, p. 32).

### ***2.2.3 Forms of Constructivism***

Constructivist theories have dominated research in science education since the 1980s (Duit & Treagust, 1998), and this widespread interest seems to have led to a debate between constructivist theorists and researchers who emphasise the individual cognitive structuring process, and those who place greater emphasis on the sociocultural factors that affect learning (Fosnot, 1996a). The former tend to view learning primarily as a process of active cognitive re-organisation, whereas the latter tend to see it as a process of enculturation into a community of practice (Cobb, 1996). As a result many researchers, attempting to explain their theoretical rationale, have introduced a range of adjectives to characterise the particular 'brand' of constructivism that is being used.

'Radical constructivism' was developed by von Glasersfeld (e.g., 1984) as a counterfoil to those who viewed constructivism only in terms of learning being built on prior knowledge (Tobin & Tippins, 1993). Specifically, von Glasersfeld emphasised the view that knowledge "does not reflect an 'objective' ontological reality, but exclusively an ordering and organization of a world constituted by our experience" (von Glasersfeld, 1984, p. 22). In other words, it is impossible for any one person to know the world exactly as it is. Similarly, it is impossible for one person to know exactly the constructions of the world as constructed internally by another person. Science educators adopting a radical constructivist perspective thus not only think of knowledge as being built up by the individual (in a particular social context), but they also recognise that in the teaching and learning context, what is being talked about is "a particular view of the world, rather than the world as such" (von Glasersfeld, 1993, p. 35).

‘Neoconstructivism’ attempts to integrate the roles of prior knowledge, short-term memory, and sensory experience in the learning process. Learning is understood to occur when the learner retrieves knowledge from long-term memory; applies information-processing skills in generating meaning from sensory data; and organises, codes and stores new meanings in long-term memory (Trowbridge & Mintzes, 1988). Neoconstructivism further emphasises the view that meaningful learning begins not with experience itself, but with selective attention (short-term memory) to specific and relevant aspects of the experience. Selective attention, in turn, dictates perceptions and is itself dependent on the store of prior knowledge (long-term memory) already possessed by the learner (Osborne & Wittrock, 1983).

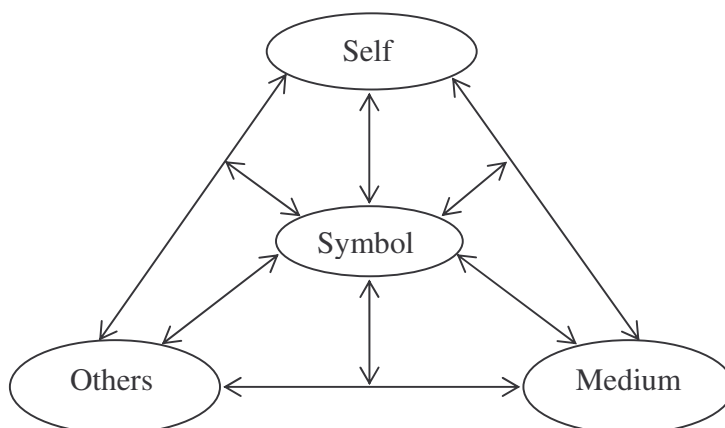
‘Social constructivism’ arose in response to approaches that some authors felt overemphasised the individual’s learning and neglected the social aspects of knowledge construction (Duit & Treagust, 1998). This type of constructivism draws on the work of Vygotsky (1962) and views the internal construction of knowledge as being driven primarily by social interaction with the outside world (Wertsch, 1985). The social context is thus of prime importance (Prosser & Trigwell, 1999) and learning from this perspective involves “negotiating understandings through dialogue or discourse shared by two or more members of a community of people who are pursuing shared goals” (Brophy, 2002, p. ix). The teacher’s role is to act as a discussion leader, posing questions, seeking clarifications, promoting dialogue, and helping groups of students to recognise areas of consensus and continuing disagreement (Good & Brophy, 2000). The students aim to make sense of new input by relating it to their prior knowledge and by collaborating in dialogue with others to co-construct shared understandings (Good & Brophy, 2000).

Whether one adopts an individual or social constructivist view of knowledge construction has implications for the ways in which teaching and learning are conceptualised. However, Tobin and Tippins (1993) argue that the individual and social components of knowledge cannot be meaningfully separated, and that “at all times, knowledge is both individual and social” (p. 6). This is consistent with the

contention of Duit and Treagust (1998) that researchers should “not focus on the differences, but ... conceptualise the different positions as complementary features ... to address the complex process of learning more adequately than from a single position” (p. 3).

Fosnot (1996a) uses a dialectical tripartite drawing to represent her view of the interactions between the individual and the social world and the way that these influence knowledge construction (Figure 2.1). In her model, meaning-making by the individual is mediated by interactions with the social and cultural context (including language and symbols), and this results in further symbols. These, in turn, can affect the social and cultural context in which the construction is occurring, both at that moment and in the future. In other words, the different components become very difficult to separate, both because of the multiple interactions between them, and because each component is non-static.

One of the important outcomes of science education research based on constructivist views of learning has been recognition of the role of prior knowledge in knowledge construction and learning. This is an important consideration in the current study, which focuses on the students entering first-year biology courses and the increasing diversity in their prior learning experiences. Thus, the role of prior



**Figure 2.1**  
A constructivist model of learning, as depicted by Fosnot (1996a, p. 28)

knowledge within a constructivist view of learning will be explored in the next section.

### **2.3 PRIOR KNOWLEDGE AND ALTERNATIVE CONCEPTIONS**

Constructivist learning theory and its variants, described above, assume an essential role for prior knowledge in the learning process, and Ausubel's (1968) famous dictum continues to be frequently quoted in the science education literature: "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him [sic] accordingly" (p. vi). Duit and Treagust (1998), for example, corroborate this view in their assertion that "domain-specific pre-instructional knowledge has proven to be *the* key factor in determining learning and problem solving in research in all science domains" (p. 19, original emphasis). An enormous amount of research reported in the science education literature has thus focused on probing learners' understanding of specific science concepts. The assumption is that studying the conceptions students have will give insight into the learning process (Wandersee, Mintzes, & Novak, 1994), as well as provide teachers with effective strategies to identify student understandings and then take them into account during teaching (Treagust, 1988).

A range of terms have been used to describe the varying ideas students have of scientific concepts – alternative conceptions, misconceptions, prescientific conceptions, naïve beliefs, alternative beliefs, erroneous ideas, multiple private versions of science, personal models of reality, spontaneous reasoning, and limited or inappropriate propositional hierarchies (LIPHS) (see, e.g., Driver & Erickson, 1983; Wandersee, Mintzes, & Novak, 1994). Each term conveys its own slightly different meaning. For example, Good (1991) favours the term 'prescientific conception' arguing that it suggests that the learners' ideas may eventually lead to the development of a concept that is more scientifically accepted. 'Misconception' on the other hand tends to suggest "a vague, imperfect, or mistaken understanding of

something ... [and] serves no cognitive purpose for the learner” (Wandersee, Mintzes, & Novak 1994, p. 179).

‘Alternative conception’ tends to refer to a conception “which differs significantly from the socially agreed meaning” (Millar, 1989, p. 593). Within this view, “students’ ‘errors’ are ... recognised as being natural developmental phenomena” (Gilbert & Watts, 1983, p. 67). Those who prefer to use the term ‘alternative conception’ seem to do so partly because it is seen to confer “intellectual respect” (Wandersee, Mintzes, & Novak, 1994, p. 178) on the learner who holds those ideas. The term also takes into account research that shows that the concepts hold meaning for students (Greene, 1990), and that they may be productive, at least within certain contexts (Smith, diSessa, & Roschelle, 1993). As a result, ‘alternative conceptions’ seems to have become the current term of choice (Mintzes & Chu, 2004). In the same vein, the research that focuses on the understandings of students has been called the ‘alternative conceptions movement’ (Millar, 1989).

The number of studies focusing on the ideas held by students and teachers has grown astronomically, with over 6,300 entries included in a recent bibliography (Duit, 2004). Several themes have emerged out of the work: learners subscribe to a host of alternative conceptions that they bring with them to formal science instruction; these views are found in students of all ages, ability, social classes and cultures; alternative conceptions have many sources, including direct observation, peer culture, everyday language, the mass media, and formal learning experiences; and, students’ prior conceptions interact with knowledge presented in formal instruction, often resulting in unintended consequences that may interfere with subsequent learning (Mintzes & Chu, 2004; Wandersee, Mintzes, & Novak, 1994). In addition, a small number of alternative conceptions tend to be shared by a large number of individuals (Fisher, 1985).

The bulk of alternative conceptions research seems to have emphasised the robust nature of students’ alternative conceptions and their resistance to change or

alteration, at least by traditional teaching methods (Fisher, 1985). However, some authors suggest that the existence of alternative conceptions should not be viewed negatively. Rather, teachers and researchers should concentrate on the potential of the alternative conceptions to be refined, rather than replaced (Clement, Brown & Zietsman, 1989; Kinchin, 2000a; Smith, diSessa & Roschelle, 1993).

The next section will explore in more detail research related to alternative conceptions relevant to the context of the current study, namely, students participating in first-year biology courses at university.

### ***2.3.1 Alternative Conceptions and First-year Biology Students***

Research that specifically investigates students' understandings of biological concepts spans a range of topics and age groups. Since the current study focuses on the teaching and learning of students in introductory biology courses at university, research related to the understandings of biology students at senior high school or the tertiary level is of most relevance. An overview of this literature suggests that the majority of studies have focused on identifying and describing the range of alternative conceptions held within fairly narrow content domains, including:

- *Evolution* (Abrams, Southerland, & Cummins, 2001; Bishop & Anderson, 1990; Brumby, 1984; Dagher & BouJaoude, 1997; Ferrari & Chi, 1998; Friedler, 1993; Greene, 1990; Jungwirth, 1975; Rowe, 2004);
- *The identification and function of genetic material (genes and chromosomes), particularly the behaviour of chromosomes during meiosis* (Banet & Ayuso, 2000; Brown, 1990; Kindfield, 1991, 1994; Lewis & Kattmann, 2004; Longden, 1982; Marbach-Ad, 2000; Wood-Robinson, Lewis, & Leach, 2000);
- *The relationship between meiosis and Mendelian-type problem-solving* (Browning, 1988; Hafner & Stewart, 1995; Johnson & Stewart, 2002; Kinnear & Simmons, 1990; Moll & Allen, 1987; Richards, 1996; Stewart & Dale, 1989; Stewart, Haffner, & Dale, 1990);
- *The sources of energy for living organisms* (Barak, Gorodetsky, & Chipman, 1997; Boyes & Stanisstreet, 1991)
- *Photosynthesis and cellular respiration and the relationship between these two metabolic pathways* (Anderson & Grayson, 1994; Barker & Carr, 1989; Carlsson, 2002; Haslam & Treagust, 1987; Hazel, 1994; Songer & Mintzes, 1994); and

- *Diffusion and osmosis* (Friedler, Zohar, & Tamir, 1993; Odom, 1995; Panizzon, 2003; Zuckerman, 1994).

Reports on senior secondary and tertiary students' understandings of concepts related to animal classification (Brumby, 1982; Trowbridge & Mintzes, 1988; Yen, Yao, & Chiu, 2004); animal and plant physiology (Arnaudin & Mintzes, 1985; Núñez & Banet, 1997); and ecology (Barman, Griffiths, & Okebukola, 1995) are fewer, and the majority of these studies are cross-age investigations reporting on general patterns in understanding at different ages and school levels. There are also isolated reports at the senior secondary or tertiary level of students' understandings of human disease (Krupka, 1991; Patel, Kaufman, & Magder, 1991) and plant reproduction (Sanders, Moletsane, Donald, & Critchley, 1997).

Considering the emphasis placed on topics such as gene expression in senior secondary and tertiary biology curricula, there seem to be surprisingly few studies investigating students' understanding of the role of DNA in protein production (Fisher, 1985; Friedrichsen, Stone, & Brown, 2004) and some of the newer technologies, like genetic screening (Hill, O'Sullivan, Stanisstreet, & Boyes, 1998). Very few research studies investigate understandings across a range of biological concepts, and those that do are necessarily shallow in their coverage of concepts, for example including a single question on photosynthesis or inheritance (Lucas, 1987; Mak, Yip, & Chung, 1999; Yip, 1998). Further, the research participants in these wide-ranging studies were teacher trainees (Mak et al., 1999; Yip, 1998) or members of the general public (Lucas, 1987) rather than senior secondary or tertiary biology students. The research focusing on introductory biology students' understandings of a wide range of biological concepts thus appears to be somewhat limited. The studies that do exist report that senior secondary and tertiary biology students have a range of strongly-held alternative conceptions. Further, lack of integration of related concepts was specifically noted by several authors (e.g., Anderson & Grayson, 1994; Brumby, 1984; Leach, Driver, Scott, & Wood-Robinson, 1996a; Núñez & Banet, 1997).



A variety of possible explanations for the existence of alternative conceptions related to biological concepts have been suggested. These include the microscopic nature of many biological structures, which may be problematic for students (Arnaudin & Mintzes, 1985; Ferrari & Chi, 1998; Friedler, Amir, & Tamir, 1987; Sanders, Moletsane, Donald, & Critchley, 1997; Zuckerman, 1994); and students' lack of experience at seeking cellular explanations for phenomena that manifest themselves at level of the organism. For example, 'cellular respiration' is physically manifested as breathing (Songer & Mintzes, 1994). Terminology has been identified as another common source of alternative conceptions, particularly where terms have different meanings in scientific and everyday contexts. For example, references to fertilisers as 'plant food' can reinforce the concept that 'food' for plants is taken in solely from the soil (Leach, Driver, Scott, & Wood-Robinson, 1996a). Terms used in evolutionary contexts also commonly have meanings that differ when the terms are used in everyday contexts. For example, 'fitness' means health and strength in everyday language, but in evolutionary contexts it is used to refer to the relative ability of individuals to produce surviving offspring (Bishop & Anderson, 1990). A further possible suggestion for the existence of alternative conceptions is that topics are often taught in isolation (Brumby, 1984; Leach, Driver, Scott, & Wood-Robinson, 1996a; Okebukola, 1990; Songer & Mintzes, 1994). For example, Mendelian-type problem solving is often taught in isolation from the behaviour of chromosomes during meiosis (Moll & Allen, 1987; Stewart, Haffner, & Dale, 1990). Teaching that emphasises the 'how' aspect as well as the 'why' of biological processes may help students to generate a more holistic understanding of specific concepts (Abrams, Southerland, & Cummins, 2001; Anderson & Grayson, 1994), as may teaching that focuses on the interrelationships between concepts (Rowe, 2004).

Understanding key propositional statements or 'anchoring concepts' also appears to be important for ongoing learning in many biological contexts. For example, an understanding of diffusion and osmosis requires an understanding of a range of physical and chemical concepts, such as the concept that all particles are in constant motion, and diffusion results from the random motion and/or collisions of

particles (Friedler, Amir, & Tamir, 1987; Odom & Barrow, 1995). In order to understand the movement of water in a plant, students must also understand the properties and nature of water molecules (Cottrell, 2004), and in order to understand plant reproduction and lifecycles, students must have an understanding of meiosis, chromosomes and chromosome number (ploidy) (Sanders, Moletsane, Donald, & Critchley, 1997). Key concepts that underpin a scientific understanding of evolution include the propositions that variation in a population is randomly generated (as opposed to developing in response to a particular need), and that the variation has a genetic basis and can be inherited (Ferrari & Chi, 1998; Greene, 1990; Rowe, 2004). Conservation of matter is a concept that underpins scientific explanations of the cycling of matter in ecosystems (Leach, Driver, Scott, & Wood-Robinson, 1996a).

Although Leach, Driver, Scott, and Wood-Robinson (1996b) demonstrated that both a growing knowledge base as well as content-independent reasoning skills affect learning outcomes, research by Carey (1985) suggests that variation in content-specific knowledge schemes developed by students of different ages is based more on differences in initial knowledge structures than levels of cognitive functioning. This is supported by the findings of studies that compare the conceptual reasoning of novices and experts solving inheritance problems, which show that expertise in problem solving is dependent on large, well-organised, domain-specific knowledge structures (Collins, 1987; Hackling, 1994; Kindfield, 1994; Kinnear & Simmons, 1990). In other words, initial knowledge structures appear to have a significant influence on learning outcomes, including the learner's ability to apply the concepts in novel situations.

To summarise, the research on alternative conceptions held by senior secondary and tertiary biology students suggests that conceptual problems that impede further understanding are common, and that greater emphasis should be placed on efforts to help students to recognise and evaluate their existing knowledge frameworks, and to link new knowledge to these existing frameworks. This is important in the context of introductory courses at university not only because of the

diversity of academic backgrounds of students (and consequently their prior knowledge frameworks), but also because conceptual difficulties that are not addressed in these courses are likely to remain intact through the undergraduate years and hinder further learning (Songer & Mintzes, 1994). The next section will focus on the role of learning approaches in student learning, and the links between learning approaches adopted and levels of prior knowledge.

## **2.4 DEEP AND SURFACE LEARNING APPROACHES**

In addition to research focusing on the prior knowledge of students and the effect that this knowledge can have on subsequent learning (described above), research into *how* students learn has “proved crucial in contributing to our understanding of the pathway to high quality learning outcomes” (Hazel, Prosser, & Trigwell, 2002, p. 738). This research, particularly as it relates to introductory-level courses at university, will now be examined more closely.

Approaches to learning are characterised by Marton and Säljö (1976a, 1976b) as being ‘deep’ or ‘surface’, a separation which refers both to the way students go about the study (their study strategy), and to their reasons, or intentions, for adopting a particular study strategy. Students adopting deep approaches tend to seek meaning and understanding, often to satisfy internal goals (Prosser & Trigwell, 1999) and, consistent with a constructive view of learning, they adopt strategies that help them to relate new material to previously-learned material in a meaningful way (Novak & Gowin, 1984b). In contrast, students adopting surface approaches tend to be pragmatically motivated and are seeking to meet the demands of a task with minimum effort (Prosser & Trigwell, 1999). They are inclined to see the task as consisting of unrelated parts, and focus on reproduction of the essential concepts as accurately as possible. Information is memorised for the purpose of assessment, rather than for understanding (Entwistle, 1998; Watkins & Biggs, 1996). Surface approaches therefore tend to lead to retention of facts, but reduced complexity;

whereas deep approaches lead to higher complexity of knowledge construction (Biggs, 1979).

The distinction between deep and surface learning strategies has inspired much research in undergraduate teaching, including in undergraduate science education (Fensham, 1992). For example, deep approaches have been shown quantitatively (Hazel, Prosser, & Trigwell, 2002; Hegarty-Hazel & Prosser, 1991a, 1991b; Prosser, Hazel, Trigwell, & Lyons, 1996; Trigwell & Sleet, 1990) and qualitatively (Prosser & Millar, 1989) to be associated with better propositional knowledge in science subjects.

The study strategy adopted by students has also been shown to depend on the requirements of the task; for example, multiple-choice versus essay-based tasks (Laurillard, 1979; Wandersee, 1988). Surface approaches are often associated with a heavy workload (Entwistle & Ramsden, 1983; Entwistle & Tait, 1990; Fensham, 1992; Prosser & Trigwell, 1999), and perceptions that assessment processes require predominantly recall (Fensham, 1992; Prosser & Trigwell, 1999). Research suggesting that the level of prior knowledge has an impact on the learning approach that is adopted by students will be explored in more detail in the next section.

#### ***2.4.1 Prior Knowledge and Adoption of a Specific Learning Approach***

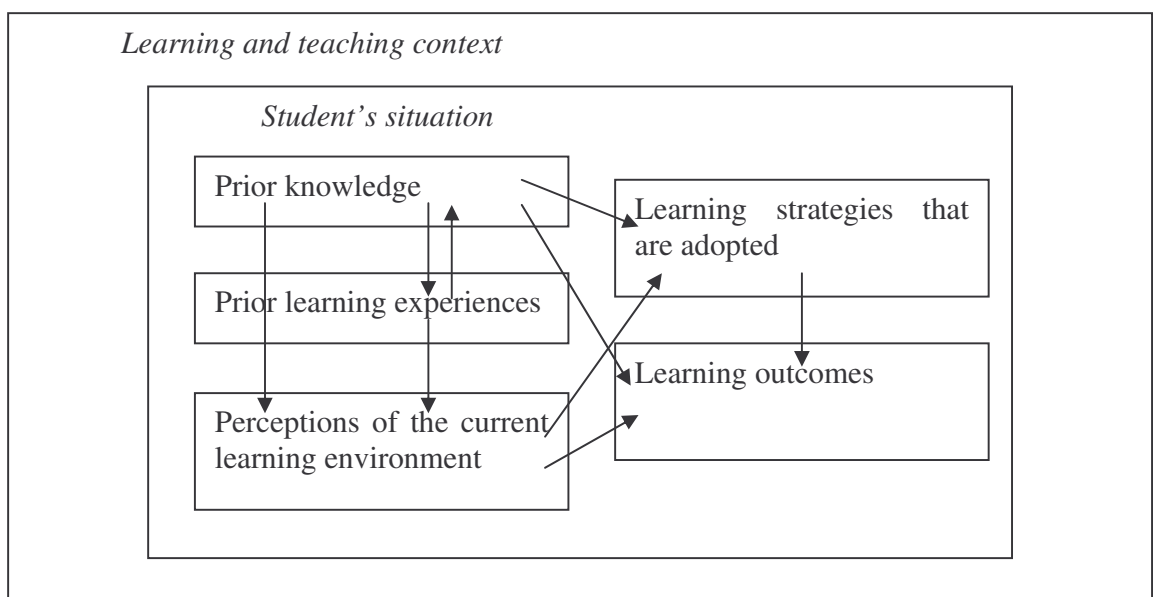
Several research studies have investigated the effect of a range of parameters on student learning and have suggested a relationship between levels of prior knowledge and the learning approach adopted by students (Entwistle & Ramsden, 1983; Hazel, Prosser, & Trigwell, 2002; Hegarty-Hazel & Prosser, 1991a, 1991b; Prosser & Trigwell, 1999), even when little prior knowledge is assumed as part of the teaching (Hegarty-Hazel & Prosser, 1991b). In other words, prior knowledge can have both a direct and an indirect impact on subsequent knowledge – direct in the sense that it affects construction of subsequent knowledge structures (see Section 2.2.2), and indirect in that it may affect the learning strategy adopted by the student.

Hazel, Prosser , and Trigwell (2002) and Prosser and Trigwell (1999) have reported that first-year biology and physics students who have very poor prior knowledge tend to adopt a shallow approach to learning, even when they perceived that a deep learning approach is required. On the other hand, those with more extensive prior knowledge tend to adopt approaches that are consistent with their perceptions of whether deep or surface learning is required. It is not clear from these studies whether addressing issues of prior knowledge will result in students adopting deeper approaches, or whether there is entrenched dissonance between perceived learning requirements and the adoption of a specific learning strategy, and that this has resulted in poor prior knowledge. It may also be that learners with more limited prior conceptual knowledge need to carry out an additional sorting step (separating information into the relevant and irrelevant), which reduces the size of the ‘usable working space’ required for information processing and learning and impacts on the learning approach that is adopted (Johnstone, Hogg, & Ziane, 1993; Johnstone, Sleet, & Vianna, 1994).

Interplay between prior knowledge and other factors, both extrinsic and intrinsic, is consistent with a constructivist view of learning in which the construction of new knowledge is thought to depend on pre-existing knowledge structures as well as student motivation to carry out the construction. A ‘relational perspective of learning’ (Marton & Booth, 1997) attempts to account for the interactions between factors that influence learning. From this perspective, an individual’s awareness of and responses to a learning and teaching situation are understood to affect, and be affected by: the prior experiences (including prior knowledge) that are evoked by the situation; student perceptions of the learning situation; and learning approaches that are adopted (Prosser & Trigwell, 1999). Figure 2.2 shows some of the potential relationships between elements. The ‘learning and teaching context’ is influenced by the teacher, including the teacher’s conceptions of teaching, teaching approaches, curriculum design, and the departmental and institutional context (Kember, 2000; Kinchin, 2001b).

A range of interacting factors alluded to but not explicitly depicted in Figure 2.2 affect students' experiences of the learning situation, and consequently their learning. These include: students' confidence and perceived self-efficacy, which can be affected by whether students perceive that they have the required prior knowledge and skills (Bandura, 1993; Cannon & Simpson, 1980); students' awareness of their own learning approaches, and ability to adjust these to these to meet the demands of particular tasks (Archer, Cantwell, & Bourke, 1999); and students' cognitive skills and deductive reasoning ability (Enyeart, van Harlingen, & Baker, 1980). Further, as depicted in Figure 2.2., these regulatory, motivational, self-evaluative, affective, and environmental factors (the learning and teaching context) all interact in a complex way. As Archer, Cantwell, and Bourke (1999) argue:

In order to be successful on a task, students need not only prior declarative knowledge, but also an awareness of necessary cognitive and self-regulatory strategies, and when and how to deploy them. They also need to feel confident that they can be successful and have the motivation to complete the task. (p. 32)



**Figure 2.2**

A relational perspective of learning, showing the interactions between factors that influence learning

To summarise, the literature presented in this section has highlighted the role of prior knowledge not only as the base on which further knowledge is constructed, but as an influence on the type of learning strategy adopted by students. It is also acknowledged that a range of other factors impact on student learning in complex ways. However, the role of prior knowledge is of particular significance to the current research because it is prior knowledge that is increasingly diverse in the cohorts of students entering first-year biology courses. The next section will explore the potential of selected teaching strategies to address diversity in student prior knowledge.

## **2.5 TEACHING STRATEGIES FOR MEANINGFUL LEARNING**

Although the curriculum can be influenced by factors outside the direct control of the learning environment (e.g., the structure of the subject, the values of society), constructivists argue that it also needs to take account of what learners bring to the learning situation – their purposes and ideas (Driver, 1995). This next section explores different teaching and learning approaches that take into account the prior knowledge of students. First, the definition of learning that is used to underpin the discussion is described.

### ***2.5.1 A Definition of Learning***

Phenomenographers like Marton (1988, 1997) emphasise the importance of the subjects' own perspectives and ways of understanding the world, and have reported that students entertain a range of conceptions about learning, including that learning can be about: increasing one's knowledge; memorising and reproducing; applying; understanding; seeing something in a different way; and changing as a person. Similarly, academics hold a range of views about what learning is, including: increasing one's knowledge; gaining expertise; increasing conceptual development (to satisfy external or internal demands; and interpreting the world differently (Biggs, 1999; Prosser, Trigwell, & Taylor, 1994). A link between teachers' views of

learning, and their pedagogical approach, has also been reported. For example, teachers who consider learning to be about accumulating more information, rather than developing and changing conceptions and understandings, are more likely to consider teaching to be about the transmission of knowledge, with little or no focus on the students or their understanding (Prosser, Trigwell, & Taylor, 1994).

For the purposes of the following discussion, the definition of 'learning' that has been adopted is one that is consistent with a constructivist view of learning, that is: learning occurs when a learner constructs knowledge by relating new knowledge to existing knowledge in a way that is non-arbitrary and meaningful. The translation of learning theory into teaching strategies is not a straightforward process, however. As Millar (1989) points out:

A constructivist model of learning does not logically entail a constructivist model of instruction. Indeed, this must be so or the constructivists would face a major problem in explaining how most people who might be said to have an understanding of science have come to acquire it. For it is very clear that most of us who think we 'understand' some science concepts did not arrive at this understanding by experiencing teaching programmes structured on constructivist lines. (p. 589)

Constructivism, therefore, is viewed by the majority of education researchers as a theory about learning, not a description of teaching (Fosnot, 1996a). However, Tobin and Tippins (1993) note that constructivism can be used as a 'referent' for teaching and suggest that it can be used to explain why certain students have been successful in learning science in any given context; and predict how a given set of circumstances (e.g., a class with 200 students) might be changed to improve the opportunities for students who have to learn in such situations. A constructivist view of learning can thus aid critical reflection in a variety of teaching contexts, acting as a referent for deciding which teacher and learner roles are likely to be more productive in a set of given circumstances.

A survey of the science education literature reveals that a huge amount of effort has been expended on implementing and evaluating teaching strategies aimed at facilitating student learning. For example, work has been done exploring: the use



of analogies (Dagher, 1998; Ingham & Gilbert, 1991; Taylor & Coll, 2001) and mental models to enhance student understanding of complex and abstract scientific conceptions (e.g., Coll, France, & Taylor, 2005; Harrison & Treagust, 1998); the use of concept cartoons to help students negotiate the validity of a range of commonly held conceptions about a topic (Keogh & Naylor, 1999; Kinchin, 2000a); and the usefulness of collaborative group work (Hersey, 2003; Jones & Carter, 1998; McKittrick, Mulhall, & Gunstone, 1999). Many of these strategies are based around opportunities in which the teacher can take into account of what students know, maximise social interaction between learners so that they can negotiate meaning, and provide a variety of sensory experiences from which learning is built (Tobin & Tippins, 1993). Two strategies seem to have received particular attention in the science education literature, and these will now be explored in more detail. They include ‘conceptual change’ approaches, and the use of graphic organisers.

### ***2.5.2 Conceptual Change Theory***

Conceptual change theory (Hewson, 1981; Hewson & Thorley, 1989; Posner, Strike, Hewson, & Gertzog, 1982) provides an example of how constructivist views of learning have been used to suggest ways of teaching that can help students move from everyday concepts to more scientific views. An underlying premise is that the learning of science concepts and principles usually involves major restructuring of students’ already-existing pre-instructional conceptions (Duit & Treagust, 1998). Related to this is the assumption that learning has to start from certain pre-existing conceptions, and that learning paths lead from preconceptions towards scientifically acceptable conceptions. Conceptual change is considered to be most likely to occur if students are ‘dissatisfied’ with their current conceptions, and the new conceptions are ‘intelligible’, ‘plausible’ and ‘fruitful’ (Duit & Treagust, 1998; Hewson & Thorley, 1989). It can be achieved by using activities to challenge student ideas and raise conceptual conflict; using bridging analogies; and providing support for students to construct an alternative theoretical system which is tested in various contexts (Driver, 1989; Hewson & Hewson, 1983; Jiménez-Aleixandre, 1992). In the case of a

‘continuous learning pathway’, instruction starts from aspects of students’ pre-instructional conceptual frameworks that are at least partly compatible with the science view (Duit & Treagust, 1998). In contrast, ‘discontinuous learning pathways’ rely on the establishment and consequent resolution of conflict between students’ conceptions and science conceptions (Scott, Asoko, & Driver, 1992). Both these pathways are only effective when they are:

Embedded in what has been called ‘conceptual change supporting conditions’ which incorporate issues such as students’ interests, motivation and self-concepts, or the classroom climate and power structures in the school [or other learning context]. (Duit & Treagust, 1998, p. 20)

Although critics of conceptual change approach have expressed concern that student confidence may be undermined (Taylor, 1993), the aim is rarely a sharp replacement of conception ‘X’ by conception ‘Y’. Rather, conceptual change appears to more often be “an accretion of information that the learner uses to sort out contexts in which it is profitable to use one form of explanation or another” (Gunstone & Mitchell, 1998, p. 134). The notion of ‘situated cognition’ explores this view that concepts are context or situation dependent (Brown, Collins, & Duguid, 1989), and the aim of conceptual change within this framework is not to replace students’ everyday views with scientific ones, but rather to reduce the status that is given to the old (‘everyday’) ideas, and to increase the status given to new (‘science’) conceptions (Hewson & Hewson, 1992).

Two reviews, one of 103 conceptual change studies (Wandersee, Mintzes, & Novak, 1994), and the other of 70 (Guzetti, Snyder, Glass, & Gamas, 1993), are optimistic about the potential of conceptual change strategies to facilitate student learning. Several studies involving students in tertiary biology courses also suggest that a conceptual change approach can be effectively used to specifically address commonly held alternative conceptions (e.g., Friedrichsen, Stone, & Brown, 2004; Rowe, 2004). However, this approach is limited to addressing only the most common alternative conceptions.

An alternative strategy to a conceptual change approach based on cognitive conflict is the use of graphic organisers. Specifically, graphic organisers emphasise the ways in which students construct knowledge, rather than the particular knowledge that is constructed. They are reviewed below in more detail.

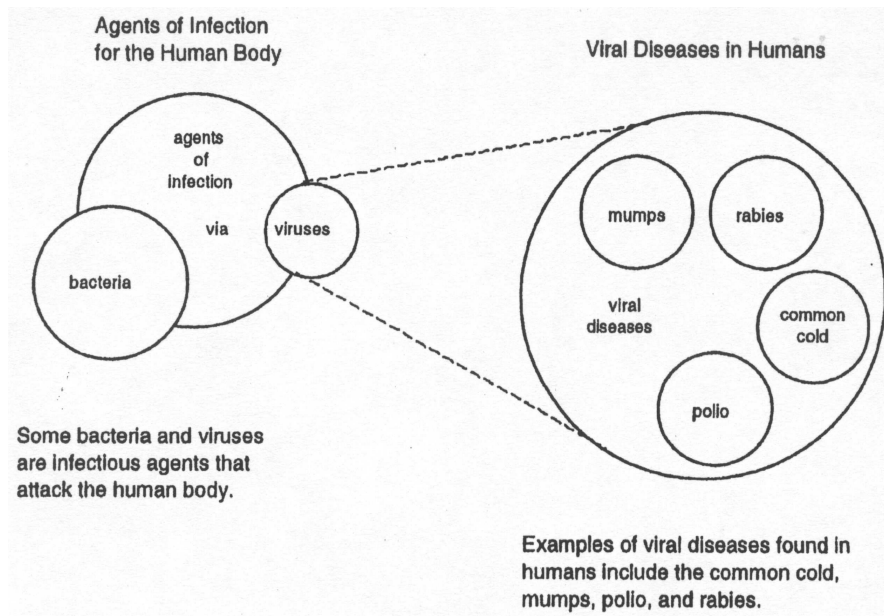
### ***2.5.3 Graphic Organisers***

While some researchers have focused on the development and evaluation of conceptual change strategies as described above, others have investigated the role and use of ‘graphic organisers’ in promoting student learning. Such graphic organisers can be defined as “visual representations that are added to instructional materials to communicate the logical structure of the instructional material” (Jonassen, Beissner, & Yacci, 1993, p. 166), and a number of different types are used by students to help them to structure their learning. They include: fishbone diagrams (e.g., Manzo & Manzo, 1990); KWL charts (what the student knows, wants to know, and has learned) (e.g., Carr & Ogle, 1987); and flowcharts (e.g., Briscoe, 1990). However, concept circles, vee diagrams, and concept mapping are the only graphical tools singled out by Trowbridge and Wandersee (1998) as being consistent with constructivist views of learning, and will now be discussed in more detail.

#### Concept Circles

Concept circles enclose up to five smaller circles, each containing a single concept, within one larger circle. The smaller circles can overlap or be distinct, depending on the relations between them (Wandersee, 1987). An example of a concept circle is presented in Figure 2.3.

Concept circles have been used as a research instrument to characterise students’ understandings, and as a tool to facilitate individual and social knowledge construction (Trowbridge & Wandersee, 1998). However, they are limited in the number of concepts that can be incorporated into the overall structure, which tends to restrict their usefulness for more complex, interrelated concepts.

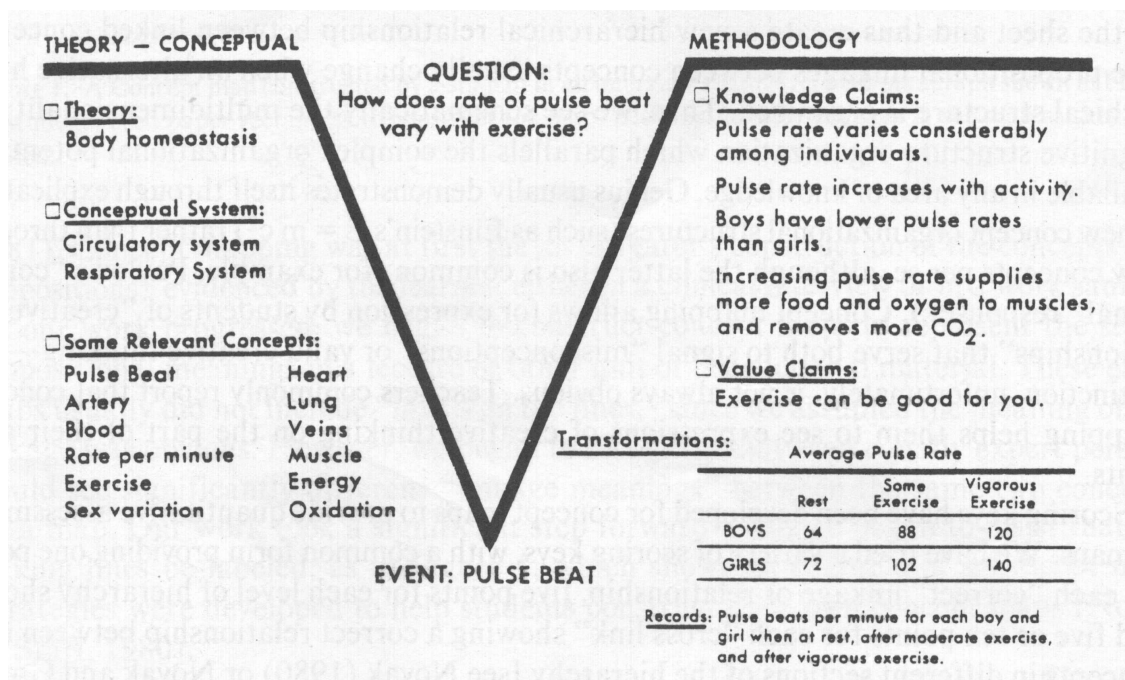


**Figure 2.3**  
A telescoped concept circle showing the relationships between viral and bacterial diseases (Trowbridge & Wandersee, 1998, p. 112)

### Vee Diagrams

Vee diagrams tend to be used primarily in the context of science laboratory activities (Novak, Gowin, & Johansen, 1983; Phillips & Germann, 2002). Figure 2.4 illustrates the key elements of a Vee diagram. The focus question for the inquiry is written in the centre of the vee, information pertaining to the epistemology of the inquiry is written on the left hand side, and information relating to the methodology is written on the right hand side (Trowbridge & Wandersee, 1998).

The Vee diagram is designed to help learners relate the methodological aspects of an investigation to the underlying conceptual components (e.g., Esiobu & Soyibo, 1995; Kaya & Ebenezer, 2003). In other words, the focus becomes understanding the interplay between conceptual and methodological elements, as opposed to rote memorisation of knowledge claims and ritualistic use of procedures (Novak, Gowin, & Johansen, 1983).

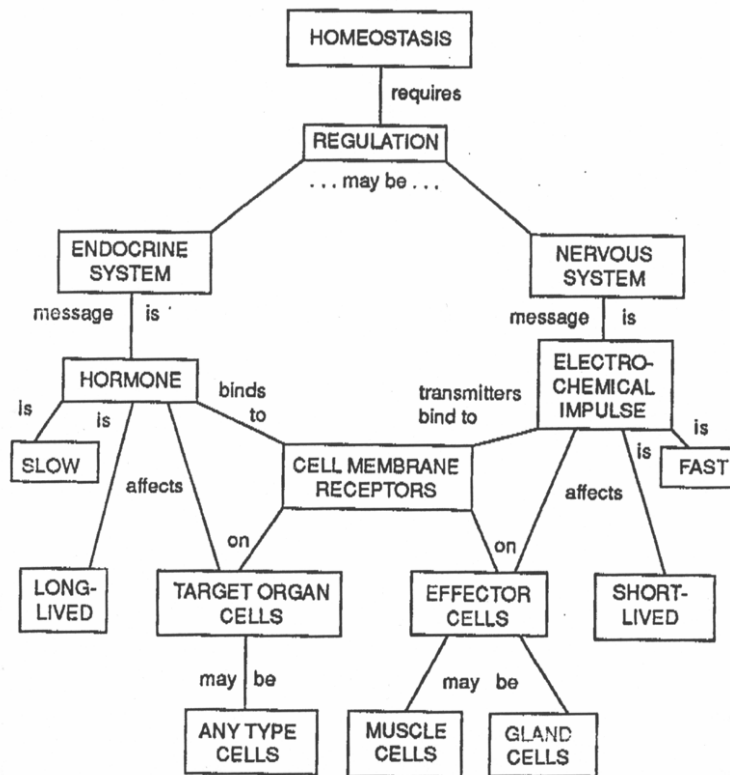


**Figure 2.4**  
A Vee diagram showing the key theoretical and methodological elements of an investigation into the effect of exercise on heart rate (Novak, Gowin, & Johansen, 1983, p. 628)

### Concept Maps

Concept maps are another graphical means of representing concepts and their relationships. Concepts are written in boxes and ordered hierarchically (with the most inclusive concepts near the top of the page and more subordinate concepts below). Labelled lines are used to identify the relationships between the concepts (Novak & Gowin, 1984a) as shown for homeostasis in Figure 2.5. This means that concept mapping requires the map-maker to identify important concepts and evaluate the relationships between them (Novak, 1979). Concept maps are thus based on the premise, consistent with constructivist views of learning, that concepts do not exist in isolation but depend on others for meaning (Okebukola, 1990). The idea that meaningful learning requires students to connect newly introduced concepts to more general prior-learned concepts is central to their use (Heinze-Fry & Novak, 1990).

Each concept only appears once on a concept map, but can be linked to any number of other concepts. In general, the greater the number of valid links between



**Figure 2.5**

A concept map showing the relationships between concepts associated with the nervous and endocrine systems in mammals (Cliburn, 1990, p. 215)

one concept and others, the more sophisticated the map is considered to be (Novak & Gowin, 1984a). The linking words, or propositions, are important because they require the person constructing the map to make the relationships between concepts explicit. They also help the reader of the map to understand what the links were meant to convey (Novak, Gowin, & Johansen, 1983). The quality and variety of the links have been reported to be an important indicator of understanding (Kinchin, 2001a).

The hierarchical structure of the concept map is also seen by many to be important (e.g., Novak, Gowin, & Johansen, 1983) because it is used to portray differences in the generality and specificity of concepts (Stewart, Van Kirk, & Rowell, 1979). Being able to organise concepts in a hierarchical, integrated manner has also been associated with the development of specialist expertise (Edmonson,

2000). However, some authors have argued that strict rules regarding hierarchies reduce flexibility in concept map creation (Taber, 1994), and not all subject matter domains have a hierarchical structure (Ruiz-Primo & Shavelson, 1996). This appears to be in contrast with research into cognitive aspects of science learning, which suggest that successful science learners as well as professional scientists develop elaborate, strongly hierarchical, well differentiated, and highly integrated frameworks of related concepts as they construct meanings (Johnson & Satchwell, 1993; Pearsall, Skipper, & Mintzes, 1997).

Concept maps are similar to semantic networks (Fisher, 1990), which also are constructed by joining concepts by named relations. However, semantic networks are multi-layered and can only be viewed one node (or concept group) at a time using a computer. In contrast, concept maps are two dimensional and can be viewed in their entirety (Trowbridge & Wandersee, 1998).

Concept maps are reported to be a very flexible tool, both in the ways that they can be constructed (the concepts and relationships that can be included) and in how they are used. The technique was initially developed by Novak and his research group as a research strategy to explore students' understandings of science concepts (for a summary, see Novak, 2004). Gradually, this group came to believe that a concept map was equally valuable as a metacognitive device when constructed by science learners (Trowbridge & Wandersee, 1998). The science education literature currently reports the use of concept maps in a variety of contexts, including: as a research tool to explore changes in meaning frameworks with instruction and/or over time (e.g., Englebrecht, Mintzes, Brown, & Kelso, 2005; Markham, Mintzes, & Jones, 1994; Novak & Musonda, 1991; Novak, 1990; Pearsall, Skipper, & Mintzes, 1997; Shymansky, Woodworth, Norman, Dunkhase, Matthews, & Liu, 1993; Wallace & Mintzes, 1990); to evaluate prior knowledge and diagnose alternative conceptions (e.g., Ross & Munby, 1991; van Zeele, Lenaerts, & Wieme, 2004); to identify critical

junctures' in learning<sup>3</sup> (e.g., Trowbridge & Wandersee, 1994); to identify differences between novice and expert thinking (e.g., Kinchin, 2001a); to measure students' knowledge for assessment purposes (e.g., Moreira, 1985; Ruiz-Primo, Schultz, Li, & Shavelson, 2001; Shavelson & Ruiz-Primo, 2000; Stoddart, Abrams, Gasper, & Canaday, 2000); to structure curriculum design (e.g., Starr & Krakcik, 1990; Trochim, 1989) and course planning (e.g., Cliburn, 1986); and as a metacognitive tool to help learners re-organise their cognitive frameworks during the learning process (e.g., Novak & Gowin, 1984a). It is this last purpose – using concept maps as a teaching and learning tool – which is of most relevance to the current work, and this will now be explored further.

#### ***2.5.4 Concept Maps as a Teaching and Learning Tool***

As described above, concept mapping is a technique that focuses on conceptual organisation and integration (Smith & Dwyer, 1995) to facilitate the connection of new concepts and propositions into an existing, relevant framework (Heinze-Fry & Novak, 1990). The result, whether it is achieved individually or socially, is an ordered framework of knowledge. In addition, concept mapping can promote meaningful learning because the process helps the learner to identify prior knowledge, progressively differentiate between concepts, sequence concepts into a distinct hierarchy, and achieve integrative reconciliation of concepts that might have been initially confusing, or where meanings may have been distorted (Novak, 2004). For this reason, the use of concept mapping seems to fit well with a constructivist view of learning (Roth & Roychoudhury, 1993; Trowbridge & Wandersee, 1998) and has been promoted as “the most important meta-cognitive tool in science education today” (Mintzes, Wandersee, & Novak, 1997, p. 424).

The process of creating and using a concept map is considered to be as important as the content of the map (Cliburn, 1987), as the creator is forced to interact

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<sup>3</sup> ‘Critical junctures’ are considered to be points in the learning process “where students must possess an essential framework of understanding (based upon previously taught concepts) in order to grasp the new material” (Trowbridge & Wandersee, 1994, p. 460).



with the target material whilst creating the map (Kinchin, 2000a; Schmid & Telaro, 1990). Through the actual process of constructing a concept map, the mapper(s) also can make new connections and recognise concepts which need to be added (Taber, 1994; Trochim, 1989). In addition, constructing maps requires learners to think in multiple directions, switching between different levels of abstraction (Okebukola, 1990). Further, the visual nature of concept mapping is seen to be “inherently superior” to verbal ways of organising information (Cliburn, 1987, p. 426), with the concept map acting as an interface that helps students to translate the linear structure of verbal information into a network structure that is likely to be more representative of their cognitive structure (Kinchin, 2000b). In other words, a concept map can depict the complexity of the relationships between concepts and ideas more effectively than linear presentations (Trochim, 1989).

Another reported advantage of concept maps is that they are very personal representations of an internal mental model, as are the interactions and choices made while producing the concept map (Freeman, 2004). This means that concept maps are useful for individualised learning, as opposed to individualised teaching (Schmid & Telaro, 1990) and, consistent with a constructivist view of learning, recognise that an individual’s cognitive structure is unique. In addition, the framework is expressed in the language of the map-maker (Trochim, 1989), and can be used to help promote the ability to use concepts as the basis of scientific language (Trowbridge & Wandersee, 1998). Maps can also be constructed by students working collaboratively (Esiobu & Soyibo, 1995; Roth, 1994; Roth & Roychoudhury, 1993) and Novak (2004) suggests the one of the principle advantages of such collaboration is that group participants can serve “to correct faulty ideas and promote meaningful learning” (p. 8).

Concept mapping is thus presented in the science education literature as a tool that can help facilitate meaningful learning (Hazel, 1994; Kinchin, 2000b; Novak & Gowin, 1984). Concept mapping as a teaching and learning strategy is also cost

effective and requires no special materials, making it a viable intervention in an ordinary classroom environment (Schmid & Telaro, 1990).

Despite numerous references to the use of concept mapping in the science education literature, surprisingly few studies seem to have evaluated the *effectiveness* of concept mapping as a teaching and learning tool. A meta-analysis by Horton et al. (1993) identified only 19 studies which examined the effects of concept mapping on student learning and contained sufficient data for comparisons of effect size to be made. Of the 19 studies included, only two (Heinze-Fry & Novak, 1990; Smith & Dwyer, 1995) were concerned with biology at the tertiary level and had been subjected to peer review by publication in an educational journal. Further, and in contrast to the majority of other studies included in the review, both of the tertiary biology studies reported no statistically significant differences in student understanding as a result of concept mapping, although it is worthwhile to note that sample sizes were small and student exposure to concept mapping was very limited. For example, Smith and Dwyer (1995) used only a short training session in the use of concept mapping, and then asked students to read a text on the human circulatory system. One group was given an instructor-prepared map to study alongside the text; a second group was asked to construct their own concept map; and a third group was not asked to consider concept mapping at all. Given the complexity of the subject matter and the paucity of training in a new technique, it is perhaps not that surprising that little gain was made as a result of concept mapping.

Since the 1993 analysis by Horton's group, few other researchers appear to have investigated the effects of concept mapping on student learning in tertiary biology courses. In one study, students in an introductory cell biology course at an Israeli university were asked to construct concept maps as part of one week's tutorial activities. Final exam performance on selected questions showed no statistically significant differences between those who had attended concept mapping tutorials and those who had not (Yarden, Marbach-Ad, & Gershoni, 2004). In contrast, Kaya and Ebenezer (2003) reported that when teacher trainees in Turkey individually

constructed concept maps and Vee diagrams as part of a laboratory course on cell biology, achievement was statistically better compared a control group who completed conventional laboratory reports. Concept mapping students' attitudes towards science laboratories were also found to be more positive (this difference was statistically significant).

In summary, it seems that despite numerous calls for using concept mapping as a teaching and learning tool, few studies have examined the effect of concept mapping in promoting meaningful learning in biology at the tertiary level. Those studies that do exist report conflicting findings, although this may be due to the limited use of concept mapping in these courses. Thus, there appears to be justification to further evaluate the usefulness of concept mapping in introductory-level biology courses.

## **2.6 CHAPTER SUMMARY**

The importance of students' prior knowledge is emphasised in a variety of current theories of learning, including constructivism and its variants. In particular, a social-constructivist view of learning postulates that learning occurs when learners construct knowledge by relating new knowledge to relevant concepts that they already possess, and that the construction occurs within a social context (e.g., Douvdevany, Dreyfus, & Jungwirth, 1997; Millar, 1989; Wandersee & Fisher, 2000). In the case of the current study, the context is a first-year biology classroom.

Prior knowledge is considered to be important because it interacts with knowledge presented during formal instruction. However, this interaction can sometimes result in undesirable outcomes, such as the formation of alternative conceptions for important scientific concepts (Pfundt & Duit, 2000; Wandersee, Mintzes, & Novak, 1994), particularly if the prerequisite knowledge necessary for the construction of a new concept is absent from a student's cognitive structure (Coll, France, & Taylor, 2005; Garnett, Garnett, & Hackling, 1995; Yip, 1998). Such

alternative conceptions can make subsequent learning problematic, as science understanding builds on certain fundamental concepts in subsequent meaning-making and learning. Prior knowledge also appears to impact on the learning strategies adopted by students, further affecting learning outcomes (Hazel, Prosser, & Trigwell, 2002; Prosser & Trigwell, 1999).

## **2.7 RESEARCH QUESTIONS**

The impact of prior knowledge on student learning has implications for teaching and learning in first-year biology courses at university, particularly since students come from increasingly diverse academic backgrounds and are likely to have very diverse prior knowledge about specific concepts. Two research questions are therefore posed:

1. What are faculty assumptions about the prior knowledge of students entering first-year biology courses?
2. What is the actual prior knowledge of students entering first-year biology courses?

In order to understand science in the way desired by faculty and the scientific community, students need particular content knowledge as well as the ability to form links between related scientific concepts (Arnaudin, Mintzes, Dunn, & Shafer, 1984). They also need to be able to reorganise their prior knowledge in the light of new knowledge (Huai, 1997). A variety of pedagogical ‘tools’ are available to secondary school and tertiary-level teachers to enhance student understanding of scientific concepts. However, concept mapping has been promoted as the “most important meta-cognitive tool in science education today” (Mintzes, Wandersee, & Novak, 1997, p. 424), with numerous science education researchers advocating its use in science classrooms (see Section 2.5.4). Although a large meta-analysis by Horton et al. (1993) showed that concept mapping generally had positive effects on both student achievement and attitudes, studies evaluating concept mapping in tertiary level biology courses are limited, report ambiguous findings, and tend to evaluate only short-term exposure to concept mapping (Heinze-Fry & Novak, 1990; Kaya &

Ebenezer, 2003; Smith & Dwyer, 1995; Yarden, Marbach-Ad, & Gershoni, 2004). A third research question was therefore posed:

3. How useful is concept mapping as a teaching and learning strategy within a first-year biology course at university?

The methodology used to address these research questions is outlined in Chapter 3, with the findings presented and discussed in the subsequent chapters.

# Chapter 3

## Research Methodology

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### 3.1 INTRODUCTION

Chapter 1 highlighted the increasing diversity in the academic backgrounds of students entering university study, including science courses. This diversity has implications for teaching and learning in these courses, as pointed out in Chapter 2. The aim of the research presented in this thesis was to investigate the prior knowledge that faculty teaching first-year biology courses assume students have; the prior knowledge students actually have; and the role of concept mapping as a pedagogical strategy that can take into account diverse prior knowledge.

This chapter sets out the research methodology that guided the study. A research methodology not only describes and analyses the methods used to gather and interpret data, but also presents the philosophical framework within which the

research project develops (Lather, 1992). This is important because researcher beliefs about what can be known (ontology) and how it can be known (epistemology) influence the selection and use of different methods in the research process.

Ontological and epistemological considerations will be outlined in Section 3.2, and positivist and interpretive research paradigms as well as critical theory will be introduced. Interpretive research design will be explored more fully in Section 3.3, including considerations such as the need to present multiple perspectives, issues of trustworthiness, the value of methodological triangulation, different methods that can be used to gather data, and ethical concerns. Section 3.4 describes the specific methods used in the current study.

### **3.2 ONTOLOGICAL AND EPISTEMOLOGICAL CONSIDERATIONS**

Education research, like all research, is influenced by the ontological and epistemological assumptions of the researcher (Hitchcock & Hughes, 1989). In other words, beliefs about what is regarded as acceptable knowledge in a discipline affect how the research will be carried out and the findings interpreted (Bryman, 2001). Ontological and epistemological considerations therefore affect the methodology and consequently the methods selected when designing and planning a research project, and it is important that they are considered. Three orientations – positivist research, interpretive research and critical theory – are identified in the literature as reflecting different ontological and epistemological positions (Carr & Kemmis, 1986). These orientations are sometimes defined as interpretive frameworks, or ‘paradigms’, where a paradigm is considered to be the “net that contains the researcher’s epistemological, ontological and methodological premises” (Denzin & Lincoln, 2003, p. 33). Each paradigm is discussed below, and its pertinence to the current research programme is considered.

The positivist paradigm is considered to be closely aligned with traditional scientific investigations (Bryman, 2001) and relies on experimental research that is

both objective and quantifiable (Merriam, 2001). The emphasis is on objectivity, measurability, predictability, and the construction of laws and rules of behaviour (Cohen, Manion, & Morrison, 2000). Numerical measurements are emphasised because they are believed to result in objective knowledge and be value-free (Robson, 2002), and also because they allow for generalisability of the findings as long as random sampling is used (Holloway, 1997). The emphasis within this paradigm is thus on objective collection and analysis of quantitative data with the aim of either rejecting or accepting a particular hypothesis. The focus, in the context of educational research, is to discover the natural and universal laws that regulate and determine individual and social behaviour and learning (Cohen, Manion, & Morrison, 2000). This means that positivists believe that there is a reality (governed by laws) which can be studied, captured and understood. On the other hand, 'post-positivists' argue that reality can never be fully comprehended, only approximated (Denzin & Lincoln, 2003), but that findings are likely to reflect reality most closely when procedures to establish validity are followed (Holloway, 1997).

An interpretive view shares the same overall concern of traditional, positivist social science, that is, to explain human behaviour. However, it is predicated on the view that differences exist between researching people and researching the objects of natural sciences (Bryman, 2001). In particular, human actions are considered to have meaning, and understanding a particular social action is seen to require an understanding of the set of meanings associated with the action (Schwandt, 2003). Interpretivists argue, for example, that when positivist researchers treat perceptions of the social world as objective and absolute, they neglect the context of the research (Cohen, Manion, & Morrison, 2000). Those who support an interpretive paradigm thus believe that it is important that research participants are viewed within the whole context of their lives, rather than as individual entities who exist in a 'vacuum' (Holloway, 1997). Interpretivists further reject the belief that human behaviour is governed by general, universal laws that can be identified and tested (Cohen, Manion, & Morrison, 2000). Complete objectivity and neutrality are viewed as being impossible to achieve, and the values of both the researchers and participants are



accepted as an integral part of the research (Holloway, 1997). Interpretivists also assert that multiple realities are constructed socially by individuals (Merriam, 2001).

Whereas positivism strives for objectivity and the construction of laws and rules to predict behaviour, interpretivism focuses on an understanding and interpretation of the research context in terms of the participants. A third orientation, critical theory research, emphasises increases in understanding so that change of social structures can be brought about (Blackmore & Lauder, 2005). This form of inquiry specifically takes into account how human lives are mediated by systems such as classism, racism and sexism (Lather, 1992). It is based on the belief that human beings are able to critically assess and change society and become emancipated (Holloway, 1997). Research findings tend to represent “an ideological critique of power, privilege, and oppression” (Merriam, 2001, p. 4), and the explicit intention of the research is not only to understand, but also to cause change in the oppressing power structures (Fay, 1987). Feminist, ethnic, Marxist and queer theory tend to be aligned with this approach (Denzin & Lincoln, 2003).

The ontological and epistemological assumptions underpinning different research paradigms affect methodological considerations and consequently the methods and instruments selected and used to collect data (Hitchcock & Hughes, 1989), which is why they should be considered. An interpretive orientation to research is most consistent with a social constructivist view of learning (outlined in Section 2.2.3), and some authors describe this paradigm as ‘constructivist-interpretive’ (e.g., Denzin & Lincoln, 2003). Within this view, an understanding of reality is considered to be socially constructed and defined by human beings as they interpret the natural and social world in light of their previous experiences.

The current study adopted an interpretive methodology and placed emphasis on understanding and interpreting the research context in the terms of the research participants. Factors that guide an interpretive methodology are considered in the next section.

### 3.3 INTERPRETIVE METHODOLOGY

The task of an interpretive researcher is to understand the multiple social constructions of meaning given to a particular context by the research participants (Robson, 2002). The research design is naturalistic in the sense that it takes place in a real-world setting (Patton, 2002). Both the researcher and the participants are understood to be influenced by the research context, and the aim is to understand all participants' intentions, motivations and actions so that a detailed view can be presented (Ary, Jacobs, & Razavieh, 2002). The research participants are viewed as helping to construct the 'reality' with the researcher (Robson, 2002), allowing the diverse, complex and unique context in which the research is grounded to be acknowledged and explored (Haigh, 2000).

The methodology guiding an interpretive project therefore emphasises the use of research methods that allow multiple perspectives to be acquired (Robson, 2002). There is also an openness to adapting the inquiry as understanding deepens or the situation changes (Patton, 2002). The understanding that develops as a result of the research process is viewed not as being objective, but rather as being co-constructed by the researcher as he/she interacts with or observes the research participants. Bryman (2001) refers to this as a "double interpretation" (p. 15), with the researcher providing an interpretation of others' interpretations.

The essence of 'good' research design for an interpretive study is that the methods used are open-ended and rigorous, and that they 'do justice' to the complexity of the social setting under study (Flick, 1998). The main considerations include the recognition and incorporation of multiple perspectives, issues of trustworthiness in data generation and analysis, the use of multiple data gathering methods, and ethical concerns. These are discussed below.

### ***3.3.1 Multiple Perspectives***

The aim of interpretive research design, as described above, is to construct a holistic understanding of the research context that authentically reflects the multiple views of participants (Patton, 2002). Interpretive methodology thus recognises the existence of multiple constructed realities, and there is a commitment to interpret the research context from the participants' point of view (Bryman, 2001). Further, the situating of the research project within the shared experience of the researcher and participants is an ongoing process that involves all parties (Janesick, 2003). The knowledge that is constructed is viewed as being imbedded in social interactions (Tolich, 2001) and it is the researcher's role to identify and understand these interactions from the point of view of the participants (Denzin & Lincoln, 2003). The research design therefore tends to comprise different data sources, or 'informants' (Denzin, 1988).

The role of the researcher in the inquiry is also acknowledged. The research is understood to be an interactive process that is shaped by the personal history and constructions of both the participants and the researcher (Denzin & Lincoln, 2003). However, the researcher still decides what the reported 'story' will be (Stake, 2003). 'Reflexivity' reflects an awareness of the ways in which the personal background, influences and perspectives of the researcher can impact the research process (Robson, 2002). It involves self-questioning and self-understanding and is important in order to take account of researcher bias (Patton, 2002).

### ***3.3.2 Issues of Trustworthiness***

Researchers working within a positivist framework tend to criticise interpretive studies for being subjective, biased and ungeneralisable (Hakim, 1994). Ensuring issues of trustworthiness regarding data collection and analysis is thus paramount if interpretive research is to have any impact on theory or practice. Being

able to trust research results is particularly important to professionals in applied fields such as education, where practitioners intervene in people's lives (Merriam, 2001).

From a positivist perspective, reliability and validity are important criteria for evaluating the quality of research and its trustworthiness. However, interpretivist research methodology is based on different assumptions (see Section 3.2), and some authors argue that validity and reliability should be considered from a different perspective. For example, a positivist's view of reliability is the extent to which research findings can be replicated (LeCompte & Preissle, 1993). However, this is problematic in most educational contexts because of the fundamental premise that the researcher deliberately does not try to control or manipulate conditions or variables, but rather aims to provide an accurate portrayal of social realities as they are perceived by the participants (Cohen, Manion, & Morrison, 2000). Further, human behaviour is never static, and the social contexts that are investigated are assumed to be multi-faceted and highly dependent on the social context (Merriam, 2001), which typically cannot be 'frozen' or re-created for replication purposes (LeCompte & Goetz, 1982).

Because of these difficulties with obtaining replicable data from complex social settings, Merriam (2001) suggests that achieving reliability within a social context "is not only fanciful, but impossible" (p. 206). Lincoln and Guba (1985) propose the use of 'dependability' and 'consistency' as alternative criteria appropriate to interpretive studies. The emphasis shifts away from being able to obtain replicable results, towards providing sufficient evidence for the reader to concur that, given the data collected, the results make sense, that is, that they are consistent and dependable. As Dey (1993) argues: "If we cannot expect others to replicate our account, the best we can do is explain how we arrived at the results" (p. 251). 'Dependability' in this context can be maximised through prolonged engagement in the field (allowing for continual data analysis and refining of constructs to ensure a match between researcher categories and participant realities); member checks, or respondent validation (respondents are asked to comment on the plausibility of results); peer

debriefing and the use of reflexive journals (to check for researcher biases); and thick or rich descriptions, not only to describe how the conclusions were derived, but also of the researcher's theoretical assumptions and position relative to the research participants (LeCompte & Preissle, 1993; Lincoln & Guba, 1985).

Whereas positivist views of reliability are concerned with whether other researchers would reach similar conclusions, a positivist's view of 'validity' concerns the degree to which the results are accurate, or reflect reality ('internal validity'), and are generalisable ('external validity') (Bryman, 2001; Robson, 2002). Because validity tends to presuppose that a single, absolute account of an external reality is feasible, in contrast to the interpretive view of multiple constructed realities, Guba and Lincoln (1994) propose that the criteria of 'trustworthiness,' 'transferability' and 'authenticity' be considered as alternative criteria for evaluating interpretive research. Here, 'trustworthiness' parallels with positivist notions of internal validity, or how closely the research findings match reality (Merriam, 2001). It reflects the notion that if there can be several possible accounts of an aspect of social reality, it is the feasibility or credibility of the account that determines its acceptability to others (Bryman, 2001). The aim is to demonstrate that the explanations and conclusions are actually sustained by the data and that they accurately describe the phenomena being studied.

Because human beings are the primary instrument of data collection and analysis (e.g., using interviews and observations), Merriam (2001) argues that the interpretive research is 'closer' to reality than if a less 'personal' data collection instrument is interposed between the researcher and the participants, and that this is a strength of interpretive research. However, the notion of researcher-as-instrument also introduces the potential for bias, both in what is recorded and how it is interpreted (Robson, 2002). Researcher bias can thus reduce trustworthiness, as can respondent biases (Lincoln & Guba, 1985).

Reflexivity, or a personal awareness of the ways in which one's own social identity, background, beliefs and theoretical frameworks impact on the research process, is an important mechanism used to minimise researcher bias (Robson, 2002). Other strategies to manage the risk of researcher bias include peer debriefing; member checking (where the participants are asked to comment on the plausibility of the researcher's interpretations); and negative case analysis (using instances that do not fit with other data to refine theoretical development) (Lincoln & Guba, 1985). As described above, many of these strategies are also used to ensure dependability, a necessary but on its own insufficient condition for trustworthiness (Bryman, 2001; Robson, 2002).

Reactivity, or the way in which a researcher's presence interferes with the social setting being studied, including any effects on the behaviour of the participants, can also decrease the trustworthiness of the research (Lincoln & Guba, 1985). Reactivity can be reduced through prolonged engagement: a researcher who spends a long time in a setting tends to become accepted, reducing the effects of initial reactivity and permitting the development of a trusting relationship between the researcher and respondents (Merriam, 2001). This strategy is also generally considered to be significantly more ethical than if the researcher was to covertly collect the data (Bryman, 2001). Reactivity can also be reduced by the use of multiple data collection methods (see the following section on data triangulation).

In addition to replicability and accuracy, generalisability (or transferability) is a third key characteristic of positivist research (Bryman, 2001), with 'external validity' referring to the extent to which the findings can be applied to other situations (Merriam, 2001). For interpretivists, human behaviour is generally recognised as being infinitely complex, irreducible, socially situated, and unique (Cohen, Manion, & Morrison, 2000), and the aim is to understand particular social contexts rather than isolate laws that describe behaviour in a range of contexts (Patton, 2002). The small sample sizes that tend to be used for in-depth investigations can also present a problem for interpretive researchers seeking

generalisability (Bryman, 2001). Although interpretive research designs include concepts such as ‘transferability’ (Lincoln & Guba, 1985), ‘comparability’ (Eisenhart & Howe, 1992) or ‘case-to-case transfer’ (Firestone, 1993), it is most often left to the reader to decide the extent to which a study’s findings apply to other situations (Lincoln & Guba, 1985; Peshkin, 1993; Schofield, 1993). In particular, the rich, thick descriptions typical of interpretive research are intended to enable readers to determine how closely their situations match the research situation (Merriam, 2001; Schofield, 1993). Multi-site designs and seeking ‘typical’ research contexts rather than ones with particularly unusual characteristics are also strategies that are sometimes employed (Cohen, Manion, & Morrison, 2000).

In summary, interpretive studies in education must be rigorously conducted and present insights that ring true to the readers if they are to have effect on practice (Merriam, 2001). Although the nature of interpretive research means that issues of validity and reliability take different forms when compared with positivist-based research, there still needs to be an accounting of the dependability, trustworthiness and credibility of all parts of the research process, including design, data collection, and interpretation. In particular, interpretive studies need to provide the reader with sufficient detail to show that the conclusions are justified (Firestone, 1987) and detailed descriptions about the purpose and methods of the study present readers with the basis for judging the credibility of a study (Maykut & Morehouse, 1994). The role of triangulation in addressing issues of trustworthiness and credibility is now discussed.

### ***3.3.3 Data Triangulation***

While ‘methodology’ refers to the theory of knowledge guiding the design of a research project, ‘methods’ refer to the specific techniques that are used to gather evidence (Harding, 1987). In interpretive research the most common data collection methods include observations, interviews, questionnaires, and document analysis. In most cases, a research question can be explored using more than one method, and it is

often the research questions that determine the specific methods that are used (Robson, 2002). However, no method is completely neutral and without limitation, and studies that only use only one method are considered to be more vulnerable to errors linked to that particular method than studies that use multiple data collection methods (Patton, 2002). Further, each method can reveal different aspects of reality, and exclusive reliance on one method may distort the researcher's picture of the particular 'slice of reality' being investigated (Cohen, Manion, & Morrison, 2000).

Triangulation, or the use of multiple sources of data, is therefore advocated by a range of social science and education methodologists. For example, Cohen, Manion and Morrison (2000) argue that multiple data sources help the researcher to "map out, or explain more fully, the richness and complexity of human behaviour by studying it from more than one standpoint" (p. 112). Triangulation thus allows the display of multiple, refracted realities simultaneously (Denzin & Lincoln, 2003) and can enhance interpretability and trustworthiness (Robson, 2002).

Several types of triangulation have been identified, including: methodological triangulation (e.g., combining qualitative and quantitative approaches); data triangulation (using more than one method of data collection, such as observations, interviews and document analysis); researcher triangulation (where more than one researcher is involved in collecting and interpreting the data); and time and space triangulation (e.g., carrying out the research longitudinally over a period of time and/or in different places) (Denzin, 1988). The use of different methods (including both quantitative and qualitative strategies) occurs most frequently in educational research, and is considered by Cohen, Manion and Morrison (2000) to be the strategy that has the most to offer.

Because triangulation can be considered to be a process of clarifying meaning by identifying different ways by which a phenomenon can be viewed and interpreted (Stake, 2003), different data sources should not always be expected to yield essentially the same result (Patton, 2002). Inconsistencies in the findings therefore



need not be viewed as weakening the credibility of the research, but rather as offering opportunities for deeper insights. For example, students may report in an interview or questionnaire that they adopt a deep approach to studying, but analysis of their course assessment tasks may suggest that only shallow learning has been achieved.

The use of a multiple method approach is therefore likely to add breadth, complexity, and richness to an inquiry (Flick, 1998) and can help to reduce researcher bias, respondent bias and reactivity (Robson, 2002). Different types of data collection methods, including interviews, observations and questionnaires, as well as their strengths and weaknesses, are discussed in the next section.

### ***3.3.4 Data Collection Methods***

A range of data collection methods are available for use in interpretive research in education, including interviews, observations, and questionnaires. The strengths and weaknesses associated with each method are described below. An outline of specific research methods used in the current study follows in Section 3.4.

#### Interviews

Interviews enable data to be collected through direct verbal interactions between individuals and are routinely used in interpretive research (Denzin & Lincoln, 2003). Because they enable participants to discuss situations from their own point of view, interviews give the researcher access to the participants' own perspectives (Fraenkel & Wallen, 2005). Consistent with an interpretive framework, interviews are based on the view that knowledge can be generated by individuals through conversation, and that the perspective of others is meaningful (Patton, 2002).

Interviews can be used for a range of purposes, including: as an explanatory tool to identify possible variables and relationships; to validate unexpected results revealed by other methods of data collection; to clarify and illustrate the meaning of the findings; and to enable the researcher to further explore with participants the

motivations and explanations for behaviour that cannot be directly observed (Robson, 2002; Patton, 2002). Interview structure varies according to the context and purpose of the interview, from structured through semi-structured to unstructured interview schedules (Fontana & Frey, 2003).

An unstructured interview, also called an informal conversation interview (Patton, 2002), an intensive interview (Lofland & Lofland, 1995), or an in-depth interview (LeCompte & Preissle, 1993), is the most-open ended interview approach and offers maximum flexibility for the researcher to pursue information in whatever direction appears to be appropriate (Patton, 2002). However, the discussion is not unfocused, and the interviewer has a general area of interest that is pursued (Robson, 2002). The aim is for the interviewees to “speak freely in their own terms about a set of concerns the interviewer brings to the interaction, plus whatever else they might introduce” (Lofland & Lofland, 1995, p. 85). This type of interview is useful in inductive research that seeks to understand complex behaviour without imposing an a priori categorisation that may limit the field of inquiry (Fontana & Frey, 2003). Because of the flexibility in topics covered, however, different data are gathered from each interview, making it more difficult to analyse the findings (Robson, 2002). This type of interview is also susceptible to interviewer biases, and reflexivity is critical (Patton, 2002).

A semi-structured interview, or interview guide approach (Patton, 2002), is based around a set of predetermined questions but the order and wording of the questions can be modified based on the interviewer’s perception of what seems most appropriate (Robson, 2002). This style of interview therefore ensures that the same basic lines or inquiry are pursued with each person interviewed, but there is some freedom to pursue new or unusual insights (Fontana & Frey, 2003; Patton, 2002).

In a structured interview, the interviewer asks all respondents the same series of pre-determined questions in the same sequence using essentially the same words (Fontana & Frey, 2003). This reduces interviewer bias and can be particularly useful

in ensuring consistency in projects involving multiple researchers, multiple sites, or data collection at different times (e.g., before, during and after an intervention) (Patton, 2002). The exact instrument can also be checked for biases beforehand (Robson, 2002). A weakness is that the interviewer cannot pursue topics or issues that were not anticipated when the interview questions were written (Bryman, 2001), so the strategy relies on the researcher being able to frame beforehand questions that will supply the knowledge required. However, the data can still be open-ended, with the respondent supplying his or her own insights when answering the questions (Patton, 2002).

Using interviews for data collection tends to result in higher response rates than self-completion questionnaires because subjects are likely to be more involved and motivated (Patton, 2002). The respondents are also in a distinctly favourable position to explain their thoughts, providing a unique window into their actions (Robson, 2002). However, the number of respondents is often limited because of the associated time and costs involved (White & Gunstone, 1992). Errors can also occur due to respondent biases and lapses in memory (Robson, 2002), and the sequencing and wording of questions can have a large impact on the results, as can the interviewer's characteristics (Fontana & Frey, 2003). Despite this, the interview remains a powerful tool for collecting both qualitative and quantitative data, and semi-structured protocols were used for a number of purposes in the current research (see Section 3.4).

### Observations

One of the central tenets of interpretive research is the quest to understand a phenomenon through the eyes of the participants (see Section 3.3.1), and an obvious technique is to watch what they do and record this in some way. Observations are particularly helpful in identifying occurrences that might not be discovered through interviews, including those that a participant might not freely talk about in an interview, or that a participant might take for granted (Patton, 2002). Interview and questionnaire responses are also notorious for discrepancies between what people say

they have done and what they actually did, and observations can provide useful checks for this (Robson, 2002). In addition, observations allow the researcher to move beyond the selective perceptions and opinions expressed in interviews (Cohen, Manion, & Morrison, 2000), although they are themselves inherently subjective (Patton, 2002). Strategies to minimise researcher bias are detailed later in this section.

Observations can be defined using several continua, including the degree of structure of the observation, the purpose of the observation, and the role of the researcher in the observation context.

Structured observations, also called formal observations (Robson, 2002), impose a large amount of structure and direction on what is to be observed and tend to involve the recording of behaviour in terms of categories that have been devised prior to the start of data collection (Bryman, 2001). Systematic, numerical data can be generated, but complexity and completeness may be reduced due to lack of attention paid to aspects not on the observation schedule (Ary, Jacobs, & Razavieh, 2002). In contrast, unstructured and informal observations allow the observer considerable freedom to select the information that is gathered and how it is recorded, but synthesis and interpretation of the data gathered is more problematic. Semi-structured protocols focus on selected issues, but the data to illuminate these issues is gathered in a far less pre-determined and systematic manner (Cohen, Manion, & Morrison, 2000).

Not surprisingly, the nature of the observation tends to be related to its purpose. For example, descriptive observations, which involve observing as much as possible, tend to be used in the exploratory phase of a project before a researcher begins to understand what is and is not relevant (Robson, 2002). In contrast, focused observations concentrate on certain aspects but ignore those that are considered to be irrelevant (Angrosino & Mays de Pérez, 2003).

A further distinction between different observational strategies depends on the role adopted by the researcher in the observation context. Gold's (1958) classification is widely cited (e.g., Bryman, 2001; Patton, 2002) and reflects a range of degrees of involvement and detachment: the researcher can be a complete participant, participant-as-observer, observer-as-participant, or complete observer.

The complete participant seeks to become a full member of the group (Gold, 1958) and the true identity of the person as a researcher is not revealed (Patton, 2002). Because of the ethical objections to this stance, this type of research tends not to be used in modern educational settings (Fraenkel & Wallen, 2005).

A participant-as-observer, sometimes known as a researcher-participant (Bryman, 2001), participates in the research context, but members of the research setting are aware of the researcher's status as a researcher (Patton, 2002). As well as observing through participating in activities, the researcher may ask members to explain various aspects of the behaviour being observed (Bryman, 2001). The participant-as-observer approach tends to allow for a more holistic view to be constructed (Cohen, Manion, & Morrison, 2000), although acceptance of the researcher depends heavily on the nature of the group (Robson, 2002).

In contrast to the participant-as-observer, the observer-as-participant, also referred to as the marginal participant (Robson, 2002), has very little involvement in the group activities (Gold, 1958). This can be achieved by adopting the role of a largely passive, though completely accepted, participant and is the strategy most frequently used in classroom observational studies (Angrosino & Mays de Pérez, 2003; Rossman & Rallis, 1998). It can involve listening in on conversations, and there may be opportunities to conduct informal interviews asking normal, conversational questions such as "What did you think of the session today?" (Patton, 2002, p. 286). Wolcott (1992) suggests that "most so-called participant observer studies in education warrant that label only in the sense that the researcher was

physically present ... researchers seldom become involved as genuine participants” (p. 20).

Because the researcher is the main instrument for gathering data in less structured observations, observer bias is a potential concern (Angrosino & Mays de Pérez, 2003). It is inevitable that the researcher’s interests, experiences and expectations will affect what they attend to, and this may result in selective perception by the observer that may distort the data (Patton, 2002). Other biases include selective coding (because expectations colour what is observed, and in turn what is recorded and interpreted), selective memory (in particular when there is a time delay between the observation and the writing up of field notes), and interpersonal factors (it may be easier to interact with those who, for whatever reason, are more welcoming and easy to get on with) (Robson, 2002). Objectivity, or reduced bias, can be approached through conscious effort to distribute attention widely and evenly as well as through a heightened sensitivity to the problem of subjectivity and the need for justifying one’s claims (Fraenkel & Wallen, 2005). Reflexivity, or critical self-awareness and self-reflection, is therefore critical (Patton, 2002).

Another potential threat to the trustworthiness of data collected by observation is reactivity, or the extent to which people alter their behaviour when they know they are being observed. Prolonged observations, as well as the use of multiple data sources, can reduce such effects.

### Questionnaires

Questionnaires are used to gather data from a specifically-defined group of individuals who all respond to identical questions. They are most often used to discern patterns of association or to describe proportions of people who possess a particular attribute (Bryman, 2001). They tend to be more focused and structured than either observations or interviews, and generally involve larger numbers of individuals (Baker, 1999). However, the sample needs to be carefully selected in

order to accurately represent the target population, and sometimes all the population may be surveyed, rather than a sample (Robson, 2002).

Although questionnaires can be conducted by personal interview using a highly structured interview format, a self-completion format (e.g., a postal questionnaire) generally means that a greater number of participants can be included (Robson, 2002). Some authors propose that the personal contact that typifies a face-to-face or telephone interview increases the engagement of the respondents (Patton, 2002), but Cohen, Manion and Morrison (2000) argue that there is little evidence to suggest that postal questionnaires will necessarily result in a lower response.

The level of response required to ensure trustworthiness of the findings is dependent largely on the degree to which the responders are representative of the sample. Baker (1999) suggests that a response rate of 70% is adequate for a carefully selected sample, although this could still be unrepresentative if the 30% who do not respond disproportionately represent a particular sub-sample within the population. On the other hand, Cohen, Manion and Morrison (2000) suggest that a researcher should be satisfied with a response rate of 50%. Follow-up strategies, for example following a mailed questionnaire with a subsequent mail-out, can increase the response rate (Lewin, 2005).

The wording of the questions in a questionnaire strongly affects the usefulness of the findings. In order to be meaningful, questions must measure the concepts that the researcher intends them to measure, and they must mean the same thing to all respondents (Baker, 1999). They should be clear, simple, unambiguous and free of bias (de Vaus, 1991).

Closed questions force the respondent to select a single response from a list, for example, multiple choice questions and rating scales. In this case, the list of responses must cover the entire range of possible responses, and each item in the list needs to be mutually exclusive (Dawson, 2002). Provision should also be made for

cases when the respondent may honestly not have a response, for example “don’t know” and “no opinion” (de Vaus, 1991). Although closed questions are useful because they can be easily coded, they do not allow the respondent to add any qualifications or explanations to the given categories (Cohen, Manion, & Morrison, 2000). There is also the risk that the categories may not be exhaustive, and that they are biased (Oppenheim, 1992).

Open-ended questions avoid the limitations of pre-set categories, and responses may contain the ‘gems’ of information that might not be captured with closed questions (Cohen, Manion, & Morrison, 2000). On the other hand, they can be difficult to code and classify (Baker, 1999), and some authors advise against including too many of them because they are more demanding of respondents’ time and may be off-putting (Lewin, 2005). An uncluttered questionnaire that looks professional is also likely to result in a greater response rate, and should be kept as short as will suffice to elicit the information required to answer the primary research concerns (Baker, 1999).

Carrying out a pilot, or pre-test, of the questionnaire is essential to check the clarity of items, the appropriateness of response categories for closed questions, and the instructions and layout (Cohen, Manion, & Morrison, 2000). The intention is to help the researcher understand the meaning of the questionnaire items to the respondents, and how they arrive at their response, in order to help improve the wording of the items (Robson, 2002). Patterns of response can also identify questions that everyone answers alike (i.e., they are unlikely to yield useful information); questions that tend to be skipped (indicating that they may need to be re-worded); and open-ended questions that result in ambiguous answers (Baker, 1999). Pre-testing can first be carried out with friends and colleagues, but it is then important that a pilot is carried out using respondents who have the same characteristics as the group of interest (Dawson, 2002). In general, pilot respondents are asked to answer as if they had received the questionnaire from someone they did not know, and then to go through it again pointing out any perceived problems



(Baker, 1999). If anything other than minor changes are made, a further pilot should be carried out and evaluated (Robson, 2002).

Pilot studies help to increase the trustworthiness, dependability, and practicability of the questionnaire (Oppenheim, 1992; Wilson & McLean, 1994). Follow-up interviews with a cohort of respondents can check whether the questionnaire items measure what they are supposed to measure (Baker, 1999). Another concern that needs addressing is whether those who fail to return their questionnaires would have given the same distribution of answers as those who did return the questionnaires (Belson, 1986), and maximising the response rate is therefore important.

### ***3.3.5 Ethical Considerations in Education Research***

Education research involves human participants, and ethical considerations are thus paramount. The main ethical concerns include: gaining informed consent and avoiding deception; participants' rights to privacy and confidentiality; protecting the participants from harm; and accuracy of reporting (Christians, 2003; Fontana & Frey, 2003). House (1990) summarises these considerations by advancing the principle of mutual respect, that is, that researchers show a willingness to see the situation of others from their point of view, respecting their reasons for doing things enough to find out what those reasons are. This position, that the perspective of others' is valuable and valued, is consistent with an interpretive view of research. Lincoln (1990) further suggests that the ethical concerns listed above are the minimum in terms of what must be considered in interpretive research, arguing:

The emphasis on face-to-face interaction, on faithfully representing multiple constructed, and often conflicting realities, and on maintaining privacy and anonymity while utilizing extensive word-for-word, natural language quotations in case studies as well as the case studies in general are all problems typically faced by the emergent-paradigm [i.e., interpretive] inquirer (p. 83).

Proper respect for human freedom generally requires that subjects voluntarily agree to participate in the research, and that their agreement to do so is based on informed consent, that is, full and open information (Christians, 2003; Fontana & Frey, 2003). Informed consent is therefore considered to have been achieved if the participant knows what the study is about, understands what will be required in order to participate in the study, understands his or her level of confidentiality in the study, and subsequently agrees to participate (Baker, 1999). Deception, where researchers present their research as something other than what it is, should be avoided (Bryman, 2001). However, in cases where participants might decline to be involved because of the sensitivity of the research topic, some regulatory bodies allow only general information to be provided if this can be suitably justified (Cresswell, 1998). Coercion or manipulation should not be employed (Baker, 1999), and exploitation or the perception of exploitation between the researcher and the participants must also be avoided (Tolich, 2001). In general, the informed consent must be recorded in writing or on tape (Baker, 1999).

Although obtaining informed consent means that participants are aware of the nature of the study, thus increasing the risk of reactive effects (where people's knowledge that they are being studied may make them behave less naturally), these effects can be mitigated in part by prolonged interaction with the participants, particularly in the case of participant observation (see Section 3.3.4). Covert research, where reactivity is reduced, is now generally seen to be unethical because it does not provide the participants with an opportunity to give their informed consent; it is viewed as an invasion of their privacy; and it entails deception (Bryman, 2001).

By getting informed consent, the issue of invasion of privacy is minimised (Baker, 1999) because the participant "in a sense acknowledges that the right to privacy has been surrendered for that limited domain [as outlined in the informed consent process]" (Bryman, 2001, p. 483). Participants' rights to privacy also require sincere commitment on behalf of the researcher to ensure confidentiality. This is usually achieved by storing and reporting data under codes or pseudonyms

(Cresswell, 1998). However, pseudonyms and disguised locations are often recognised by insiders (Christians, 2003), and in certain cases participants' identities cannot be fully concealed by virtue of their unique position in an institution. The general stance in this situation seems to be to ensure that the participants are informed of cases in which confidentiality cannot be assured (Chambers, 2003). Another position is to present case studies of individuals that represent a composite picture rather than an individual picture (Cresswell, 1998), or to present 'fictionalised stories' that preserve the truth of individual experience without making explicit the identifications of particular people in specific situations (Angrosino & Mays de Pérez, 2003).

Besides informed consent and participants' rights to privacy and confidentiality, ethical conduct also requires that harm to participants is minimised. Here, 'harm' can entail a number of facets, including harm to participants' academic or professional development, and any loss of self esteem (Bryman, 2001; House, 1990). Harm can also be associated with invasion of privacy and unwanted exposure, which is why confidentiality is paramount. Researchers should also be aware that reported information that they consider to be "innocent" could be perceived by participants as misleading, or even betrayal (Christians, 2003). Fine, Weis, Weseen and Wong (2003) suggest that researchers ask: "Who am I afraid will see these analyses? Who is rendered vulnerable/responsible or exposed by these analyses? Am I willing to show him/her/them the text before publication? If not, why not?" (p. 138). As Fontana and Frey (2003) point out, to learn more about people, researchers need to treat the research participants as people.

A final ethical consideration in education research, like all research, concerns the accuracy of data interpretation and reporting. Fabrications, fraudulent materials, omissions and contrivances are obviously unethical, as well as lacking in internal and external validity (Christians, 2003).

In summary, the main considerations associated with an interpretive project include the incorporation of multiple perspectives, issues of trustworthiness in data generation and analysis, the use of multiple data gathering methods, and ethical issues. The next section discusses how these considerations were specifically addressed in the current research.

### **3.4 THE CURRENT RESEARCH**

The research reported in this thesis focuses on introductory-level biology courses at university. The research was carried out within an interpretive framework, and the perspectives of both faculty and students were sought and valued. Ethical approval to carry out the work was granted by the Human Research Ethics Committee of the Centre for Science & Technology Education Research at the University of Waikato, and was based on the principles of informed consent, lack of coercion, anonymity, and protection from harm.

The work adopted a social-constructivist view of learning, as described in Section 2.2.3. ‘Meaningful learning’ was thus considered to occur when individuals seek to make sense of new concepts by relating them to relevant prior knowledge structures in a process that is stimulated by interaction with others. The research involved several phases, with each phase seeking to address a different research question, as introduced at the end of Chapter 2. Thus:

- Phase 1 sought to investigate faculty views of the role of prior knowledge in student learning in introductory-level biology courses at university, and in particular to identify key concepts that students were assumed to know prior to participating in these courses
- Phase 2 sought to determine the actual prior knowledge of students entering first-year biology courses, and compare this with faculty assumptions, as identified in Phase 1
- Phase 3 involved the implementation and evaluation of a teaching intervention. The design of the teaching intervention, which used concept mapping, was based on a review of the science education literature, as well as the data collected in the first two phases of research.

The specific methods used to address each of these research themes are detailed in the following sections.

### *3.4.1 Phase 1. Faculty Assumptions Regarding Students' Prior Knowledge*

In order to investigate and describe faculty assumptions about the prior knowledge of students entering first-year biology courses at New Zealand universities, several methods of data collection were used. These included: interviews with faculty, analysis of curriculum documents and student lecture and laboratory manuals, and observation of classes. Each of these is explained in more detail below.

#### Faculty Interviews

An extensive survey involving 35 faculty who lecture (n=32) or tutor<sup>4</sup> (n=3) in first-year biology courses at six different universities in New Zealand was carried out, in which participants were interviewed and asked about their assumptions regarding the skills and prior knowledge of students entering first-year biology course(s) that they taught. A semi-structured schedule was used to allow respondents to “extend, elaborate, add to, provide detail for, clarify or qualify their responses” (Cohen, Manion & Morrison, 2000, p. 278). Questions focused on interviewees’ views of students’ prior knowledge and the biological concepts that they considered to be important for students to be familiar with prior to engaging in first-year biology courses. Participants also were asked about the chemical and mathematical concepts that they assumed students were familiar with, and were presented with a list of mathematical competencies (used by Marsh & Anderson, 1989) and asked to select the ones that were required of students. A copy of the interview protocol and list of mathematical competencies is provided in Appendix A.

Initially, the chairpersons of the relevant university departments were approached by telephone and sent a follow-up letter describing the research and asking for permission for the researcher to approach faculty. The participants were selected on the basis of their involvement with first-year biology courses, and effort

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<sup>4</sup> Lecturers are responsible for presenting information to a whole class. Tutors are employed to facilitate discussions with smaller groups of students.

was made to ensure that they represented a wide range of content areas typically covered in first-year biology courses, including: cell structure (seven faculty), biochemistry (four faculty), genetics (nine faculty), plant form and function (11 faculty), animal systems (seven faculty), microbiology (two faculty), ecology (two faculty), and evolution (five faculty). Some of the participants contributed to more than one of these topic areas, in one or more introductory biology courses. Information about faculty and their areas of teaching expertise were obtained from course outlines either available on the internet, or sent to the researcher on request (this level of information was found to be publicly available).

Participants were approached informally by telephone and invited to participate in the research. Informed consent was obtained in writing prior to each interview (Appendix B). All interviews were conducted in the participants' offices at an agreed time and lasted between 30 and 50 minutes. The conversations were tape-recorded with each participant's permission and transcribed. The transcripts were returned to the participants so they could make any changes/clarifications. Such 'member checking' is used to enhance the trustworthiness of the data. Pseudonyms are used to report the findings so that the anonymity of the participants is protected.

### Document Analysis

Additional data about faculty assumptions regarding students' prior knowledge were gathered from student lecture and laboratory manuals, which were collected wherever possible (this generally depended on whether the interviewee had one available, although several sent copies after the interviews). Six lecture manuals (from three cell biology courses; one animal biology course; one plant biology course; and one animal and plant biology course) and 12 laboratory manuals (from five cell biology courses; two animal courses; two plant courses; and three combined animal and plant courses) were obtained in this way. These manuals were analysed to identify concepts and/or mathematical skills that it seems students need to be familiar with in order to understand the work, but that are not specifically explained. The manuals were also analysed for information about strategies that were used to address

issues of student diversity in terms of background content knowledge, for example, the provision of a glossary.

### Classroom Observations

In addition to faculty interviews and document analysis, classroom observations were undertaken at one university. Particular attention was given to the way new topics were introduced, and assumptions that appeared to be made regarding students' prior knowledge (e.g., when the molecule 'ATP' was referred to for the first time, but without explanation). Two courses were observed, one focusing on animal and plant biology and the other on cellular and molecular biology. Each course ran for 12 weeks, and included three 50-minute lectures per week, all of which were observed.

Observations of lectures were undertaken with the permission of faculty, who each gave their informed consent in writing (Appendix C). The lectures were didactic in style, with only the occasional student interrupting to ask a question. The researcher adopted the role of observer-as-participant in the sense that she participated in the lectures in much the same way as any of the other students, listening to the lecturer and reading the lecture notes in the lecture manual handed out to all students in this course. She was also introduced to the class during the first lecture as a PhD student interested in teaching and learning of first-year biology courses, which meant that her role as researcher was known to students.

In addition to the lectures (which were observed) and a compulsory three-hour laboratory class each week, six weekly tutorial slots were scheduled as part of the first-year biology courses that were observed for this part of the study. The tutorial sessions were taken by the course tutors, with the current lecturer also responsible for two of the sessions each week. Suggested questions for tutorial discussion were included in the back of the student lecture manual. The tutorials were voluntary and students could attend any of the sessions in a given week. Attendance was not normally recorded, but for the purpose of the present research an attendance sheet

was passed around at the start of each session and students were asked to write their student ID numbers on the list. This allowed the researcher to keep a record of regular tutorial attendees, although she did not have access to their names. The attendance sheets were not used in any way for assessment of the students, and students were informed of this (this was clearly stated at the top of each attendance sheet).

Four of the six tutorial classes were observed each week over the 12 teaching weeks in each of the two courses, and students attending these sessions were informed in advance of the researcher's presence and her intention to observe the discussion and take notes about questions that were asked. No names were recorded in the field notes (indeed, there was no way that these could have been known, unless the teaching staff knew and used them). Students were able to attend either of the two unobserved tutorial slots each week if the researcher's presence or activities as an observer made them uncomfortable. As with the lectures, the researcher's role was one of observer-as-participant in that she sat alongside the students in the classes, and participated in casual conversation with students before and after the class. Her presence appeared to be readily accepted by the students, and she was often greeted by them when they saw each other outside of class on the university campus. Many of the students also indicated an interest in the research and asked informally about progress.

The field notes that were taken during the tutorial observations were based on the conversations that took place between the students and the tutor, that is, the questions that were asked, and how they were answered. Notes that were made on the board by the tutor were also copied down. The questions that students asked gave insight into concepts that appeared problematic, and which often seemed to be associated with a deficiency in their relevant prior knowledge (e.g., when discussing osmosis, one student asked, "But why are the molecules moving?" This was taken to indicate a lack of prior understanding of the random motion of molecules). Often the same question was asked in more than one tutorial session, suggesting that the lack of



understanding was widespread. All observation notes were written as fully as possible to bring to mind a vivid picture of each conversation, and a reflective summary of each session was written as soon as practicable (typically within two days) after the session. In the early phases of the research, these notes were also discussed with the relevant faculty to provide a form of member-checking.

#### Use of Data Collected in Phase 1

Taken together, the data collected from Phase 1 of the project (interviews with faculty, document analysis and classroom observations) were used to construct a list of key concepts (biological, chemical and mathematical) that students are assumed to know when entering first-year biology courses (i.e., these concepts would be used by faculty without explanation). In Phase 2 of the research, this list of concepts was used to construct a questionnaire designed to probe students' prior knowledge, and in particular to investigate how students from different academic backgrounds compare with regards to prior knowledge about specific concepts.

The results from the faculty interviews, analysis of course notes, and classroom observations, are presented in Chapter 4.

#### ***3.4.2 Phase 2. Students' Prior Knowledge When Entering First-year Biology Courses***

A wide range of techniques used to probe students' understandings of specific science concepts have been reported in the science education literature. These include: personal interviews (Stephans & Dyche, 1987); interviews-about-instances (White & Gunstone, 1992); predict-observe-explain scenarios (Liew & Treagust, 1995; White & Gunstone, 1992); concept circles (Wandersee, 1987); concept maps (Edmonson, 2000; Freeman, 2004; Wandersee, Mintzes, & Novak, 1994); word association tasks (Leach, Driver, Scott, & Wood-Robinson, 1995); and written questionnaires (Mak, Yip, & Chung, 1999). In the case of questionnaires, a range of design options are available, including: identification of correct/partially

correct/incorrect statements (Boyes & Stanisstreet, 1991; Hewson & Hewson, 1983; Mak, Yip, & Chung, 1999; Yip, 1998); providing definitions of selected terms (Adeniyi, 1985); multiple choice items (Treagust, 1988); two-tier multiple choice tests (with the second part of each question exploring reasons for students choices in the first part of the question) (Haslam & Treagust, 1987; Odom & Barrow, 1995; Wang, 2004); open-ended questions (Yip, 1998); and a combination of different types of questions (e.g., multiple choice and open-ended) (Núñez & Banet, 1997).

Although interviews can probe students' mental processes more effectively than written questionnaires, they are time-consuming to administer and typically a smaller number of students can be sampled within a reasonable time frame (White & Gunstone, 1992; Yip, 1998). A questionnaire was thus selected for use in the current study because of its potential to give a general picture of first-year biology students' understandings of selected concepts. As discussed in Section 2.3.1, few questionnaires reported in the literature cover a range of biology-specific content, with the majority focusing on specific concepts. Consistent with the notion of social constructivism, a 'prior knowledge questionnaire' specific to the research context was therefore constructed. The questionnaire included both open and closed (multiple-choice) questions. Some of the questions were adapted from instruments used by others (Leach, Driver, Scott, & Wood-Robinson, 1996a; Lewis, Leach, & Wood-Robinson, 2000; Núñez & Banet, 1997; Odom & Barrow, 1995; Stewart & Haffner, 1994; Tariq, 2002).

The prior knowledge questionnaire was piloted by three different cohorts: students who had recently completed Year 13 biology (i.e., the highest level of biology in New Zealand schools; n=8); students enrolled in a biology bridging course (i.e., students who had little biology background but who intended to enrol in first-year biology courses; n=13), and a panel of experts (two teachers of senior biology at high school, two university biology lecturers, and an education researcher with experienced in designing concept questionnaires). The intention of the piloting process was to maximise the trustworthiness, dependability, and practicability of the

questionnaire (see Section 3.3.4), and several of the questions were subsequently modified.

The resultant ‘prior knowledge questionnaire’ (Appendix D) was administered to all students enrolled in a first-year biology course offered at one university during March 2003 (i.e., Semester A). The questionnaire was administered during laboratory classes held in the first week of the semester, and students were informed of the purpose of the questionnaire by the researcher. They were encouraged to complete the questionnaire during the scheduled laboratory time as long as all their other work had been completed. Some questionnaires were also returned during lectures. Of the 184 questionnaires that were distributed, 148 were returned to give a response rate of 80%. A few students (six) did not complete the whole questionnaire, and the sample size was adjusted where necessary to take this into account. Where students did not respond to specific questions, but had otherwise completed the questionnaire, their responses were recorded as ‘missing’.

The results were analysed using the Statistical Package for the Social Sciences (SPSS) software. Analysis for statistically significant differences in the frequency of responses from respondents with more extensive prior biology study (the ‘high bio’ cohort) and those with more limited prior biology study (the ‘low bio’ cohort) was based on the use of a Chi-square test for independence. This test is a non-parametric test used with nominal (frequency) data<sup>5</sup> (Muijs, 2004). It is only valid if the data are independent (i.e., a response cannot be coded more than once); no cell has an expected frequency of less than one; and no more than 20% of the expected frequencies can be less than 5 (i.e., the test is not valid if the sizes for any of the variables are too small) (Foster, 1998). The null hypothesis tested in this part of the current work is that there is no difference in the frequency of responses given by students with more extensive prior biology study and those with more limited prior biology study. Confidence levels of greater than 95% or 99% are reported.

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<sup>5</sup> In this research, column variables - biology background (‘high bio’ versus ‘low bio’) - were compared against row variables (responses to questionnaire items, coded according to themes that emerged from the data), both of which represent nominal data.

The questionnaire data were supported by interviews with a cohort of students (n=16). These students were selected to represent as wide a range of academic backgrounds and questionnaire responses as possible (see Ross & Munby, 1991). At the end of the questionnaire, these students had also identified themselves as being willing to participate in a follow-up interview. Students were interviewed individually for approximately 30 minutes. The questionnaire that had been completed by the student was used as the basis for interview questions, and students were asked to explain why they had given particular responses. This provided a more detailed description of the thinking behind the responses, and was intended to check the dependability of students' responses. The participants provided their written consent at the start of the interview (Appendix E), and with their permission the interview was tape-recorded. The researcher stressed that she was looking for the interviewee's ideas, rather than the 'right' answers, and made an effort to reassure each participant that it was acceptable if they did not know the answer to a particular question (Leach, Driver, Scott, & Wood-Robinson, 1995). This was intended to minimise negative impacts on student confidence as a result of the interview. A transcript of the interview was sent to each participant, and they were asked to provide any alterations/additions they wished. None of them did.

A second version of the prior knowledge questionnaire (Appendix F) was administered in March 2004 with a different cohort of students. This questionnaire was very similar to the one administered the previous year, although some of the questions had been modified in order to probe more deeply specific responses provided for the 2003 questionnaire items.<sup>6</sup> A small number of questions were also re-worded to improve their clarity, and some items were removed because the majority of students had given very similar responses in the first administration, suggesting that the questions were not useful determinants of differences among students. The same administration procedures as the previous year were used, except

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<sup>6</sup> For example, one of the items in the 2003 questionnaire asked where DNA is found. The majority of respondents wrote that it is found in the nucleus, or in cells. In 2004, the question was modified to include a list of different cells. This was intended to probe respondents' understandings about whether all cells contain DNA, or only some cells (a common alternative conception reported in the literature).

that the researcher relied on the laboratory supervisors to encourage students to complete and return the questionnaires. In total, 126 of the 205 distributed questionnaires were returned to give a response rate of 61%. This lower response rate, when compared with that obtained in the previous year (80%), was possibly because of the absence of the researcher during the administration of the 2004 questionnaire. However, it was still deemed to be acceptable.

The purpose of administering the prior knowledge questionnaire on two occasions in successive years was to provide data triangulation, providing a check that responses were not specific to a particular cohort of students. The findings from the two administrations of the questionnaires, supported by data from subsequent follow-up interviews, are presented in Chapter 5.

### ***3.4.3 Phase 3. Implementation and Evaluation of a Teaching Intervention***

As a result of a review of the literature and the findings from Phase 2 of the project, a teaching intervention based on concept mapping was implemented. As described in Section 2.5.3, concept mapping is a strategy reported to facilitate meaningful learning because it requires the person(s) constructing the concept map to make explicit the links between concepts. Despite numerous calls to use concept mapping more extensively in science education, the majority of papers report its use in identifying students' conceptions. Few actually evaluate the effectiveness of concept mapping in student learning (see Section 2.5.4).

Tutorial classes were considered to be the most appropriate educational vehicle for the intervention because they are smaller in size, and potentially more interactive, than lectures. As is described more fully in Chapter 6, the intention of using concept mapping was threefold: to encourage students to form explicit links between concepts; to assist students with more limited prior knowledge to identify and address any gaps in their prior knowledge; and to help students to become "active constructors of meaning" (Dawson, 1993, p. 74).

The evaluation of the intervention was concerned primarily with three issues. First, it was considered important to understand students' perceptions of the use of concept maps as a teaching and learning tool. This was deemed necessary since new pedagogies have been reported to be unappealing to tertiary-level students, who quickly become accustomed to lectures in which they can 'turn off' and become passive (Dalgety & Coll, 2005). Hence, a new teaching approach, whatever its potential learning benefits, needs to be introduced with caution. Second, the research sought to explore the tutor's perceptions of concept mapping as a teaching and learning tool. This was consistent with the interpretive nature of the research design, and the commitment to valuing multiple perspectives. Third, the research sought to gain some insights into the impact of concept maps on student learning.

The intervention, as well as the methods used to evaluate it, are described below.

#### The Concept Mapping Intervention

The concept mapping intervention was implemented during the second half of 2003 (*Course 1*) and repeated in the first half of 2004 with a different cohort of students (*Course 2*). This meant that it was iterative in nature, incorporating a process of inquiry maturation (Guba & Lincoln, 1994) in which data analysis and modifications to the research design were conducted side by side. For example, an open-ended 'tutorial experience questionnaire' was administered at the end of *Course 1* to investigate students' affective responses to the concept mapping classes. The open-ended nature of such questions provides insights into student thinking, but it was unclear how wide-spread some of the opinions were. The responses from the first administration of the questionnaire (*Course 1*) were coded thus thematically and used to develop closed question items for a second version of the questionnaire, which was administered at the end of *Course 2* and which provided quantitative data related to student responses to the use of concept mapping in the tutorial classes.

Although the two courses in which concept mapping was implemented focused on different content (*Course 1* covered cellular and molecular biology; and *Course 2* covered animal and plant classification, structure and physiology), they were similar in structure and pedagogy and included three 50-minute lectures each week, as well as a weekly laboratory class which was compulsory. The process of the lectures consisted of lecturers covering course content in a didactic manner according to a transmissive model of instruction.

Two of the six weekly tutorial classes associated with each of these first-year biology courses were set aside for teaching students to use concept mapping as a learning tool. As described in Section 3.4.1, the tutorial classes ran for 50 minutes and attendance was voluntary. The tutorials were advertised as usual during the first week of teaching, and students were told which tutorial classes had been set aside for teaching them “a study technique that could be useful to their learning.” The other tutorial classes were run in the conventional manner and tended to involve the tutor going through a list of pre-set questions (made available to students in the course lecture notes in advance of the tutorial classes). The differences between the conventional and concept mapping tutorials, based on classroom observations, are described in greater detail in Chapter 6.

One tutor facilitated all of the concept mapping tutorial classes. In *Course 1*, she also took some of the conventional tutorial classes that were observed, and in *Course 2* she took most of the other tutorial classes. This was considered important to minimise any ‘tutor effects’ associated with the concept mapping classes (i.e., students responding in a particular way because of the tutor, not the teaching strategy per se).

### Classroom Observations

Four of the six weekly tutorial classes (including the two weekly concept mapping tutorials), as well as all lectures, were observed throughout the two 12-week courses during which the concept mapping intervention was implemented. The aim

of the observations was to develop an understanding of course content covered prior to and during the tutorials, and the general conduct of both forms of tutorial classes (concept mapping and conventional). The relevant tutor provided details of content covered in the two unobserved tutorials (knowledge of content discussed in tutorials was important for later analysis of student learning).

The observations were carried out as in Phase 1 of the research, with the researcher assuming the role of observer-as-participant. Permission to observe the tutorials was obtained in writing from the relevant tutors and lecturers. Students were informed (both verbally and via a notice on the overhead projector, see Appendix C) of the researcher's presence and her intention to observe the discussion and take notes about questions that were asked, although no names were recorded. Students were further informed that they could attend one of the two alternative, unobserved tutorial slots each week if the researcher's presence as an observer made them uncomfortable. Although attendance at tutorials was voluntary, the students were asked at each tutorial (observed and not observed) to write their ID numbers on a sheet of paper for the purpose of the research, as in Phase 1. This was done so that performance on assessment tasks could be correlated with tutorial attendance (see below).

### Students' Perceptions of Concept Mapping as a Pedagogical Tool

To answer the first research question of this phase (i.e., to investigate students' perceptions of concept mapping), students were asked to provide feedback on their experiences in the tutorial classes that employed concept mapping by responding to an open-ended 'concept mapping experience questionnaire' in *Course 1* (Appendix G). The responses to this questionnaire were analysed thematically (Patton, 2002; Taylor & Bogdan, 1998) and used to develop a second concept mapping experience questionnaire which included Likert scales and was used to measure how widespread certain responses were (Appendix H). This second concept mapping experience questionnaire was administered during concept mapping tutorial classes at the end of *Course 2*. A modified version of the questionnaire, called the 'tutorial experience questionnaire' (Appendix I) was also administered to students



attending the non-concept mapping tutorials during *Course 2*. The purpose of this questionnaire was to check whether students' responses to the concept mapping experience questionnaire were related specifically to concept mapping, or tutorial attendance in general. The trustworthiness and dependability of the instruments were enhanced by the use of follow-up interviews which probed students' responses to open-ended questions and confirmed that what had been written reflected their opinions about the tutorials.

### The Tutor's Perceptions of Concept Mapping as a Pedagogical Tool

The ongoing implementation of concept mapping in the first-year biology courses forming the context for this part of the study depended largely on the perceptions of the tutor involved in the implementation of the intervention, and her views of the process were considered to be important. This is also consistent with interpretive research, which highlights the value of understanding the research context from multiple perspectives.

In order to gain an understanding of the tutor's views of concept mapping as a teaching and learning strategy, informal discussions were held with the tutor before and after the tutorial classes when there was opportunity to do so, and field notes were taken. Summaries of these discussions were sent to the tutor for checking. More formal interviews were also carried out five times during the two courses in which the intervention was implemented. These were tape-recorded and transcribed and the tutor was invited to make alterations/additions to the transcripts. In some cases this initiated additional reflective comments which were incorporated in the analysis. The tutor also read the final analysis resulting from these interviews. She indicated that what had been written accurately reflected her views, providing a high degree of respondent validation.

### Analysis of Student Performance on Assessment Tasks

To investigate the effects of concept mapping on student learning, data were collected from selected questions that formed part of course tests administered to the

whole class for traditional knowledge/comprehension-level assessment purposes. These questions were similar to those used in assessment tasks in previous years. Being part of assessment tasks, the answers were likely to represent the students' best attempts.

The test questions were examined thematically by a panel of experts (the researcher, two first-year biology tutors and an experienced science education researcher) and classified into two types. One type of question, in the judgment of the expert panel, could be answered by repetition of information provided in the course lecture notes (i.e., shallow, rote learning). The second type of question required students to have an understanding of a range of biological concepts, and to link these together in a meaningful way. The questions, as well as a more detailed explanation of this classification into the two different types, are presented in Chapter 6.

The statistical significance of differences in performance between students was investigated using Chi-square tests for independence with the null hypothesis that there is no difference in the performance of students who attended a relevant concept mapping tutorial, a conventional tutorial, or no tutorial. As in Phase 2 of the study, the Statistical Package for the Social Sciences (SPSS) software was used.

The disadvantage of relying on data from course assessment tasks was that the researcher had no control over what was asked (i.e., concepts of particular interest to the researcher would not necessarily be concepts explicitly examined by the teaching staff). Additional questions, written by the researcher, were administered to the class at the start of each laboratory session each week during *Course 1*. One to two questions were asked each week, and were specifically designed to investigate students' understanding of relationships between concepts. The questions were checked in advance for clarity by two tutors and six graduate students who were employed as teaching assistants for the laboratory component of the course, and were

therefore expected to be familiar with student understanding of first-year biology course concepts.

Students were encouraged by the researcher and laboratory supervisors to complete these questions before the start of each laboratory session, and to return them to a box placed at the front of the laboratory. Out of a total class enrolment of 166 students, response rate varied in any given week from about half the class, to just less than two thirds. Although this response rate may appear to be relatively high, when the responses were separated into groups of students who had attended a relevant concept mapping tutorial, a conventional tutorial, or no tutorial, the sample sizes for one or more of the cohorts tended to be too small for Chi-square tests to be valid (Coakes & Steed, 2001; Foster, 1998). These data were therefore not included in the current study, and instead specific items selected from whole-class assessment tasks proved to be suitable for analysis of tutorial effects on student learning (described above).

#### Summary of Methods Used to Evaluate the Concept Mapping Intervention

To summarise, the concept mapping intervention was implemented and evaluated during two different first-year biology courses, with different cohorts of students. This enabled a process of enquiry maturation (Patton, 2002) to be employed. The evaluation of the intervention consisted of three components: feedback from the students (based on questionnaires and follow-up interviews); feedback from the tutor (based on interviews, including informal conversations after some of the tutorial sessions); and an analysis of student performance on selected assessment tasks. The mixed-methods design for this part of the work (i.e., using both quantitative and qualitative methods) was chosen to allow triangulation of the findings, providing a more comprehensive picture of the intervention and its effectiveness. The approach also sought to minimise the inherent limitations of each research method, allowing for both in-depth understanding based on students' own conceptions, from the qualitative data, and the ability to generalise from the quantitative data. The results are presented in Chapter 6.

### **3.5 CHAPTER SUMMARY**

The research presented in this thesis adopted an interpretive methodology, congruent with the research questions and the epistemological underpinnings of the study. Data were generated through semi-structured formal and informal interviews, analysis of course documents, questionnaires (administered both to investigate students' prior knowledge of particular scientific concepts, as well as their perceptions of tutorial classes), observations (with the research acting as observer-as-participant), and student responses to course assessment items.

The trustworthiness of the data was ensured as far as possible using data triangulation (e.g., supporting faculty interviews with classroom observations); member checks (e.g., by returning interview transcripts to participants to verify that the data accurately represented their viewpoints); and pilot studies of questionnaires. The findings from the research are presented in the next three chapters, followed by a discussion of findings in relation to the science education literature, as well as suggested conclusions and implications (Chapter 7).

# **Chapter 4**

## **Faculty Assumptions of Students' Prior Knowledge**

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### **4.1 INTRODUCTION**

To answer the first research question, “What do students need to know prior to entry into introductory biology courses at university?” an extensive survey was carried out that involved semi-structured interviews with 35 faculty from six New Zealand universities. In order to provide data triangulation, course documents were also collected and analysed, and classroom observations were carried out at one university.

The interview participants all contribute to introductory biology courses and were selected to represent a wide range of content areas, including: cell structure; biochemistry; genetics; plant physiology and diversity; animal physiology and

diversity; microbiology; ecology; and evolution (see Section 3.4.1). Most of the interviewees contribute to more than one of these topic areas, in one or more introductory biology courses. The interview discussion focused on participants' assumptions regarding the skills and prior knowledge of students entering first-year biology courses, specifically the concepts that they assume students are familiar with prior to teaching. Details of the semi-structured protocol that was used are presented in Section 3.4.1, and the specific starter questions in Appendix A. This phase of the research took place in the final quarter of 2002.

The course documents that were analysed included the course descriptions for all biology courses offered by seven of the eight New Zealand Universities<sup>7</sup> (to identify details about course content and prerequisites), and lecture and laboratory manuals that are distributed to students. These included the 2002 student laboratory manuals associated with 12 courses (five cell biology; two animal biology; two plant biology; and three combined plant and animal biology courses) and six study manuals (three cell biology; one animal biology; one plant biology; and one combined plant and animal biology course). These course manuals were examined for examples of concepts and/or mathematical skills that students need to be familiar with in order to understand the work. Concepts that had been specifically introduced at an earlier stage in the course were ignored.

In addition to document analysis and the interviews with faculty, classroom observations were carried out at one university, with the researcher acting as participant-observer (see Section 3.4.1). Two courses were observed: one focusing on animal and plant physiology and diversity (March to July 2003); and the other covering concepts related to cellular and molecular biology (July to November 2003). Each of the three weekly lectures were observed over the 12 teaching weeks associated with each course. In addition, four of the six weekly tutorial classes were observed each week in each of the two courses. Notes were made of concepts that were specifically introduced in the lectures, and concepts that were used but not

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<sup>7</sup> One university did not offer a traditional Bachelor of Science degree.

defined (i.e., prior knowledge of these concepts was assumed). In the tutorials, notes were taken about the questions that students asked (to identify any concepts that students seemed to be unclear about after their use in the lectures).

The document analysis and classroom observations were intended to provide triangulation for the faculty interview data. The aim was to construct a picture of the concepts that students were expected to be familiar with prior to their studies in the introductory-level biology courses, that is, concepts used without explanation.

## **4.2 INTRODUCTORY BIOLOGY COURSES**

At the time this phase of the research was carried out, seven of New Zealand's eight universities offered a range of introductory biology courses, including at least one course in general cell biology (covering topics such as eukaryotic and prokaryotic cell structure, membranes and cell transport, DNA structure and protein synthesis, cell division, and biochemical pathways like photosynthesis and respiration) as well as at least one course on plant and animal diversity, structure and function. In three cases these two content areas were split into two courses, one focusing on animal biology and the other on plant biology. One university offered additional animal and plant courses which had a strong agricultural focus. Several of the other universities also offered additional courses, for example, in human biology, ecology, evolution, conservation, and more advanced molecular biology and biochemistry. These were specific to each university and were not investigated as part of this study. Only the general cell biology and the animal and plant biology courses were included.

Details about prerequisite requirements (i.e., courses that a student is required to have passed prior to being admitted into a particular course) can be found in the university calendars and course outlines, and in 2002 no tertiary-level introductory biology courses in New Zealand required students to have completed Year 13

(bursary) biology at high school prior to enrolling.<sup>8</sup> Year 13 is the final year of high school in New Zealand.

Although the course descriptions for the introductory biology courses did sometimes include references to prior knowledge, only one course description specifically indicated that the course “assumes knowledge of bursary [Year 13] biology.” Course descriptions for the introductory biology courses at another university indicated that Year 13 biology was “desirable,” and the course description from a third university stated: “It would be helpful if students have a good sixth-form [Year 12] understanding in biology, mathematics, physics and chemistry.” Prior knowledge of introductory chemistry was also recommended by two other universities, with one offering an introductory chemistry course specifically for biology majors with limited prior knowledge of chemistry. Students could enrol in this course at the same time as enrolling in the first-year biology courses.

The lack of formal prerequisite requirements means that students entering first-year biology courses may have a range of prior academic experiences, and the literature reviewed in Chapter 2 suggests that this has the potential to influence student learning in these courses. The next section outlines faculty perceptions of the diversity in students’ academic backgrounds.

### **4.3 FACULTY PERCEPTIONS OF DIVERSITY IN STUDENTS’ ACADEMIC BACKGROUNDS**

Many of the faculty who were interviewed referred spontaneously to the diverse academic backgrounds of students and the perception that the range in prior academic experiences had recently increased. For example, Aaron<sup>9</sup> reported:

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<sup>8</sup> This was sometimes in contrast to other introductory science courses. For example, students wanting to enrol in first-year chemistry courses at several universities were required to have completed Year 13 chemistry, or a pre-degree (bridging) alternative.

<sup>9</sup> Pseudonyms have been used throughout; details of interview date / time have been omitted for the sake of the narrative.



“There’s been an increasingly diverse array of students coming in ... you get people with virtually no background right through to students who have done everything you could ask.” Many participants went on to indicate that they believed this had implications for the way that they taught the required content. As Adam commented: “There’ll be those who have a good grasp already and who are probably thinking, ‘Here he goes, I know all of this already,’ and others who say, ‘What on earth is he talking about?’”

Some of the participants reported that because of the range in student academic backgrounds, they felt they had to assume very little prior knowledge. For example, Patrick said: “The course has to be structured to cater for students who didn’t do biology at school, and therefore I work on the assumption that nobody in the class has done any biology before.” Donald expressed a similar view: “I pretty much start from ground zero ... there are variable standards amongst the students.”

Starting “from scratch” was also reported by faculty to be consistent with the lack of prerequisites for the introductory biology courses. As Debbie commented: “By virtue of saying that they don’t have to have biology coming into the course, we make a commitment to teaching the biology starting from the ground upwards.” Ryan similarly indicated that he believed the courses he was involved with had been specifically designed to accommodate students with little biology-specific prior knowledge, and when asked about the role of bridging, or preparatory, courses he responded: “If there was a formal system where students without a biology background were required to do a bridging course, then we would change the nature of our introductory biology course accordingly.”

Faculty commented, however, that it was a challenge to try to always “go back to basics” because it means covering content that some students were already familiar with. For example, Doug reported: “The real drawback is that the ones who have done well [in biology at school] are probably bored out of their trees.” Donovan said: “Some students say to me that they like it when I take things really slowly, but

other students say that I could speed up a little bit,” and Richard observed: “It’s a case of trying to pitch it to the middle, although there aren’t actually people in the middle.” These responses suggest that taking a diverse range of prior knowledge into account during teaching is a complex process, and faculty were concerned that students with more extensive prior biology knowledge would find such teaching boring. In order to accommodate these students, while at the same time taking into account the more limited prior knowledge of other students, some participants reported deliberately using examples that differed from those that tend to be used at school. In addition, Ryan said: “We teach it in a different way to teaching in schools, and with a different emphasis.” Barry similarly felt that it was important to have a different focus because “they get turned off if you tend to use the same or similar sorts of words in ways which they think are familiar.”

In summary, faculty who were interviewed reported differences in students’ prior academic experiences and knowledge, and reported that because of this they tried to assume very little prior knowledge. However, they suggested that this was not always easy, and were particularly concerned about the risk of boring students who had done extensive biology study at high school. Several interviewees reported that they tried to use examples and emphases that differed from the ones students were likely to have been exposed to during school biology courses. Faculty perceptions of the role of the specific prior knowledge is explored in the next section.

#### **4.4 FACULTY PERCEPTIONS OF THE IMPORTANCE OF STUDENTS’ PRIOR KNOWLEDGE**

Several faculty indicated they had considered the importance of prior knowledge prior to being approached to participate in the current study. This suggests that faculty at other universities were keen to explore the relationship between diverse academic backgrounds of students, variations in prior knowledge, and the impacts on student learning. For example, Renee reported that she had conducted a small survey on student background to investigate the usefulness of

secondary school biology courses. Commenting on her findings, she said: “If they’ve done sixth form [Year 12] or bursary [Year 13] biology, they seem to get higher grades and the failure rate is 10%, whereas 26% of those with no biology, or fifth form [Year 11] failed.”

Other participants, although not having surveyed their students, also indicated that they thought prior study in biology would be helpful. Debbie, who had said that her course was taught “from the ground upwards,” also said, “I suspect that those who have done biology find it a lot easier than those who haven’t.” Candice commented: “If you have the choice of having sixth [Year 12] and seventh form [Year 13] biology, of course you’re better off.” Similarly, Richard said, “We have the assumption that they don’t have to have done any biology at school, but it’s obviously an advantage to those who have done it.” Gary said, “Some knowledge is better than none.” Simon referred to what he called a “cyclical learning process,” adding: “If they’ve had it at school first, it will be easier the second time and even easier the third time. They’ll begin to put it together and start to put things in context.” Debbie similarly commented, “If you’ve got some background and you build on that ... it expands the timeframe in which you’re consolidating information.”

Several faculty referred to the enormous volume of content covered in introductory biology courses, particularly “if they don’t already know it.” For example, Donald said: “If you’ve got no biology, then the volume of information can easily overwhelm you,” and Debbie felt: “If students have no background at all, we probably cover it really fast.” The extensive vocabulary associated with introductory biology courses was also commented on by faculty, who suggested that students with prior knowledge of some of the terminology may have an advantage. For example, Sonja, referring to students with limited prior study in biology, said: “I think that is the most difficult thing for them – that they have not being exposed to the language of biology.”

A number of participants qualified their comments about the usefulness of prior knowledge by adding that literacy, interest in the subject, and motivation, seemed to be equally important. As Ryan said: “If they are interested and enthusiastic, they’re more likely to do well, whether they’ve got prior background or not.”

Three of the 35 interviewees also reported that they thought extensive prior study in biology might actually hinder student learning, perhaps because students were less likely to engage with the material. For example, Donald, who had commented that students who had previously studied biology “at least have some familiarity with the terms,” then added: “But with familiarity come some forms of contempt. I know trying to teach Mendelian genetics, you see the students’ eyes roll back in their heads. It is hard to teach, because they think they know it all.” As reported earlier, interviewees suggested that one strategy to address this is to use examples and emphases that differ from those that students are likely to have encountered at school.

‘Mature students’ were spontaneously referred by several faculty. These students have often not studied for several years, and may or may not have studied biology at high school. Although many of these faculty appeared to be very positive about having them in the classroom - Donald said, “They’re such fun to teach because they’re so interested” - several reported that these students did seem to find the courses challenging, at least in part because of their limited biology-specific prior knowledge. For example, Renee said: “They’ve done no biology since fifth form science, and they’re saying that it’s really hard and they’re asking if there’s anything else they can do to catch up.” In contrast, other faculty suggested that these students were sufficiently motivated, and simply worked harder in order to stay abreast with the course content. For example, Sonja said, “They recognise that they don’t understand something, but they are very keen and motivated and go and read up about it.”

To summarise, there appeared to be general agreement that faculty need to and tried to accommodate students with limited prior knowledge in their teaching, and many reported teaching topics “from scratch.” However, a large proportion indicated that prior biology study would be likely to help students cope with both the vocabulary and the high level of content associated with introductory biology courses. Language skills and motivation were also considered to be important. The wording from one course outline seems to provide an appropriate summary: “[This course] is aimed at students who have minimal background in biology, chemistry and physics, but relies on students accessing background reading where they find their existing knowledge inadequate.”

The next section will explore specific concepts that faculty assume students are familiar with prior to participating in the first-year biology courses.

#### **4.5 SPECIFIC PRIOR KNOWLEDGE ASSUMED BY FACULTY**

Although the majority of faculty reported that they assume very little prior biological knowledge when teaching, they were able to provide examples of specific biological terms and concepts that they do assume students are familiar with, and that they would not specifically explain during teaching. They also assume that students had some understanding of specific mathematical and chemical concepts.

Faculty comments about assumed prior knowledge of specific terms and concepts are grouped into the following topic areas: biological concepts (classification of living organisms, plant and animal systems, the cellular basis of life, biochemical pathways, and genetics); overarching themes (evolution, unity and diversity, and the scientific method); chemical concepts (atoms and molecules; chemical symbols and molecular formulae; chemical reactions, including redox reactions; and osmosis and diffusion); and mathematical skills. Table 4.1 provides a summary of the key concepts that were identified. A more detailed analysis of

faculty views, supported by analysis of the relevant course documents as well course observations at one university, is provided in the subsequent sections.

**Table 4.1**

Concepts faculty assume students have some understanding of prior to their participation in first-year biology courses

General theme	Specific concepts
Classification of living organisms	Hierarchical nature of the classification system
The cellular basis of life	Living organisms are composed of cells
Biochemical pathways	Cells need energy Requirements for and products of cellular respiration and photosynthesis Significance of cellular respiration and photosynthesis
Genetics	Living organisms contain DNA The location and function of DNA in living organisms The location of chromosomes and genes Simple Mendelian-type problem solving
Overarching themes	Evolution Unity and diversity Scientific method
Chemistry	Atoms and molecules Bonding, including hydrogen bonding The meaning of chemical symbols (e.g., 'C' for carbon) Concepts related to osmosis and diffusion (solute, solvent, random movement of particles)
Mathematical skills	Drawing and interpreting graphs Simple algebraic calculations Scientific notation Metric units (e.g., being able to convert between millimetres and micrometres)

#### ***4.5.1 Biological Concepts***

##### Classification of Living Organisms

When asked about prior knowledge required of students entering introductory biology courses at university, four faculty said that they expected students to be familiar with the “main kingdoms.” For example, Ryan said that he assumes that students have a “basic understanding of the characteristics of the major kingdoms of life.” Six other faculty said that students should have some prior understanding of the hierarchical system used to classify living organisms (i.e., that species are classified into groups nested in even bigger groups; the taxonomic group ‘kingdom’ is most inclusive, ‘species’ is most exclusive).

Document analysis showed that the classification system and taxonomic hierarchy was explained in only two of 12 laboratory manuals (one cell biology course and one combined animal and plant biology course). Classification nomenclature (kingdom, phylum, class, order, family, genus and species) was used without description or explanation in four of the eight plant and/or animal biology courses. In the laboratory component of the plant and animal biology course that was observed, the students were taken on a ‘taxonomic walkabout’ and a range of different plant species (and their taxonomic classification) was described without an explanation of what the hierarchical taxonomic system meant, although a brief explanation had been included in the first lecture. In three of the four tutorial classes observed following the taxonomic walkabout, students asked about how plants were classified, suggesting that lack of understanding of the classification system was fairly widespread.

Knowledge about classification thus appeared to largely be assumed. However, the *diversity* of organisms is specifically introduced in lectures and laboratory classes in six of the seven plant and/or biology courses investigated. Laboratory activities ranged from observing and comparing representatives from different animal or plant groups on display, answering questions about groups of

animals during a visit to a museum, and using the library to find information about specific organisms.

In summary, students seemed to be expected to be familiar with the taxonomic hierarchy used to classify living organisms, but detail about specific animal and plant groups is explicitly taught in all but one of the plant and/or animal biology courses included as part of this study.

### Animal and Plant Systems

All seven universities offering first-year biology courses in New Zealand have specific courses on animal and plant biology, with animal and plant systems combined into a single course at three universities.

Faculty reported that they believed limited prior knowledge is required for students to understand and follow topics on animal and plant physiology in these courses. As Keith put it: “They don’t really need to have any prior knowledge, other than Discovery Channel.” Patrick said that he assumes “Some sort of concept of circulation in animals; breathing; the need for oxygen – just a basic understanding of life that I assume people to know and that I don’t expect them to go to sixth form [Year 12] biology to know.”

According to faculty, details about different animal and plant systems are specifically taught. This was supported by an analysis of course lecture notes. However, some faculty suggested that prior knowledge about some of the systems may be helpful, largely because of the rate at which the information is covered in the first-year courses. They also indicated that familiarity with some of the terminology may be helpful. For example, Dylan said: “Something like ‘inferior vena cava’ is a mouthful for somebody who hasn’t come across it before.” The number of specific terms that are used is also enormous. For example, analysis of one laboratory manual revealed that in a single class on animal transport systems, the following terms were used: ventral, dorsal, atria, ventricles, venae cavae, pulmonary artery, pulmonary



veins, aorta, atrioventricular valves, chordae tendineae, semilunar valves, tricuspid valve, papillary muscle, haemoglobin, oxyhaemoglobin, carboxyhaemoglobin, trachea, spiracles, and thorax. Students were required to understand these terms in order to carry out the laboratory activity, and then they had to remember them in order to label a diagram of a sheep's heart in a laboratory test held later in the semester.

In spite of the terminology and volume of content covered, there was a general perception that students find plant and biology topics conceptually easier than topics in cell biology. For example, Linda, who runs tutorials on all three topics, commented: "None of it is as taxing as parts in the cell biology course. The only real problem is the sheer volume ... You don't get the same sort of 'I don't understand this' response." This is consistent with faculty reports that little specific prior knowledge is required for course content focusing on animal and plant systems.

#### The Cellular Basis of Life

When asked about concepts that students are expected to be familiar with prior to teaching, six of the interviewees (two who teach cell morphology, three who teach genetics, and one who teaches biochemical pathways) said that students should know that organisms are composed of cells. Shaun added that he expects students have "some prior understanding of the concept ... of a prokaryotic and a eukaryotic cell ... and the concept of compartmentalisation." Thirteen other faculty were asked specifically whether they assume that students know that organisms are made of cells, and all said that they did. However, several of these participants indicated that although an understanding of cells was assumed, it would also be briefly explained. For example, Jarred said: "In the very first lecture we talk about prokaryotes and eukaryotes, but in a way that indicates we expect students to have some idea about them already."

An analysis of course outlines suggests that although cell structure and function is specifically introduced in courses on cell biology, 'cells' may be referred

to without explanation in animal biology courses, as was the case in the one animal biology course that was observed. This is also consistent with a comment made by Richard, who teaches animal biology at another university: “There are some ongoing assumptions – not only are animals made out of cells, but cells have a particular structure ...”

In contrast to animal biology courses, courses on plant biology generally seem to include descriptions of specific cell types in the course content (based on an analysis of course outlines). However, there is extensive use of specific terminology (e.g., xylem, phloem, collenchyma, sclerenchyma), and seven faculty who teach plant anatomy were asked about their assumptions regarding student understanding of specialised cell types. Whilst two reported that they expected students to have come across the terminology before, the other five said that they assume students know plants are made up of cells, but that details about specialised cell types are taught. However, the lecture time allocated to these topics is limited. As Derek commented: “There’s one lecture on plant morphology and one lecture on the plant cell ... That’s difficult to teach and to squeeze it all in.”

In summary, details about eukaryotic and prokaryotic cell morphology as well as plant cell morphology and differentiation are specifically taught in cell biology and plant biology courses respectively. However, the interviews with faculty, and also the classroom observations, indicate that it is assumed students understand the context of this teaching, that is, that organisms are composed of cells. Some faculty also suggested that students not already familiar with some of the associated terminology would be likely to find the content overwhelming because of rapid coverage in lectures.

#### Biochemical Pathways: Cellular Respiration and Photosynthesis

Cellular respiration and photosynthesis are the two biochemical pathways that are taught in the introductory biology courses included in this research. These chemical pathways are directly related to the use and conversion of energy within the

cells of living organisms, and are taught one after the other in courses on cell biology. Photosynthesis is also taught in four of the six plant biology papers that were investigated, with one of these courses also including a lecture on cellular respiration.

An underlying principle of photosynthesis and cellular respiration is that cells need energy. Regarding students' prior knowledge about energy, Chris said: "They should understand ... that life is based on very, very simple reactions that generate energy." Alan said that he assumes students know that "for cells to perform work they need energy." In the cell biology course that was observed, the concept that all cells require energy, and that they use it for a variety of functions, was introduced in two tutorials, but not during the lecture.

Four faculty specifically said that they expect students to be familiar with the overall purpose of cellular respiration and photosynthesis prior to entering introductory biology courses. None of these participants specifically teach either cellular respiration or photosynthesis as part of a course on cell biology, but they reported that they would refer to these pathways without explaining them (e.g., in the context of evolution). Document analysis also indicated that these pathways are sometimes referred to without explanation. For example, in one course on organism diversity, cyanobacteria were described as "organisms with photosynthesis based on chlorophyll *a*," but no explanation of photosynthesis or chlorophyll was given. Similarly, in the animal biology course that was observed, cellular respiration was referred to briefly as a prelude to a lecture on gas exchange systems. However, the process was not explained in detail, and questions asked during tutorials suggested that some students did not understand the concept (indicating that some prior knowledge had been assumed by the lecturer). For example, one student asked in a tutorial class: "He started off [the lecture on gas exchange] with some equations [relating to the difference between anaerobic and aerobic respiration]. What did they mean?"

It seems that a basic understanding of photosynthesis and cellular respiration is required for courses on organism biology, but details of the specific reactions involved are explicitly taught in cell biology courses. Four faculty who teach these topics reported that they assumed no prior knowledge at all. For example, Jarred said: “We basically start with a leaf and work in ... They get told almost everything.” However, these faculty also referred to the time constraints imposed on them by the lecture schedule (1 – 2 lectures per pathway). For example, Derek said: “It’s a real juggle. We simply can’t cover everything that is listed [in the course outline] well.”

Faculty further indicated that students seemed to find both cellular respiration and photosynthesis difficult to understand. Several possible explanations were suggested: strongly held alternative conceptions (e.g., plants photosynthesise and animals respire); lack of understanding of the underpinning concepts (e.g., light energy can be converted into chemical energy); new terminology; and the poor chemistry background of some students. There was evidence of each of these in the tutorial discussions that were observed (e.g., students asking for definitions of some of the terms that were used; or asking for the chemistry to be explained). This suggests that although the topics of photosynthesis and cellular respiration are specifically taught, students’ prior knowledge (particularly where it is limited, or where alternative conceptions are strongly held) may affect their understanding. In addition, observations of course lectures at one university suggested that the limited time available for teaching these topics means that while some concepts and terms may be explained when they are introduced, they are subsequently used without further explanation and students are expected to have quickly assimilated the new concepts into their cognitive structures.

To summarise, although cellular respiration and photosynthesis are specifically taught, coverage of content is very rapid during lectures. There is also the assumption that students can connect an understanding of each pathway with prior knowledge that cells require energy, and also that students are able to understand and use chemical symbols and formulae. A general understanding of cellular respiration

and photosynthesis is required for when these processes are referred to without explanation in other parts of the first-year biology courses. Prior exposure to some of the terminology, as well as the ability to use and understand chemical notation, are likely to impact on student understanding.

### Genetics

When asked which parts of the first-year biology courses students found difficult, many faculty referred to genetics. In particular, faculty reported that students with limited prior knowledge were likely to struggle with the rapid coverage of course content. For example, Candice said: “It’s not that it’s not done clearly or well in the lecture, it’s that it’s only done on one or one and a half days and then we move on.” Alister similarly commented: “It’s a lot of work for students to keep up with if they don’t already know it.” Richard observed: “Those that are comfortable with it did it at school.”

Faculty assumptions about prior knowledge of specific concepts related to genetics are grouped for clarity according to the following themes: molecular genetics (DNA structure and function), Mendelian genetics (the physical outcome of particular genetic combinations), and references to genetics in terms of plant life-cycles.

### Molecular Genetics

Several of the interviewees said that they assume that students know that living organisms contain DNA. For example, Kerry referred to a student who had asked whether algae have DNA and commented: “People should be beyond that level before they tackle biology at university level.” Richard commented that “Although it is pointed out that all cells contain DNA, we assume we’re going over familiar material.”

DNA structure and function (e.g., the concept of a gene) is taught during three or four lectures in all the cell biology courses investigated. As with other topics, faculty indicated that this imposed constraints on the rate of coverage of the concepts.

For example, Aaron said: “Most textbooks would spend about a third of their length going over genes and alleles and so on, and we only spend three lectures and a lab on it.”

Vocabulary was also considered to be an important factor affecting student learning, and was viewed as being particularly confusing for those unfamiliar with the topic. For example, Sarah, a tutor, observed: “Often you find there are several terms for the one topic. With DNA they talk about a nucleotide sequence. They also talk about bases. They talk about base pairs and codons and amino acids. That’s five things – are they the same or are they not? It’s very confusing.” Linda similarly commented: “It’s helpful if they’ve come across the terminology ... Otherwise, when they read the textbook, they’ll have to stop at every third word because they won’t know what it is.” Observations of tutorial classes at one university did indeed suggest that students found the terminology confusing, and they frequently asked for clarification of the relationship between different terms. For example, one student asked during a tutorial: “What is the difference between a DNA nucleotide and a chromosome?”

In order to address the challenges associated with the extensive vocabulary that is used, the student lecture manual at one university included a glossary which explained genetic terms. The laboratory guide from another university included explanatory diagrams showing, for example, the relationships between chromatids, chromosomes and replicated chromosomes. In addition, one university had introduced a special tutorial held before the first genetics lectures “because we knew that there would be students who had never done it before.” When this tutorial was advertised, it was announced it was not intended for those who had recently completed Year 13 Biology. At this same university, an additional tutorial is available to specifically help students form links between transcription, translation and replication, processes which are all related to DNA functioning within cells. Renee, the lecturer, explained: “The students are taught those in separate sections.

Although I try to link things as I go ... there's a tendency for them not to see the whole picture.”

To summarise, all the cell biology courses include lectures on DNA structure and its function in cells. However, the time spent on these sections is limited to three or four lectures, and faculty seemed to assume that students would come into the course having heard of DNA, and knowing that all living organisms contain DNA. Although participants reported making an effort to explain all concepts as they were introduced, there was the expectation that a lot of it would be familiar material. Familiarity with some of the terms would also reduce the amount of new information that needed to be assimilated. For students unfamiliar with the terminology, even reading the textbook could be confusing. Additional tutorials were introduced at one university to cater for the needs of students with more limited prior knowledge, and to help all students to form links between the concepts. This suggests that there was the perception that not all students were adequately prepared for this topic in terms of their prior knowledge.

### Mendelian Genetics

Mendelian genetics refers to the inheritance of characteristics, and the physical outcome resulting from particular genetic combinations that are inherited (e.g., the risk that a child might inherit a particular genetic disorder). It is first introduced as a topic in New Zealand secondary schools in Year 11 but, as the science education literature points out, is a topic many students find problematic (see Section 2.3.1).

More than any other topic, faculty referred to the diversity in student prior knowledge about Mendelian genetics, and the impacts this consequently seems to have on student understanding. For example, Renee said that after attending lectures given by her predecessor and listening to comments from the students, she had cut her teaching of this section from four down to three lectures because “A lot of them said they'd done it before.” However, she subsequently introduced two tutorials to

specifically give students with insufficient prior knowledge additional support. Extra tutorials specifically related to this topic are also offered at a second university “out of necessity, to pull everybody up to speed.”

On the one hand, there appear to be a group of students who have what the faculty consider to be inadequate prior knowledge. On the other hand, faculty like Donald believe that part of the reason why a different group of students struggle with Mendelian genetics is because “they think they know it all.” He proposed that teaching this section requires an introduction of “the unexpected” and advocates the use of examples different to the ones students are likely to have encountered at school.

In summary, Mendelian genetics stood out as being a topic where the diversity in student prior knowledge was considered by faculty to be particularly problematic. In response, two of the six universities have introduced additional tutorials to bring students with limited prior knowledge “up to speed.” This strongly suggests that faculty assume some prior knowledge related to Mendelian-type problem solving when teaching this topic.

#### Genetics and Plant Life-cycles

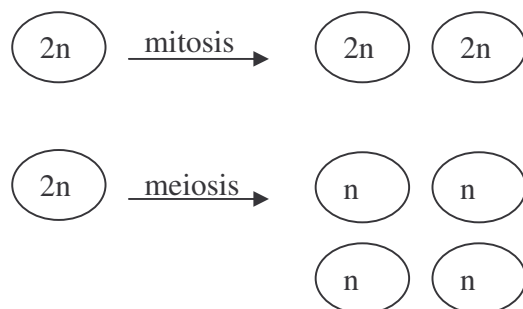
Several faculty indicated that although they do not teach genetics directly, they do rely on the underpinning concepts in order to teach other topics. An example of this is the teaching of plant life-cycles. Like many other first-year biology topics, this one is rich in terminology and students are required to be able to negotiate their way through text filled with terms such as: sporophyte, sporangium, gametophyte, haploid, and diploid. Second, students need to understand what happens to the chromosomes in each stage of the life-cycle, and whether the cells of the new plant are diploid (i.e., have two sets of chromosomes) or haploid (i.e., have a single set of chromosomes). Third, students are also required to have an understanding of the different types of cell division (i.e., mitosis and meiosis). Analysis of course manuals suggests that concepts like gametophyte and sporophyte are specifically introduced.



However, concepts like ploidy (chromosome numbers) and cell division are referred to without explanation, and one participant explained that teaching these concepts (cell division and ploidy) had deliberately been removed from the course he teaches on “because we decided that the majority of them have done it in the first semester [a cell biology course].”

Faculty who teach plant life-cycles were specifically asked about their assumptions regarding student prior knowledge of terms such as haploid, diploid and chromosomes. Donovan replied: “When talking about haploid, I was always saying, ‘It’s a single set of chromosomes’.” He went on to say that he assumes students understand what is meant by ‘chromosomes’. Gary reported that he gives “a brief definition of mitosis and meiosis and then a definition for haploid versus diploid.” He said he supports this with a quick illustration (Figure 4.1), but that he assumes students are familiar with the use of *n*-notation (*n* = haploid; *2n* = diploid). Like Donovan, he also said that, given time constraints in the lectures, he assumes students are able to understand what he meant by ‘chromosomes’.

Angela said that she is asked to explain terms such as haploid and diploid in tutorials. This was also seen to occur during tutorial classes observed at one university, in which several students asked the tutor to clarify terms such as haploid, diploid, and chromosomes. This suggests that some prior knowledge of these concepts is assumed during lectures.



**Figure 4.1**  
Illustration reportedly used by one lecturer to compare mitotic and meiotic cell division

In summary, a general understanding of DNA, chromosomes, haploidy, diploidy, and cell division is important for understanding plant life-cycles. Because of time constraints on the lecturers, these terms are described only briefly, if at all.

#### ***4.5.2 Overarching Themes***

When faculty were asked about concepts that they assume students are familiar with prior to starting introductory biology courses, several referred to general biological themes, such as an understanding of evolution, the unity and diversity of life, and the scientific method. Each of these is explained in more detail in the following sections.

##### Evolution

An analysis of course outlines revealed that evolution is taught as a topic in several courses. Five faculty who teach this section were interviewed, and all said they have very few assumptions about students' prior knowledge related to this topic. For example, Aaron said: "Because evolution can be so easily misunderstood by the general public, I don't expect students to come with too much prior knowledge." Adam reported: "I start right from scratch with evolution ... because they come from a diverse background of knowledge." These faculty also observed that students often held alternative conceptions about the process of evolution, and Aaron said that he gives students a short quiz during the first lecture "just to see what they think about when they think about evolution ... it's quite good to talk about them as we go on through the course." Richard also commented on the number of alternative conceptions held by students, saying that evidence from an online discussion forum indicated that students were "obviously confused about the processes of natural selection, and all the misconceptions that go with it."

Faculty who specifically teach evolution therefore indicated that they had very few prior assumptions about student prior knowledge of evolution. However, four did specifically report that students should have a good understanding of the "genetic

basis of inheritance and evolution” prior to teaching. Faculty also felt that this topic was difficult to teach because of alternative conceptions held by students. They also reported that variable student background and a lack of understanding of ‘scientific method’ made teaching this section problematic. For example, Adam commented: “Because they come from a diverse background of knowledge ... there’ll be those who have a good grasp already ... and others who say, ‘What on earth is he talking about?’” Angela reported: “You’re going to understand how science works a bit better if you also understand how it’s done.” In addition, two faculty specifically referred to the impact that students’ belief systems can have on their learning. For example, Chris said that he assumed students accepted evolution as ‘fact’, and that when referring to creationism “one has to draw the distinction and say that we’re not talking about science.”

Analysis of course documents revealed that, as well as being specifically taught, ‘evolution’ is also referred to in many other teaching contexts as an overarching theme. In contrast to faculty who specifically teach this topic, interviewees who refer to it as one of biology’s underpinning themes indicated that students should have some prior knowledge of the concept. For example, Richard said: “If they haven’t really got an understanding of what evolution is, or maybe they’re a bit unclear of some of the underlying principles, it could be a little bit difficult. It’s an assumption that we don’t explicitly test them on, but we do assume they know it.” This was consistent with course observations, where evolution as a concept was referred to without explanation. For example, one of the lectures that was observed was introduced with the lecturer saying: “Today we’ll be covering the evolution of vascular plants” (i.e., he assumed that students understood what he meant by ‘evolution’). Evolution as a concept was also used without explanation in some of the laboratory manuals, for example: “This reduction of the gametophyte generation is another major evolutionary event.” In each of these cases, it appeared that a rudimentary understanding of evolution as changes in a population over time would be likely to suffice. When Angela reflected on references to evolution in the course she co-ordinates, she commented: “Obviously we should make our coverage

of evolution a bit more explicit throughout.” She indicated that she felt she did not currently do this.

In summary, the concept of evolution is specifically taught in some introductory biology courses. Faculty who teach this section reported that they took care to assume very little prior knowledge. However, they believed that students’ prior knowledge was likely to impact their learning, particularly where alternative conceptions are strongly held, or where there is a lack of understanding of ‘scientific method’. Evolution is also referred to in other contexts, and in other introductory biology courses (e.g., when teaching about animal and plant diversity or physiology), and in these cases a basic level of understanding is assumed.

### Unity and Diversity

Besides evolution, a second unifying theme in biology that three faculty said students should be familiar with prior to starting introductory biology courses at university is what they called “unity and diversity” or “sameness and difference”. For example, when Chris was asked about concepts he assumes students are familiar with, he replied:

They’ve got to understand the unity and diversity, as it is sometimes called, namely that life is all identical and that, depending on which way you look at it, there’s virtually no difference between my cells and cabbage cells. On the other hand, there is a difference. A cabbage cell is green for a very good reason, and mine is red for a very good reason. They’ve got to understand the similarity and difference, the unity and diversity.

This theme of unity and diversity was not specifically referred to in either of the two introductory biology courses that were observed, and was only overtly apparent in one of the course outlines that was analysed. However, the textbook by Campbell and Reece (2002), which is used by eight out of the 15 biology courses investigated as part of this study, includes a section on unity and diversity in its opening chapter, “Ten themes in the study of life”. It seems that while students may be expected to be familiar with this concept, it is not explicitly taught or examined.

### Scientific Method

Although it is noted in the science education literature that there is no one 'scientific method' (e.g., Carey, 1994; Gibbs & Lawson, 1992), several faculty interviewed in this study indicated that students were expected to have some understanding of scientific method as being the formation and testing of hypotheses, and the replication of results. For example, when Fred was asked about prior knowledge he assumes when teaching a first-year biology class, he replied: "A basic understanding of science – the principles and philosophy of science – is important. Things like the scientific method, how hypotheses are established and tested, that a null hypothesis is as valuable as a proved hypothesis, and so on." Alister said he assumes students have some understanding of "The scientific method and the use of controls, the need to replicate, the formulation of hypotheses."

Two of the 15 courses that were investigated included specific information on the scientific method in their lectures (based on information about lecture content). Gary, who is involved with one such course, said: "I think this section [on scientific method] is mandatory." In addition, one of the 14 laboratory manuals that was analysed included a two-page description of 'scientific method' as well as two exercises in which students were required to generate hypotheses, test them, and draw conclusions. Later in this course, students were required to use the same procedure to carry out their own investigation on bacteria, including references to dependent, independent and controlled variables. Four other laboratory courses included activities which required students to generate hypotheses and predict results, but none of these explicitly linked this to 'scientific method'. A fifth laboratory course included two experiments where students were asked to suggest ways in which the experiments could be improved (students were provided with the basic 'recipe' needed to carry out the initial experiments).

In lectures observed at one university, four faculty referred to the ‘nature of science’,<sup>10</sup> using narrative (story-telling) to explain, for example: how the structure of DNA was determined; how the structure of the cell membrane was determined; the other ideas around at the time of Darwin; and the general acceptance (until recently) of auxin concentration as the main driver of phototropism in plants. However, the lecturers did not make explicit links to the messages they were conveying about the nature of science. Conversations during tutorials suggested that students were not clear on the purpose of these narratives. For example, one student asked: “Do we have to remember how it [DNA] was discovered?” The tutor replied, “No ... But you should understand how it works because you’re doing science.”

To summarise, some faculty assume students have knowledge of ‘scientific method’ prior to entering first-year biology courses, although concepts such as fair testing were specifically taught in some laboratory courses. Some faculty also use narrative to demonstrate the ‘nature of science’ although students may not intuitively develop clear understandings of the nature of science from these narratives.

#### ***4.5.3 Chemical Concepts***

Classroom observations and analysis of course documents suggest that an understanding of chemical symbols and formulae is a pre-requisite for understanding the chemical reactions involved in cellular respiration and photosynthesis. Reference to ions and molecules is also associated with topics such as neural transmission and muscle contraction, as well as with the concepts of diffusion and osmosis taught as part of cell biology courses (e.g., movement across cell membranes), animal biology courses (e.g., osmoregulation<sup>11</sup> and kidney function), and plant biology courses (e.g., movement of water and solutes in plants). In addition, most courses on cell biology

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<sup>10</sup> Here, the ‘nature of science’ is distinguished from ‘scientific method’ (the formulation and testing of hypotheses) and taken refers to concepts such as scientific ideas being subject to change (as new knowledge challenges prevailing theories), science demanding evidence, and the blend of logic and imagination in developing scientific understanding (Rutherford & Ahlgren, 1991).

<sup>11</sup> The control of water balance in organisms.

include a specific section on organic compounds in cells (i.e., carbohydrates, lipids, proteins, and nucleic acids), and schematic diagrams of chemical structures tend to be used when teaching these topics. The course outlines for three of the first-year biology courses that were investigated as part of this study specifically recommended that students have an understanding of Year 12 chemistry.

The majority of faculty who were interviewed indicated that some chemical understanding is an important pre-requisite for introductory biology courses, and 13 out of 14 participants referred to chemistry when specifically asked about school subjects that would be helpful for students to have completed. Only Dylan, who teaches animal biology, said: “School chemistry is only of peripheral importance.” Mark and Candice, from different universities, also said that students without a background in school chemistry were expected to refer to the biology textbook (by Campbell & Reece, 2002), which contains an introductory chapter on basic chemistry (elements and compounds; atomic structure; chemical bonding; and chemical reactions).

In spite of the perceived importance placed on chemical understanding, faculty reported that many students have poor or inadequate background in chemistry. For example, Alister, a lecturer in ecology, said that students seem to find nutrient cycles difficult “because of their lack of adequate chemistry knowledge, for example, that NH<sub>3</sub> represents ammonia, that hydrogen ions can be gained or lost, and basics about chemical reactions.” Alan, who teaches biochemical pathways, similarly commented: “The more chemical I get, the more difficult it becomes for students.” As well as student difficulty with chemistry, several participants commented on what they perceived to be student attitudes towards chemistry. For example, Henry said: “They get terrified of it – even just the mention of the name of a molecule. And it’s just a name.”

When asked about chemical concepts that were particularly important for students to understand prior to entering introductory biology courses, faculty

identified several concepts: atoms and molecules, chemical symbols and molecular formulae, chemical reactions, redox reactions, and concepts related to osmosis and diffusion. Each of these are explored in more detail in the following sections.

### Atoms and Molecules

Many faculty indicated that they assume students are familiar with the concepts ‘atoms’ and ‘molecules’ prior to entering first-year biology courses, and reported that they would use these terms without explaining them. Jarred added: “I actually assume a whole lot more than that,” and Chris said that he expects “that they know about atoms, orbitals, the electrons in atoms and how they interact.”

When asked about bonding between atoms, both Adam and Dylan said that it would help students to “know some basics about bonding.” Kerry reported that it would particularly be useful for students to know what a hydrogen bond is, as she would refer to it in the context of DNA structure.

Hydrogen bonds are also referred to in the context of water movement within xylem in plants. Two underpinning concepts are that water is a polar molecule, and that polar molecules can interact with each other. When asked about how she addresses this in her teaching, Amy answered: “We talked about the properties of water, but not in any great detail.” Donovan reported: “I draw little pictures of water molecules and show how they can stick to each other and how they can relate to elements that are dissolved in them.” Louise said: “We did one slide on the unique properties of water and we went through some of the properties of hydrogen bonds, but very, very briefly.” In the plant biology course that was observed, hydrogen bonds were also briefly introduced using a simple diagram.

It seems that although the properties of hydrogen bonding are a critical part of the explanation of water movement in plants, they are explained only briefly and there is an assumption that students have some prior knowledge about different types of chemical bonding.



In addition to knowledge about atoms, molecules and bonding, three faculty referred specifically to student knowledge of carbon chemistry, particularly in the context of biochemical pathways. As Jarred commented: “The thing that I think is extremely hard is if they’re not used to the fact that carbon has four bonds.” In the tutorial classes that were observed, students also asked about carbon chemistry in the context of DNA structure, suggesting that some assumptions about their understanding of carbon chemistry had been made during the lectures.

A specific section on organic molecules (carbohydrates, lipids, proteins, nucleic acids) is taught in most of the cell biology courses. When asked about whether prior knowledge of these groups of molecules is important, Renee said: “An awareness helps ... but we go over it.” However, she added that she does expect students to have an understanding of “how you build a polymer from a monomer.” Gary also expects students to be familiar with “the whole idea of building blocks.” Patrick, who also teaches the section on organic molecules, said that he expects students to be familiar with the terms “only from a nutritional point of view, not to know anything about what they are.” On the other hand, Jarred said that he hands out a sheet with chemical diagrams of four organic compounds (a lipid, carbohydrate, protein, and nucleic acid) at the start of the course, and tells students that they are expected to be able to interpret the diagrams and match each one to the appropriate name (i.e., knowledge of the molecules and their chemical structures is assumed).

Terms such as amino acids, nucleotides, proteins and nucleic acids are also used when teaching about protein synthesis. Although this section generally comes after the section on organic molecules in cell biology courses, course outlines indicated that it tends to be taught by someone other than the lecturer responsible for the section on organic compounds. This suggests that students are required to make links with the earlier content on organic compounds. However, tutorial discussions that were observed suggested that students were still confused between the different groups of organic compounds, despite having ‘covered’ them earlier in the course.

For example, one student asked: “What’s the difference between amino acids and nucleic acids?”

In summary, faculty reported that students are expected to be familiar with the concepts of atoms, molecules, and chemical bonding. Prior knowledge of carbon chemistry (i.e., that carbon can bond to four other atoms) is helpful. Details about the four different groups of organic molecules tend to be specifically taught, although reference is made to these groups in other contexts, where some understanding may be assumed.

### Chemical Symbols and Molecular Formulae

Chemical substances and their interactions are typically represented by symbols. Document analysis as well as classroom observations at one university revealed that molecular formulae and diagrams of chemical structures are used in a variety of contexts in introductory biology courses, including photosynthesis and cellular respiration, DNA structure, protein synthesis, muscle contraction and nerve impulse conduction, and a range of laboratory activities.

Several faculty reported that they assume students understand what these molecular formulae mean. For example, Angela said: “We do certainly expect them to understand the basic chemical formulae and use them competently.” Patrick reported: “I expect that I could use symbols when explaining something like a carbohydrate – I could put up  $\text{CH}_2\text{O}$  [on the board] and have them have some concept of what I’m doing.” Chris commented: “If they don’t know that ‘C’ stands for carbon and that there are bonds then there’s just no hope for them, and they shouldn’t be in the class.”

In contrast, Alan and Derek said that they try to “remind” students how to interpret diagrams of chemical structures. Barry also said that while he assumes students understand “that Cl-minus means something ... It’s absolutely clear that they very often don’t.” He said that because of this he does explain it, “but very briefly;

there just isn't time to go into detail about ions and what charges are and so on.” Students also often asked about chemical symbols and formulae in the tutorial classes that were observed, suggesting that some assumptions were made by faculty about students' ability to provide names for common chemical symbols, and to be able to use these interchangeably.

Students enrolled in introductory biology courses are therefore going to come across molecular formulae and diagrams representing chemical structures. Although these diagrams might be explained, the explanations are brief and there is the expectation that students are familiar with the names of common atoms and molecules (e.g., C, O, N, H, CO<sub>2</sub>, etc.). Background information is provided in many of the first-year biology textbooks, but faculty consider it to be up to the students to locate, read, and understand this information.

### Chemical Reactions

Chemical reactions are of particular relevance to sections on metabolic pathways (cellular respiration and photosynthesis), and to a lesser degree ecological concepts such as nutrient cycling. The reactants and products are often represented by molecular formulae, and faculty indicated that students were assumed to be familiar with this. As Chris said: “If they can understand that everything can be described by a simple formula, and they can see how that can be applied to something that looks complex, like biochemistry, which is just simple reactions between *a* and *b* ... that's what's needed.”

However, several participants commented that some students seemed to be unfamiliar with the use of chemical reactions. For example, Louise said: “I put up the photosynthesis equation and a few students didn't understand what it meant. Things like: you start off with some starting materials, and you end up with other things.” This was consistent with student comments during tutorial classes that were observed. For example, one student asked the tutor to go over photosynthesis, saying: “I'm just

a bit lost with the chemicals.” Another student commented: “When the slides come up with the equations, everything just goes in one ear and out the other.”

It seems that, like molecular formulae, there is an assumption that students should be able to use and interpret chemical equations.

### Redox Reactions

One specific type of chemical reaction referred to in the context of cellular respiration and photosynthesis is reduction-oxidation (redox) reactions, for example, the reduction of NAD to NADH.

Some faculty reported that because students struggle with this concept, they make an effort to explain what redox reactions are. For example, Patrick reported: “I explain and define all of those [redox reactions, electrons] and take some time over it.” On the other hand, Chris (who also teaches biochemical pathways) said that he assumes that students understand what redox reactions are, adding: “We would expect them to know what they are better than we would explain it ... We’re not going to stop the lecture to explain what oxidised means or what reduced means.” Kerry also thought that students should have an understanding of oxidation and reduction prior to starting first-year biology courses.

Five of the 12 laboratory manuals that were analysed included references to oxidation or reduction, all without explanation. For example, the Fehlings test for simple sugars was explained in this way: “All simple monosaccharides ... will *reduce* the cupric ion in hot alkaline solution to form red cuprous oxide” (emphasis added). As part of an investigation into enzyme activity, another laboratory manual included the following explanation for the enzyme activity associated with the browning of peeled potatoes: “Many storage tissues contain enzymes that in the presence of oxygen ... will catalyse the *oxidation* of phenolic compounds” (emphasis added). Students were then instructed to observe this reaction by using catechol: “When catechol is *oxidised*, the products are brown-red” (emphasis added). Four tutorials

were observed just prior to students undertaking this particular laboratory session, and students asked about oxidation and reduction in three of the four classes.

In summary, although some faculty reported explaining concepts like reduction and oxidation, others indicated that they use these terms without explanation. A range of laboratory activities also expected students to be familiar with these concepts. Observations of tutorial classes at one university suggested that lack of understanding of these concepts amongst students was fairly widespread, despite expectations that they should be familiar with them.

### Concepts Related to Osmosis and Diffusion

As has already been indicated, diffusion and osmosis are taught as part of cell biology courses (e.g., movement across cell membranes), animal biology courses (e.g., osmoregulation and kidney function), and plant biology courses (e.g., movement of water and solutes in plants).

Two of the four laboratory manuals that included activities investigating osmosis or water potential provided a short glossary,<sup>12</sup> suggesting that prior knowledge was not required. In contrast, three faculty specifically indicated that students should be familiar with terms like ‘solute’ and ‘solvent’ prior to studying these sections in first-year biology courses. Three others reported that they felt they had to teach diffusion and osmosis “from scratch” because of the variation in student prior knowledge. As Shaun commented: “We would expect them to know about diffusion and osmosis when they first arrive. I guess that’s why we teach it, though, to make sure that some of them are up to speed.” In the lecture on osmosis that was observed, the lecturer drew dots representing molecules in solution and arrows to show that they move in random directions. However, one student asked in a tutorial: “But why are they moving?” This suggests that, even though the lecturer tried to “go

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<sup>12</sup> One glossary included the terms: osmosis, diffusion, solute, hypotonic, hypertonic, isotonic, and osmolarity; the other included: solute, solvent, and water potential.

back to the very basics,” there was still an assumption that students understand that molecules are moving.

Diffusion is also referred to in the context of movement of ions in animal systems, for example, in muscle contraction, neural conduction, and osmoregulation in the kidneys. Barry, who teaches this section, said he expects students to know about movement down chemical gradients and Kerry said that she thought students should know about the charge of molecules and how positive charges are attracted by negative charges. In the course that was observed, diffusion was referred to in the context of animal systems without explanation, and students asked about the movement of the ions or molecules in tutorial classes.

In summary, osmosis and diffusion are explicitly taught in some introductory-biology courses, although there may be the assumption that students understand terms such as solute and solvent, and also some of the underpinning chemical concepts, such as the random movement of particles. Diffusion and osmosis are also referred to in other contexts, such as animal systems, where they may be used without explanation.

#### ***4.5.4 Mathematical Skills***

As well as an understanding of some chemical concepts, mathematical skills were seen by many faculty as being important. As Linda commented: “I put mathematical skills in the same context as reading, writing and comprehension skills.” In contrast, a few faculty reported that mathematics was not particularly relevant to either their section of the course (topics such as microbiology, evolution, cell structure, and animal biology) or to particular courses (plant and animal biology courses). For example, Derek, talking about a course on plants, said that the course “tends to be descriptive rather than take on mathematical relationships.” Sonja commented that because of student complaints, mathematics had been dropped from the laboratory component of an animal biology course. Only one course outline

stated “It would be helpful if students had a good sixth form [i.e., Year 12] level of understanding of ... maths.”

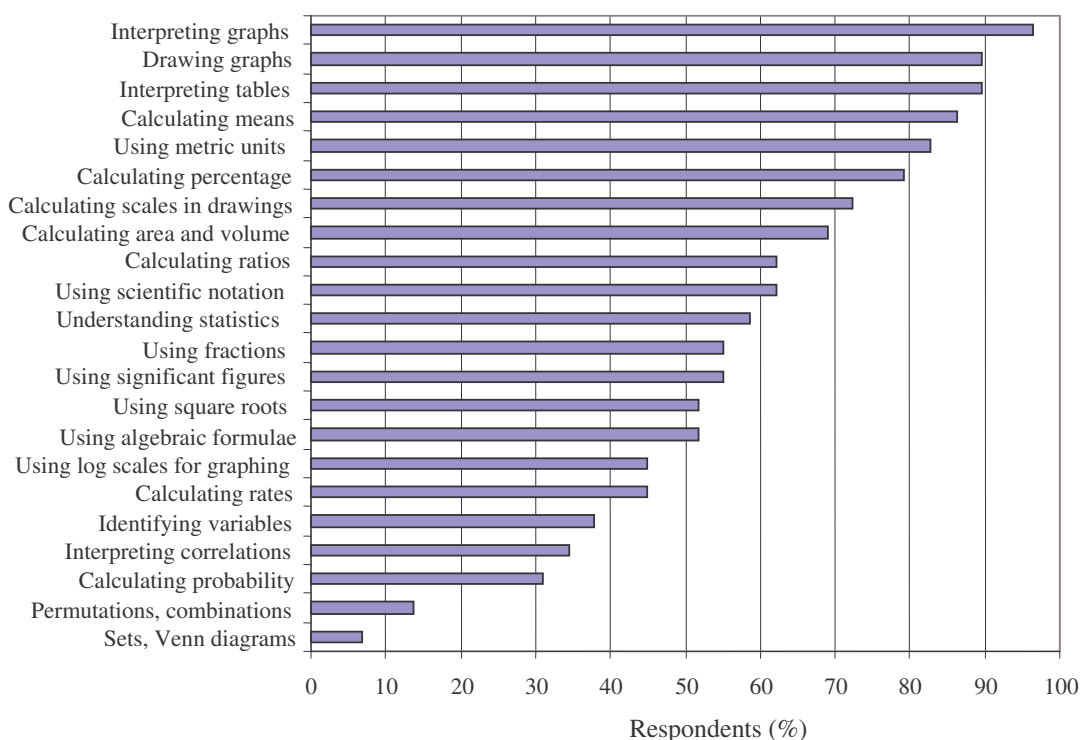
The comments reflected above suggest that although mathematics is not required for all parts of every course, or even for all introductory biology courses, it is a necessary component of at least some courses. Some faculty also indicated that it becomes more important at higher levels of study in content areas like ecology. Several of the student lecture manuals that were examined included copies of previous year’s test questions. Analysis of these tests revealed that a considerable proportion of the practical tests required mathematical manipulation (for three cell biology courses where past tests were available, the mathematical component of the laboratory tests was between 26% and 46%; for the plant and animal biology course where past tests were available, mathematics accounted for 37% of the laboratory component). This suggests that although some faculty did not specifically require understanding of mathematical concepts in order for students to understand their topics, mathematics does form a significant component of several laboratory activities, and is consequently tested in assessment tasks.

Many of the participants commented on the wide variation in students’ mathematical abilities, as well as the tendency for some students to be very fearful of maths. For example, Barry said: “Students are divided into two populations: One that is scared, turned off by, any mathematical or chemical or physical explanation of biological phenomena, and the other that isn’t.” Sarah similarly commented: “Usually it’s not that the maths is difficult ... it’s just an initial panic that it is maths and that maybe they can’t do it.” These comments from faculty suggest that they do not consider the mathematical skills that are required as being very complex. Simon was explicit in pointing this out: “It’s helpful if they have anything arithmetical, and I stress *arithmetical* rather than *maths* ... can they add and divide and rearrange an equation?” Chris also commented: “Nothing that we give them requires more than the four functions – addition, subtraction, multiplication, division – and yet they still pretend it’s too complicated.”

Twenty-nine of the 35 interviewees were given a list of mathematical skills and asked to tick those that they expected students to be familiar with before starting a first-year biology course. The results are presented in Figure 4.2 and show that more than 80% of the respondents assume students are able to draw graphs; interpret graphs and tables; calculate means; and use metric units (e.g., millimeters and micrometres). Between 50 and 80% of respondents considered it to be important for students are able to use algebraic formulae, square roots, significant figures, fractions, and scientific notation; understand statistics; calculate area and volume; and calculate scales in drawings. Some of these are discussed below in more detail.

### Tables and Graphs

Figure 4.2 shows that the mathematical skills faculty considered to be most important for students entering introductory biology courses were the ability to



**Figure 4.2**  
Mathematical skills considered by faculty to be important for students entering introductory biology courses (n=29)



interpret graphs (97% of interviewees), interpret tables (90%), and draw graphs (90%). However, only 38% indicated that it was important for students to be able to identify independent and dependent variables.

Of the 12 laboratory manuals that were studied, 10 included activities where students were required to graphically present experimental results obtained as part of their laboratory work. However, only one manual included guidelines on drawing graphs as an appendix. Three courses also required students to calculate the gradient of a line graph, with none of these providing instructions on how to do so. Six laboratory manuals included activities which required students to interpret graphs.

These data strongly suggest that faculty assume students participating in introductory-level biology courses can construct and interpret graphs. Sarah observed that it is also important for students to keep in mind the explanatory purpose of the graph: “I often find that you get very involved in the small picture – gathering information from the lab results, putting it on a graph and making sure that the axes are labeled right ... they get so involved that they don’t know why they’re doing the graph in the first place.” Kristina similarly said students should know “Which graphs are appropriate to use when.” Although 45% of faculty participants indicated that they expect students to be able to use a log scale for graphing, construction of a log graph was only required in two of the 12 laboratory manuals studied, and interviewees involved in the laboratory component of these courses said that students are taught how to do this during the relevant laboratory classes.

#### Calculations and Manipulating Algebraic Formulae

Like graphing, many faculty indicated that students should be able to carry out calculations using fairly simple algebraic formula, including calculating: mean values (86%); percentages (79%); scales for diagrams (72%); area and volume (69%); ratios (62%); and rates (45%).

These responses were consistent with requirements in the laboratory component of the first-year biology courses that were investigated. Of the 12 laboratory manuals that were analysed, six (50%) required students to calculate means; seven (58%) to calculate percentages; 10 (83%) to calculate the size of specimens examined using a microscope; four (33%) to calculate scales (for specimen drawings); four (33%) to calculate area or volume (where the formula for volume was given); four (33%) to calculate ratios; and three (25%) to calculate rates.

Faculty also thought it was important for students to be able to use and convert metric units (e.g., converting millimetres to micrometres) (83%), scientific notation (e.g.,  $0.000037 = 3.7 \times 10^{-5}$ ) (62%), and square roots (52%). Of the 12 laboratory manuals that were studied, nine (75%) required students to convert between millimetres and micrometres, and three (25%) specifically required students to use indices, powers of 10, and scientific notation. Participants commented in particular on student difficulty with working at the microscopic level and converting from millimetres to micrometres. As Matthew reported: “We could sit down and teach them those things, but I just don’t see that as our job.”

Although only 52% of participants said that being able to use algebraic formulae and rearrange equations was important, nine of the 12 laboratory manuals (75%) included activities where students were required to use mathematical formulae (e.g., to calculate the number of spores in a sporangium). Faculty who were directly involved in teaching these laboratory courses indicated some frustration that students were not better equipped to do this, suggesting that some prior knowledge was assumed. As Candice reported: “I even had to do up a little sheet that I handed out in the lab about how to rearrange equations ... I couldn’t believe the number of students who didn’t know.”

Besides the laboratory components of the courses, algebra is also introduced in the context of evolution and the Hardy-Weinberg theorem.<sup>13</sup> Several faculty who teach this section referred to student difficulty with understanding the nature of the mathematical equations and again suggested that some prior knowledge was required. For example, Aaron observed: “As I put a quadratic equation on the board, they seem to get overwhelmed.” Angela similarly reported: “They do have a lot of trouble simply with the mathematical nature of the theorem.” Doug said that his approach is to work through “an example that was in the textbook so that they could go back to it if they were having trouble.” He also reported that he deliberately does not include any mathematical questions on this work in the exam, unlike at least two of the other universities.

To summarise, the findings reported above suggest that students are expected to be able to calculate: percentage, area and volume, ratios, rates, and scales for diagrams prior to participating in first-year biology courses. Students are also expected to be able to manipulate algebraic equations to calculate the value of an unknown variable. Use of square roots, scientific notation and conversion within the metric system is sometimes required to complete these mathematical tasks correctly. Quadratic equations are also introduced in the theoretical component of first-year biology courses, in the context of the Hardy-Weinberg theorem, and students appear to have difficulty with this topic, ostensibly because of their mathematical backgrounds which are perceived by faculty to be inadequate.

### Statistics

In addition to the mathematical skills already described, 52% of the 29 faculty presented with the list of mathematical tasks indicated that students should have some understanding of statistical testing. Four of the 12 laboratory manuals that were studied included activities where students were required to statistically evaluate results (e.g., compute a Chi-square test or students *t*-test). In all these cases a worked

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<sup>13</sup> The Hardy-Weinberg theorem is a quadratic equation used to describe the frequency of alleles (gene variants) in a population at equilibrium.

example was provided for students to refer to, as well as an explanation of the importance of statistical testing. However, carrying out each test requires students to be able to use and manipulate algebraic formulae (see above).

The concept of probability was considered by the majority of participants not to be very relevant. Of the 31% who said that it was required, all were involved with teaching Mendelian genetics. As Kerry explained: “I did expect some basic probability calculations for heredity and the likelihood of inheriting a particular molecular disease.”

It appears that although statistical analysis is required for some laboratory activities, the tests are described in detail, presumably for the benefit of students with little prior knowledge. However, there is the assumption that students will be able to use the algebraic formulae that are described. Students are also required to have some understanding of probability calculations in the context of Mendelian-type problem solving.

#### **4.6 CHAPTER SUMMARY**

The data presented in this chapter represent an extensive survey of faculty views regarding the prior knowledge of students entering introductory-level biology courses at university, and the concepts that students are assumed to be familiar with. Many faculty spontaneously reported an increasing diversity in prior knowledge of students, and indicated that this made teaching a challenging task, with the need to “start from scratch” on the one hand to accommodate students with more limited prior knowledge, and the risk of boring students with more extensive prior knowledge on the other.

Despite indicating that they assumed very little prior knowledge, a list of concepts students were required to understand was identified. These included not only specific biological concepts (e.g., the hierarchical nature of the classification

system, the cellular basis of life, DNA, and the significance of photosynthesis and cellular respiration); but also chemical concepts (e.g., atoms and molecules, bonding, the use of chemical symbols, and redox reactions), and mathematical skills (e.g., constructing and interpreting graphs, carrying out algebraic calculations, and using metric units and scientific notation). In addition, a very general understanding of overarching themes like evolution and the scientific method is required because of the pervasive reference to these concepts throughout the first-year biology courses. There was also evidence that while some concepts are specifically taught, they are often referred to without explanation in other parts of the course, or in other first-year courses. This strongly suggests the need for students to be able to make links between concepts covered in different topics. Rapid coverage of content and extensive use of biology-specific terminology was also considered to be likely to make introductory-level courses difficult for students with more limited background knowledge, and there was some evidence that faculty may sometimes assume more prior knowledge than they realise.

The data presented in this chapter were used to construct a 'prior knowledge questionnaire', which was used to investigate students' actual prior knowledge, as described in Chapter 5.

# **Chapter 5**

## **An Exploration of Students' Prior Knowledge**

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### **5.1 INTRODUCTION**

Chapter 4 reported on faculty views of prior knowledge as it relates to students entering first-year biology courses at university, and provided a list of key concepts that faculty assume students understand prior to participating in these courses. These data were used to construct a prior knowledge questionnaire that was administered to students during the first week of a first-year biology course at one university in March 2003 (see Appendix D). A second prior knowledge questionnaire (Appendix F) was administered to a different cohort of students in March 2004. This questionnaire was similar to the one administered the previous year, except that minor modifications were made in order to probe responses to the 2003 questionnaire in more detail, and in a few cases to improve the clarity of the

questionnaire items. Response rates were 80% in 2003 and 63% in 2004. A detailed description of the questionnaire development and administration is presented in Section 3.4.2. The purpose of administering the questionnaire on two occasions in successive years was to provide data triangulation, providing a check that responses were not specific to a particular cohort of students.

This chapter reports on the findings from the questionnaires. Responses were grouped by categories that emerged from the data (Lewis & Kattmann, 2004; Patton, 2002; Taylor & Bogdan, 1998) and subsequently classified by a panel of experts<sup>14</sup> as being scientifically acceptable or as representing alternative conceptions. The data are supported by follow-up interviews with a cohort of students.

Analysis of the questionnaire results revealed three themes (Bunting, Campbell, & Coll, 2003):

- students with more extensive prior biology study were more likely to provide scientifically acceptable answers to some questions (e.g., those relating to specific biological concepts, like classification of animals, transport structures in plants, and concepts like cells, DNA, chromosomes, and genes);
- the extent of prior biology study did not appear to be correlated with student understandings of other concepts (e.g., those relating to the hierarchical nature of biological systems of classification, the role of energy in living organisms, and some mathematical and chemical concepts); and
- very few students, regardless of prior biology study, were able to demonstrate links between concepts and an understanding of the ‘bigger picture’.

These themes are discussed in Sections 5.3, 5.4, and 5.5 respectively. Section 5.2 describes the academic background of students. Because of the number of concepts included in the questionnaires, the findings for some questions have been omitted.

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<sup>14</sup> The panel of experts consisted of two tertiary biology tutors and two biology school teachers (see Section 3.4.2).

## 5.2 ACADEMIC BACKGROUND OF STUDENTS

In order to investigate possible correlations between student responses to questionnaire items and the extent of prior biology study, the first question of both the 2003 and 2004 questionnaires asked respondents to indicate the highest level of biology that they had studied prior to enrolling in the first-year biology course in which the questionnaire was administered. The following options were provided:

- Year 11 science
- Year 11 human biology
- Year 12 science
- Year 12 biology
- Year 12 human biology
- Year 13 science
- Year 13 biology
- Year 13 human biology
- Bridging course<sup>15</sup>
- Other<sup>16</sup>

The results for the two cohorts (2003 and 2004) are presented in Figure 5.1. Perhaps the most striking observation is that only approximately 50% of the cohort had completed Year 13 biology (48% in 2003; 53% in 2004). However, a further 10% (both cohorts) had completed a bridging course; and 10% (2003) or 20% (2004) had already completed a tertiary-level biology course.

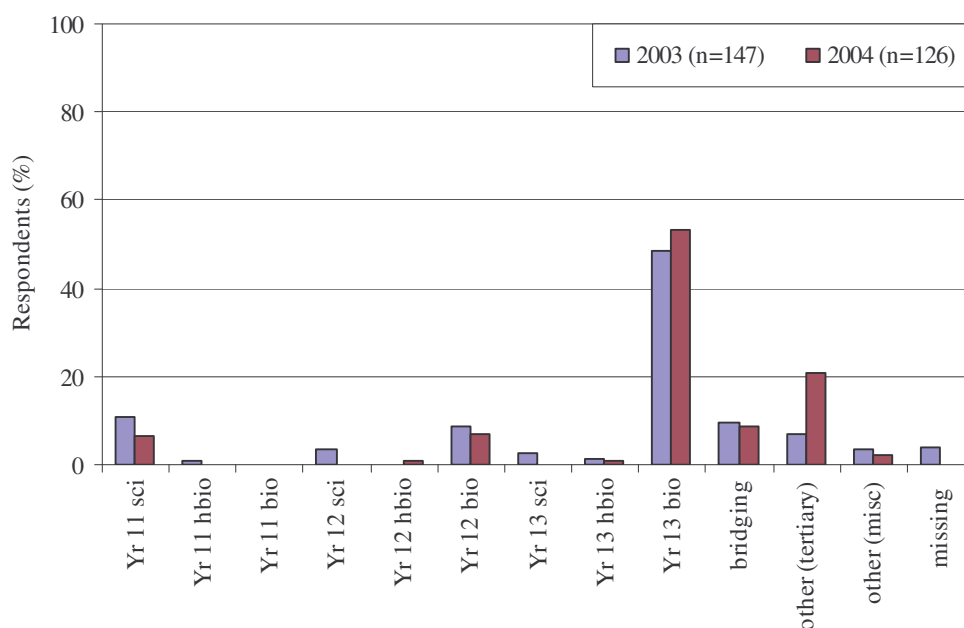
Because one of the aims of the prior knowledge questionnaire was to identify differences in prior knowledge associated with the level of previous biology studied, respondents were separated into a cohort that had what was considered to be a more extensive level of prior biology study ('high bio'), and a cohort who had undertaken

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<sup>15</sup> Although the first-year biology courses at the university at which the questionnaires were administered do not have a prerequisite requirement for prior biology study, several bridging courses are available and students with limited school science are encouraged (but not required) to participate in these courses prior to undertaking degree-level study in the sciences. The courses range in length from 27 to 65 hours of teaching time and are offered at various stages throughout the year (summer school, A semester, B semester, and full year).

<sup>16</sup> The "other" category was separated during analysis into students who indicated that they had very little prior biology experience, or that it "was a long time ago"; and those who had completed a tertiary-level biology course.





**Figure 5.1**

Biology background of students who completed the prior knowledge questionnaire

Note: 'hbio' represents human biology; 'other (misc)' represents students who reported that they had done very little biology, or that they had studied it a long time ago (e.g., one student wrote "My studies were >25 years ago and seem irrelevant now").

more limited prior biology study ('low bio'). Students were divided into these two groups as detailed in Table 5.1. As can be seen, 63% of students in the 2003 cohort were considered to have undertaken more extensive prior biology study, compared with 82% in the 2004 cohort. The difference between the two years appears to be mainly due to the higher proportion of students who had completed a tertiary biology course prior to enrolling in the 2004 course in which the questionnaire was administered. There was no obvious explanation for why the number of these students had increased in 2004 when compared with 2003, and the difference may simply reflect fluctuations in the nature of the sample who completed the questionnaire in each administration.

To summarise, although the majority of respondents had completed a Year 13 biology course or its equivalent, a large proportion (34% in 2003; 18% in 2004) had

**Table 5.1**

Classification of questionnaire respondents into 'high bio' and 'low bio' cohorts (n=147, 2003 questionnaire; n=126, 2004 questionnaire)

'High bio'	2003	2004	'Low bio'	2003	2004
Year 13 biology completed in 1997 or later <sup>A</sup>	46%	52%	Year 11 science or human biology	12%	6%
Bridging biology course <sup>B</sup>	10%	9%	Year 12 science, biology or human biology	12%	8%
Other tertiary	7%	21%	Year 13 science or human biology	4%	1%
			Year 13 biology completed before 1997	2%	1%
			Other (misc.) <sup>C</sup>	4%	2%
<b>TOTAL</b>	<b>63% <sup>D</sup></b>	<b>82%</b>	<b>TOTAL</b>	<b>34%</b>	<b>18%</b>

<sup>A</sup> In 1997 the Year 13 biology curriculum was changed to include additional concepts related to genetics and biotechnology.

<sup>B</sup> Analysis of curriculum content showed that the bridging courses were designed to include concepts similar to those that students would have been exposed to had they completed Year 13 biology at school.

<sup>C</sup> Several students reported that they had done very little biology, or that they had studied it a long time ago (e.g., one student wrote "My studies were >25 years ago and seem irrelevant now"). These students were placed in the 'low bio' category.

<sup>D</sup> Data on prior biology study were missing for five students (3%) in 2003.

not. These latter students were considered to have more limited prior background in biology and were placed in the 'low bio' category. The proportion of students in this category would have been even higher if bridging courses had not been available for students who had a more limited biology/science background.

The responses to questionnaire items, detailed below, were analysed according to student background ('high bio' and 'low bio') to determine whether students with more extensive prior biology study are more likely to be familiar with the concepts that faculty deem to be important prior knowledge for candidates participating in first-year biology courses. Statistical analysis was based on Chi-square tests for independence between the two cohorts.

### **5.3 PRIOR BIOLOGY STUDY AFFECTS STUDENT UNDERSTANDING OF SOME CONCEPTS**

Students with more extensive prior study in biology were statistically more likely to provide scientifically acceptable answers to some questionnaire items than those with more limited prior study. Unsurprisingly, these items tended to relate to specific biological concepts, such as ‘animals’ as a classification group; transport structures in plants; cells, DNA, chromosomes and genes; and Mendelian-type inheritance problems.

#### ***5.3.1 Classification of Animals***

In biology, a hierarchical classification is used to classify living organisms. According to Whittakers’ five-kingdom system, which is introduced at secondary school (Bayley, 2000), organisms can be classified into five kingdoms: animals, plants, fungi, protists or monera. A more modern view, introduced in first-year biology courses, separates monera into two distinct domains (i.e., bacteria and archaea), and protista into five or more distinct kingdoms (Campbell & Reece, 2002). Each organism can further be classified into a phylum (or division), class, order, family, genus, and species; ‘kingdom’ is the most inclusive taxonomic grouping, and ‘species’ is the most exclusive. In phase 1 of the research, faculty indicated that they assume students are familiar with “the main kingdoms” and the hierarchical nature of the classification system (see Section 4.5.1).

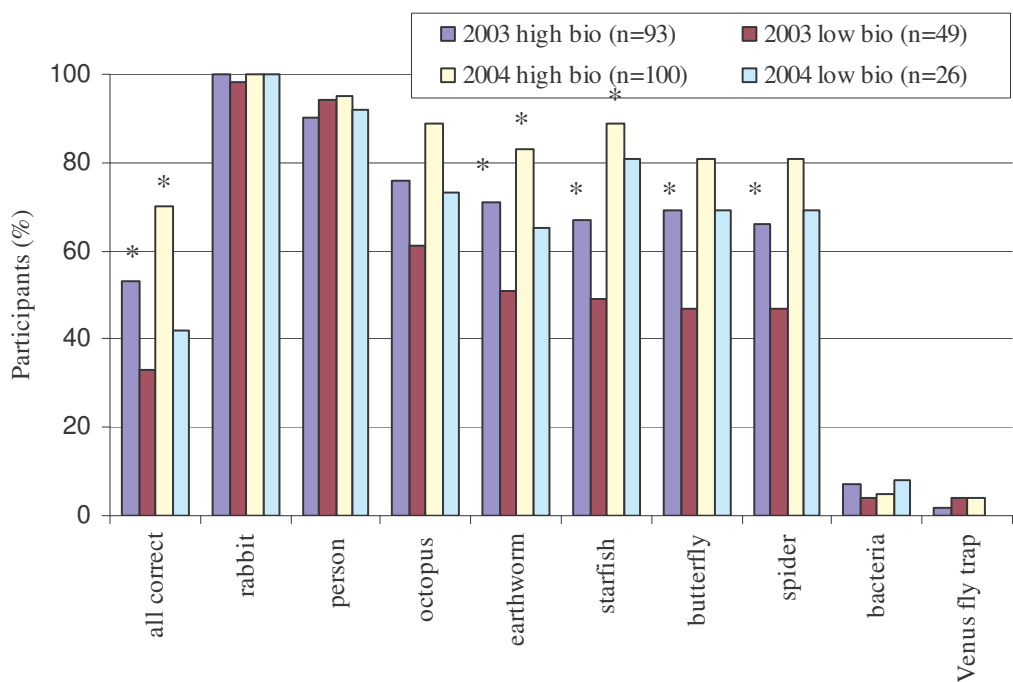
In order to investigate students’ understanding of classification of living organisms into kingdoms, students were provided with a list of organisms (earthworm, rabbit, starfish, spider, bacteria, octopus, person, Venus fly trap and butterfly) and asked to indicate the ones that “could be called animals” (Question 1, 2003 and 2004 questionnaires). The most scientifically acceptable answer was considered to be one that included person, rabbit, and all the invertebrates (i.e., earthworm, spider, starfish, octopus and butterfly).

Only 45% of the 2003 cohort correctly identified all the invertebrates as animals, with 19% considering only rabbits and people (i.e., mammals) to be animals. This is despite the fact that the questionnaire was administered *after* the first lecture in which systems of classification had been introduced, albeit briefly. At least some of the students had also had a second lecture, in which key features of one of the less complex invertebrate animal phyla, porifera (sponges), had been introduced.

In 2004, a larger proportion of students (64%, compared with 45% in 2003) correctly selected all the invertebrates as animals. This difference between the 2003 and 2004 cohorts was statistically significant ( $p < 0.05$ , based on a Chi-square test for independence) and may be partly due to changes that the lecturer had made as a result of seeing the responses to the previous year's prior knowledge questionnaire. Specifically, she incorporated additional slides (using Microsoft PowerPoint) on the diversity of each of the kingdoms, including slides that showed images of sea anemones, starfish, rabbits and fish as being part of the animal kingdom (her original slide, used in 2003, used an image of a shark to represent this kingdom). The lecturer also replaced her textbook images of the different classification systems with a more interactive lecture where she asked students to contribute to the discussion by asking them to name the different kingdoms and give examples of each.

Students in both cohorts (2003 and 2004) who had more extensive prior biology study were more likely to identify all the invertebrates as animals, when compared with students with more limited prior study in biology (see Figure 5.2). This difference was statistically significant ( $p < 0.05$ , based on a Chi-square test for independence).

Subsequent interviews in 2004 with 10 students who did not identify all the invertebrates as animals provide insights into the potential importance of these findings. The interviews were conducted after four lectures on animal diversity. Students had also completed a laboratory assignment in which they were required to list the main characteristics of nine animal phyla (including eight invertebrate phyla).



**Figure 5.2**  
Student classification of organisms as ‘animals’

Note: Statistically significant differences between the ‘high bio’ and ‘low bio’ cohorts in each year are represented by an asterisk ( $p < 0.05$ , based on a Chi-square test for independence).

Kevin explained that he initially considered just ‘rabbit’ and ‘person’ to be animals because: “I’d always associated animals with fluffy things.” However, he indicated that after attending the lectures on animal diversity he would change his response to include all the invertebrates listed. Tammy similarly indicated that she had broadened her understanding of what an animal is: “I wasn’t sure what you actually meant by ‘animals’, like whether you meant insects and stuff as well, but we covered that in the first couple of lectures.” However, three of the 10 students continued to consider some of the invertebrates as not being ‘animals’. For example, Nicole commented: “Now that I’ve done some biology I think I’m even more confused. I think I wouldn’t have ‘octopus’ ticked any more, I’d just have the other two [rabbit and person].”

In summary, responses to this questionnaire item suggest that a large proportion of students did not consider one or more of the given invertebrates to be animals, despite explicit attempts by the lecturer in 2004 to address this. Students

with more extensive biology knowledge were more likely to consider invertebrates to be animals, although a large proportion (30% in 2004) did not do so. Some students explicitly indicated in interviews that the lectures on animal diversity had not changed their views.

### ***5.3.2 Transport Structures in Plants***

A second area of difference between students with different levels of prior biology study concerned student knowledge of transport structures in plants (i.e., xylem cells transport water and dissolved inorganic chemicals, and phloem cells transport organic products from photosynthesis). Whilst several faculty reported that they would introduce and specifically explain these concepts when teaching plant anatomy, they also indicated that the topic is terminology-rich and that lecture time allocated to this topic is limited (see Section 4.5.1).

In order to probe students' knowledge of xylem and phloem, a question in the 2003 questionnaire asked students to name the tissue that is used to transport substances like water and sugars in plants (question 11). The results showed that students who had completed more extensive prior biology study were more likely to provide a response referring to xylem and/or phloem (65%, n=92) when compared with those who had completed more limited prior biology study (26%, n=47). This difference was statistically significant ( $p < 0.01$ , based on a Chi-square test for independence).

Because the 2003 question relied on students being able to remember specific terminology, the question was reworded in the 2004 questionnaire to ask "What is xylem?" This time, although students with more extensive prior biology study were more likely to provide an answer that referred to plant transport (53%, n=98) than those with more limited prior biology study (32%, n=25), the difference was not statistically significant ( $p > 0.05$ ). This is possibly because the phrasing of the question requires students to be familiar with both the term xylem, and its meaning.

Although these questions relied on student memory rather than understanding, the findings suggest, as might be expected, that students with more extensive prior biology study may be more familiar with terms associated with plant anatomy, such as xylem and phloem. This has implications for students with less extensive prior study when faced with the number of new terms introduced in lectures on plant anatomy in first-year biology courses.

### **5.3.3 *Cells, DNA, Chromosomes, and Genes***

A third content area where students with more extensive prior biology study seemed to hold more scientifically acceptable views than students with more limited prior biology study relates to biological concepts like cells, DNA, chromosomes, and genes. These concepts form the basis of many of the topics included in both cell biology and animal and plant biology courses (e.g., chromosomes are referred to when teaching about plant life-cycles). Having more extensive prior biology study also appeared to affect students' confidence regarding their ability to answer questions related to these concepts.

In order to investigate the students' confidence in their understanding of each of the concepts (cells, DNA, chromosomes and genes), the questionnaire items that probed students' understandings of these concepts included a question that asked respondents to indicate whether they:

- have heard of [the concept]
- have heard of [the concept] but do not really know what [the concept] is
- have heard of [the concept] and can say something about [the concept].<sup>17</sup>

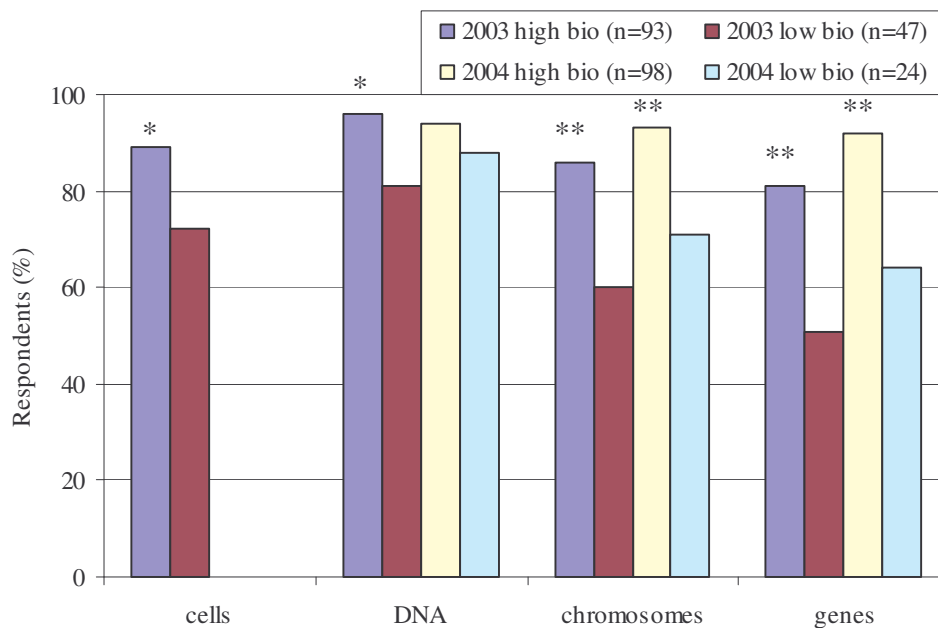
In each case (both the 2003 and 2004 questionnaires), less than 3% of respondents indicated that they had never heard of one or more of the concepts. The rest of the respondents indicated that they had either heard of each of the concepts, but were unsure what they mean; or they had heard of the concepts and could say

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<sup>17</sup> This question was used by Lewis, Leach, and Wood-Robinson (2000) and was included because of faculty's perceptions that some students do not pay attention in topics related to DNA because "they think they know it all already" (see Section 4.4).

something about them. The responses for the students indicating they had heard of the concept and could say something about it were analysed according to student background ('high bio' and 'low bio'), and the results are presented in Figure 5.3. Chi-square tests for independence showed that students with more extensive prior biology study were more likely to indicate confidence in being able to answer questions about cells, DNA, chromosomes, and genes ( $p < 0.05$ ).

Responses to specific questions are summarised in Table 5.2 and are discussed below in more detail. The majority of students demonstrated a scientifically acceptable understanding of cells as being the basic component of living organisms; and that DNA is found in all human cells. They were less clear that all living organisms contain DNA. Questionnaire items related to the location and



**Figure 5.3**

The effect of student background on student confidence regarding questions related to cells, DNA, chromosomes, and genes

Note: Statistically significant differences between the 'high bio' and 'low bio' cohorts in each year are represented by asterisks (\* $p < 0.05$ ; \*\*  $p < 0.01$ , based on Chi-square tests for independence).



**Table 5.2**

Student responses to questionnaire items relating to cells, DNA, chromosomes, and genes (n=143, 2003 questionnaire; n=119, 2004 questionnaire)

Question	Findings	Year	Scientifically acceptable responses 'High bio' versus 'low bio' (%)
Describe a cell	78% - biological units, reference to specific structural features	2003	83 : 70
Where are cells found?	88% - everywhere, all body parts, tissues and organs	2003	95 : 83
	85% - all body parts (multiple choice)	2004	86 : 81
Where is DNA found?	91% - everywhere, in cells, in genes / chromosomes (open-ended)	2003	52 : 15 ** (DNA is in the nucleus)
	92% - all cells (multiple choice)	2004	92 : 92
Which organisms contain DNA?	58% - all organisms listed (multiple choice)	2003	63 : 49
	63% - all organisms listed (multiple choice)	2004	65 : 54
Where are chromosomes found?	77% - DNA, nucleus, all cells (open ended)	2003	84 : 63 **
	76% - all cells, including those involved in reproduction (multiple choice)	2004	85 : 42 **
Are chromosomes bigger than genes?	77% - yes	2004	81 : 60 *
Where are genes found?	71% - cells, DNA, chromosomes, nucleus (open-ended)	2003	79 : 54 **
	71% - all cells, including those involved in reproduction (multiple choice)	2004	76 : 52 *
What are genes used for?	53% - code (for proteins <i>or</i> personal characteristics) (open-ended)	2003	60 : 36 *
	73% - code (for proteins <i>or</i> personal characteristics) (open-ended)	2004	73 : 32 **
Where do proteins come from?	58% - protein synthesis <i>or</i> proteins are "made in cells" (open-ended)	2004	65 : 40 *

Note: Statistically significant differences between 'high bio' and 'low bio' cohorts are represented by asterisks (\* $p < 0.05$ ; \*\* $p < 0.01$ , based on Chi-squared tests for independence).

function of chromosomes and genes were also generally less well answered. Students with more extensive prior biology study were more likely to provide scientifically acceptable responses to the questions than students with more limited prior biology study. More detailed analysis of responses to individual questionnaire items is presented below.

### Cells

Student responses to the 2003 questionnaire item asking them to describe a cell (question 16a) included responses referring to:

- Cells as the biological units of living organisms (32%), for example: “Cells are said to be the building blocks of life,” and “[A cell is] a small biological unit that has a distinct function/purpose and forms part of a larger tissue.”
- The structure of cells (38%), for example: “A cell contains a nucleus with cell membrane (and sometimes cell wall), cytoplasm, membrane-bound organelles, and undergoes meiosis/mitosis,” and “A cell is small. It has a nucleus and many other bodies inside it.”
- The inclusion of DNA (8%), for example: “A cell holds genetic information.”

There were no statistically significant differences in responses given by students with more extensive prior study in biology when compared with those who had undertaken more limited prior biology study (based on a Chi-square test for independence,  $p > 0.05$ ). This is interesting, since more students from the ‘high bio’ cohort had indicated confidence in being able to answer questions on cells. Alternative conceptions that were identified included references to cells as micro-organisms (e.g., “Cells are living things which live in plants, animals, etc.”).

In the 2004 questionnaire, the open-ended question investigating student views of where cells are found was changed to a multiple choice question which asked students to indicate from a list of options (skin, heart, lungs, eyes, muscles, and brain) the “parts of a person’s that are made up of cells” (question 6). The results, presented in Table 5.3, show that the majority of students (85%) indicated that all of

**Table 5.3**

Student views of body parts composed of cells (n=125, 2004 questionnaire)

The following body part is composed of cells ...	Respondents (%)
Skin	100
Brain	97
Muscles	93
Lungs	90
Heart	87
Eyes	88
<u>All</u> body parts selected	85

the body parts listed are composed of cells. There were no statistically significant differences between responses from the ‘high bio’ and ‘low bio’ groups of students (86% versus 81%;  $p > 0.05$ , based on a Chi-square test for independence).

Taken together with the results from 2003, the findings suggest that the majority of respondents have some understanding that cells are the basic components of living organisms and, for example, make up all parts of a person’s body. These findings further suggest that faculty assumptions regarding students’ prior knowledge of cells as building blocks of living organisms are probably justified.

The questions about DNA similarly indicated that the majority of students had some understanding about the location and role of DNA in living organisms (in a general sense), as described below.

### DNA

As has already been noted (see Figure 5.3), a large proportion of students (87% in 2003; 93% in 2004) indicated that they had heard of DNA, and felt that they could say something about it.

When asked “Where is DNA found in your body?” in the 2003 questionnaire (question 16b), 8% of respondents (n=143) indicated “everywhere”; 19% indicated

“in cells”; 40% specified the nucleus; 24% referred to chromosomes or genes; and 9% did not answer the question. Students who had completed more extensive prior study in biology were statistically more likely to specify that DNA is found in the nucleus (52% versus 15%;  $p < 0.01$ , based on a Chi-square test for independence).

In the 2004 questionnaire, the question about the location of DNA was modified to specifically investigate the prevalence of some of the alternative conceptions revealed in response to the 2003 question (e.g., that DNA is only found in certain cells) using a multiple choice format:

Where is DNA found in your body?

- In all cells involved in reproduction, but in no other cells
- In the sex cells (eggs and sperm) only
- In all cells, including cells involved in reproduction
- In cells involved in reproduction and a few other cells
- Other: \_\_\_\_\_
- Don't know / not sure

Of the respondents, 92% considered DNA to be found in all cells. There were no significant differences in responses between the ‘high bio’ and ‘low bio’ cohort of students (92% for both cohorts).

A separate questionnaire item related to the presence of DNA in a range of living organisms (algae, mammals, ferns, fungi, bacteria, insects, tomatoes, and genetically modified tomatoes), and students were asked to indicate whether each one contains DNA (question 17, 2003 questionnaire; question 19, 2004 questionnaire<sup>18</sup>).

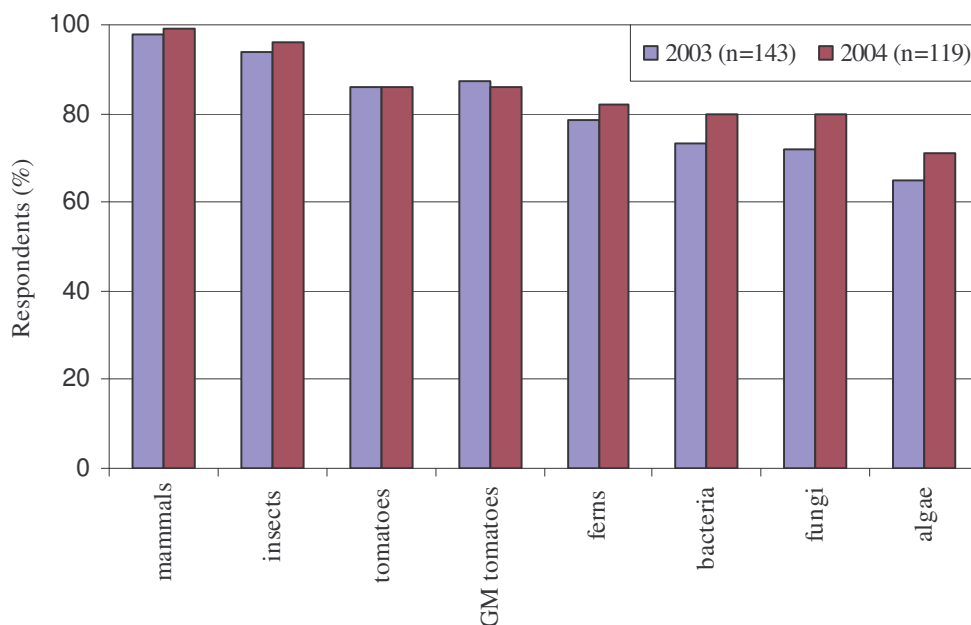
Less than two-thirds of students (58% in 2003; 63% in 2004) indicated that DNA is found in all of the organisms listed. Specifically, students were less likely to consider that organisms such as ferns, fungi, algae and bacteria contain DNA (see

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<sup>18</sup> This question was used by Lewis, Leach, and Wood-Robinson (2000) to investigate high school students' understanding of the nature of genetic material after being taught a unit on genetics. Tomatoes, genetically modified tomatoes and algae were added here in response to faculty reports that students should understand that all these organisms also contain DNA (Section 4.5.1).

Figure 5.4). In general, there were no statistically significant differences in responses for students with more extensive prior biology study when compared with those who had undertaken more limited prior biology study, except that the ‘high bio’ cohort in 2003 were more likely to indicate that insects, ferns and tomatoes contain DNA ( $p < 0.05$ , based on Chi-square tests for independence).

Taken together, the responses to questionnaire items related to DNA suggest that although the majority of students seem to have a scientifically acceptable understanding of the location of DNA in humans, many are less clear about whether *all* living organisms contain DNA. This has implications for student understanding of the ‘bigger picture’ regarding the importance and role of DNA in all living organisms. The topic of gene expression was not contextualised in the lectures that were observed, and there was no preamble about the widespread occurrence of this process in *all* living cells, suggesting that student understanding of this concept is assumed. However, the findings presented here suggest that this assumption may not be justified.



**Figure 5.4**  
Student views of living organisms that contain DNA

## Chromosomes

After being asked about DNA, students were asked about the location of chromosomes as well as the relationship between chromosomes and genes (question 16c, 2003 questionnaire; 18b 2004 questionnaire). In the 2003 questionnaire, an open-ended question was used: “Where are chromosomes found in your body?” The majority of students referred to DNA (15%), the nucleus (41%), or all cells (17%). Eighteen percent did not respond to this question, although they did complete related questions. Only 8% of responses were identified as alternative conceptions: that chromosomes are found in genes (4%) and in sexual organs only (4%).

The probe exploring student understanding of chromosome location was consequently modified in the 2004 questionnaire to investigate the prevalence of alternative conceptions regarding the types of cells that contain chromosomes:

Where are chromosomes found in your body?

- In all cells involved in reproduction, but in no other cells
- In the sex cells (eggs and sperm) only
- In all cells, including cells involved in reproduction
- In cells involved in reproduction and a few other cells
- Other: \_\_\_\_\_
- Don't know / not sure

The various options were included to specifically investigate student understanding of the presence of chromosomes in different cell types, given that the majority of respondents in 2003 (73%) had indicated that chromosomes are found in cells. Only 76% (n=122) correctly indicated that “all cells, including cells involved in reproduction” contain chromosomes.<sup>19</sup> Students with more extensive prior biology study were more likely to select this option (85%) when compared with students with more limited prior biology study (42%) ( $p < 0.01$ , based on a Chi-square test for independence).

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<sup>19</sup> Red blood cells do not contain chromosomes when mature. However, this option was not included because of the concern it could cue students to the expected answer. Six percent of students selected “other” and indicated that chromosomes are found in all cells except red blood cells; their responses were grouped with those who selected “all cells, including cells involved in reproduction”.

In order to explore students' understanding of the relationship between chromosomes and genes (some students had indicated in the 2003 questionnaire that chromosomes are found in genes), a question in the 2004 questionnaire asked respondents to indicate whether genes or chromosomes are bigger. Of the respondents (n=121), 77% correctly selected chromosomes as being larger, and again students with more extensive prior biology study were statistically more likely to select this option (81%) when compared with students with more limited prior biology study (60%) ( $p < 0.05$ , based on a Chi-square test for independence). Seventeen percent of students indicated that genes were bigger, and 6% did not respond to the question.

In summary, responses to the 2003 questionnaire item asking where chromosomes are found resulted in some modifications to the questions that were asked in 2004. The responses to these modified questions suggested that just under a quarter of students did not consider chromosomes to be found in *all* human cells, and just over 15% considered genes to be bigger than chromosomes. There may therefore be value in faculty specifically addressing these alternative conceptions when teaching about the function of genes and chromosomes in cells.

### Genes

As well as being asked about the location of chromosomes, students were asked about the location and function of genes (question 16d, 2003 questionnaire; question 18c, 2004 questionnaire).

When presented with an open-ended question asking, "Where are genes found in your body?" in the 2003 questionnaire, the majority of respondents indicated that genes are found in the DNA, in chromosomes, or in the nucleus (62%, n=142), with a further 10% writing that genes are found in cells, or "everywhere". Only 2% referred to genes as being in the sex cells (or gonads) only. Twenty-six percent of respondents did not provide an answer. Of those who had indicated that they were

confident they could answer questions about genes, 91% provided a scientifically acceptable answer.

As with the questions relating to the location of DNA and chromosomes, the question probing the location of genes was modified in the 2004 questionnaire to read:

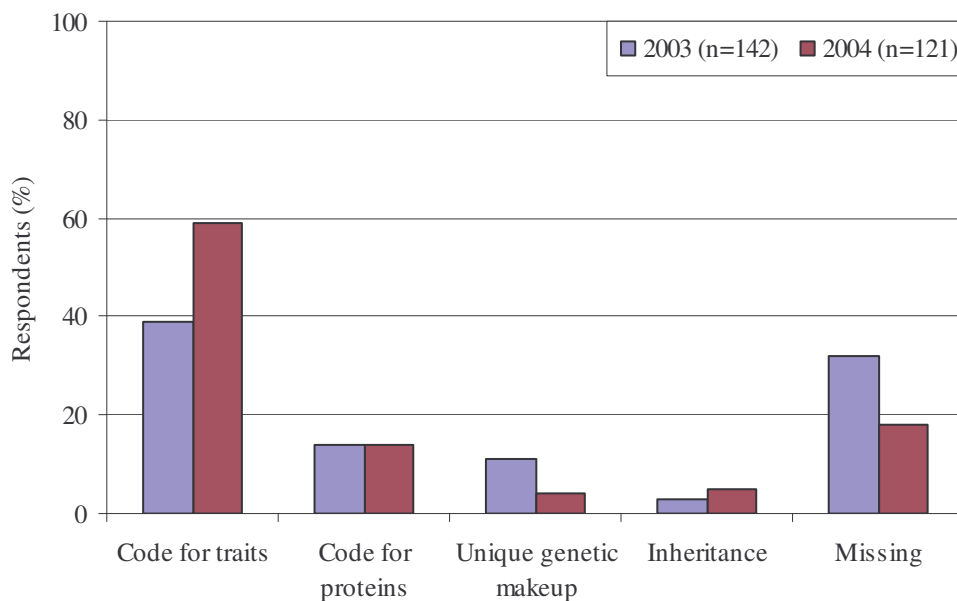
Where are genes found in your body?

- In all cells involved in reproduction, but in no other cells
- In the sex cells (eggs and sperm) only
- In all cells, including cells involved in reproduction
- In cells involved in reproduction and a few other cells
- Other: \_\_\_\_\_
- Don't know / not sure

Responses revealed that only 71% of respondents (n=121) considered genes to be found in all cells. As with the other concepts (DNA and chromosomes), those with more extensive prior biology study were more likely (76%) to select this response than the other students (52%). This difference was statistically significant ( $p < 0.05$ , based on a Chi-square test for independence).

After indicating where genes are found, students were asked in both the 2003 and 2004 questionnaires: "What are genes used for in a person's body?" The results, presented in Figure 5.5, show that less than 15% of respondents (2003 and 2004) specifically referred to the role of genes in coding for proteins, although a large proportion (39% in 2003; 59% in 2004) did refer to the role of genes in coding for specific characteristics or traits. This difference in responses to the 2003 and 2004 administrations of the questionnaires (39% versus 59%) is possibly related to the larger proportion of 'high bio' students responding to the 2004 questionnaire: Students with more extensive prior biology study were more likely to refer to the role of genes as a code (either specifically as a code for proteins, or more generically as a code for individual characteristics) (60% versus 36% in 2003, statistically significant





**Figure 5.5**

Student views of the function of genes in a person's body

at  $p < 0.05$ ; 73% versus 32% in 2004, statistically significant at  $p < 0.01$ , based on Chi-square tests for independence).

When students were asked in the 2004 questionnaire where proteins in cells come from, responses included references to synthesis within cells (e.g., protein synthesis, 28%; amino acids, 12%; DNA, 6%; ribosomes, 7%; and “made within cells”, 5%) and the alternative conception that proteins in cells come directly from digested food (10%). Students with a more extensive biology background were more likely to provide an answer that referred to synthesis within cells (65% versus 40%, statistically significant at  $p < 0.05$ , based on a Chi-square test for independence). Thirty-two percent did not respond to the question, and interview data from six students suggests that this was because they simply did not know the answer.

To summarise, nearly one third of respondents did not appear to consider genes to be found in all cells. A similar proportion were also less likely to associate

genes with a coding role within cells, and only 60% indicated that proteins are made within cells.

Overall, the questionnaire items relating to the location and function of genes and chromosomes were less well answered than items relating to cells and DNA, with the exception being that a large proportion of students (approximately 40%) did not consider all organisms to contain DNA. In addition, a number of students indicated that they felt they could answer questions about each of the concepts (cells, DNA, chromosomes and genes) but did not subsequently go on to provide what were considered to be scientifically acceptable responses. This provides some support for faculty's views that a number of students "think they know it all already, but they don't" (see Section 4.4).

Perhaps not surprisingly, students with more extensive prior biology study were more likely to provide scientifically acceptable responses to many of the questions included in this section of the questionnaires, particularly those related to the more complex concepts of chromosomes and genes. This difference was statistically significant (see Table 5.2 for a summary).

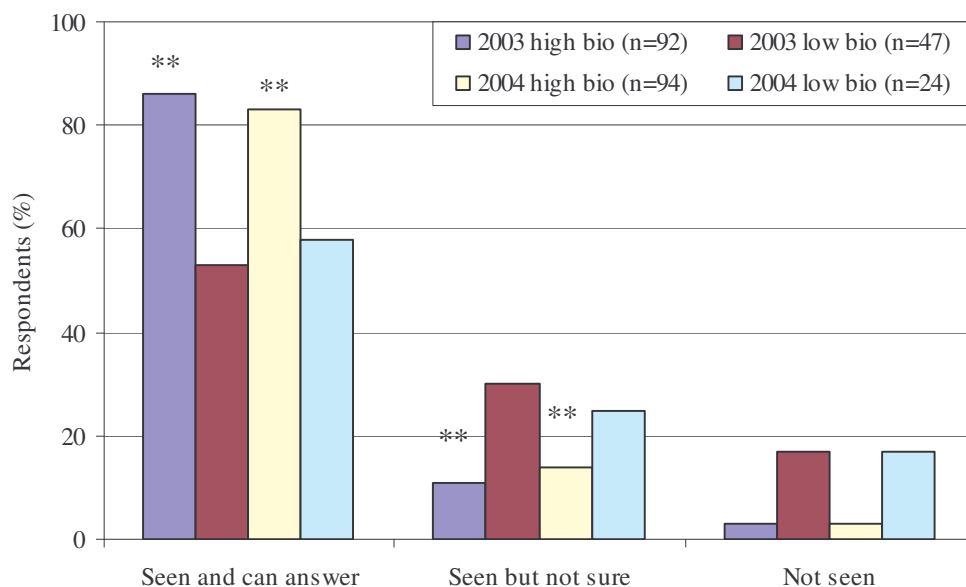
#### ***5.3.4 Mendelian-type Inheritance***

Most sexually reproducing organisms inherit two copies of any particular gene, one from each parent. These two copies are called alleles. Mendelian genetics refers to a type of problem where the outcome of the different allele combinations must be calculated, that is, how the allele combinations (the 'genotype') affect the organism's physical characteristics (its 'phenotype'). The concept is introduced in New Zealand schools in Year 11, with more complicated scenarios introduced in later years of study (i.e., Years 12 and 13).

The type of question posed in the prior knowledge questionnaires (question 18, 2003 questionnaire; question 20, 2004 questionnaire) requires students to use the information provided to determine the genotype of the parents (in this case, two black horses), and then use laws of probability to determine the likelihood that the offspring produced will have a particular phenotype (in this case, a black foal).<sup>20</sup> The question also required respondents to indicate whether they had:

- never seen this kind of problem before
- seen this kind of problem, but did not know how to answer it
- seen this kind of problem and thought they could answer it.

The results, presented in Figure 5.6, show that students with more extensive prior biology study were more likely to indicate that they felt they could answer the



**Figure 5.6**  
The effect of student background on student confidence regarding a Mendelian-type inheritance problem

Note: Statistically significant differences between the ‘high bio’ and ‘low bio’ cohorts in each year are represented by asterisks (\*\* $p < 0.01$ , based on a Chi-square test for independence).

<sup>20</sup> This question is similar to one used by Stewart and Haffner (1994), although here an open-ended form was used as opposed to the closed, multiple choice format used by Stewart and Haffner. This was done to encourage students to show their working, and to reduce the opportunities for respondents to guess the answer.

question (statistically significant,  $p < 0.01$  based on a Chi-square test for independence). Approximately three quarters of respondents (75% in 2003; 78% in 2004) placed themselves in this category, suggesting that the remaining quarter did not feel confident about their understanding of this topic.

Students were also asked to answer the inheritance question if they thought they could do so, and to show all their working. The responses were coded as shown in Table 5.4. In the majority of cases where the working was shown, the responses appeared to have been calculated using an algorithm that is often taught at school as a way of solving this type of inheritance problem (see Figure 5.7a).

**Table 5.4**

Student responses to a Mendelian problem regarding inheritance of coat colour in horses (n=143, 2003 questionnaire; n=118, 2004 questionnaire)

Category	Sub-categories	2003 responses (%)	2004 responses (%)
Scientifically acceptable	Correct working and correct conclusion	51	57
	Correct conclusion but no working	1	3
	Correct working but no conclusion	7	4
	TOTAL	59	64
Alternative conceptions	Working incorrect but conclusion correct	1	1
	Working correct but conclusion incorrect	4	5
	Working incorrect and conclusion incorrect	9	6
	TOTAL	14	12
Missing	Question started but crossed out, or not completed	5	3
	Question not attempted	21	20
	TOTAL	26	23

	B	b
B	BB	Bb
b	Bb	bb

(a)

Chestnut mare = bb  
 Black stallion = Bb or BB

	B	B	or	B	b	
b	Bb	Bb		b	Bb	bb
b	Bb	Bb		b	Bb	bb

therefore all Black foals have characteristic B

2 black foals Bb = BB

	B	b
B	BB	Bb
b	Bb	bb

chance that the foal produced by this mating is black is 75%

(b)

	B/b	
b	Bb	bb
b	Bb	bb

$\frac{1}{2}$  chance of having a black horse

(c)

original horses

	B/b
B	BB
b	B/b

foals

<del>B</del>	B/b
B	BB
B	BB

100% that it will be black

(d)

**Figure 5.7**

The type of algorithm that is commonly used to solve Mendelian-type inheritance problems (a) and examples of student responses (b-d)

Note: In figure (a), the genotypes of possible gametes (represented by the letters 'b' for brown and 'B' for black) from each parent are depicted along the top row and left hand column respectively. The remaining cells represent the various combinations of alleles that are possible after fertilisation, depending on which gametes combine.

Approximately 60% of respondents (59% in 2003; 64% in 2004) were able to provide a scientifically acceptable answer to the question (i.e., they indicated that there was a 75% chance that the foal would be black, and showed how they had calculated this; see Figure 5.7b for an example). That 40% did not provide a

scientifically acceptable response has implications for the teaching of this section in first-year biology courses, where some prior knowledge of the topic is generally assumed (see Section 4.5.1).

As detailed in Table 5.4, some students seemed able to complete the algorithm but not interpret it, possibly suggesting rote learning of how to complete the algorithm without understanding the meaning of the different elements, as has been pointed out elsewhere in the science education literature (e.g., Banet & Ayuso, 2003; Stewart & Haffner, 1994). Other respondents used incorrect parental genotypes (e.g., BB x BB; BB x bb; Bb x bb; see Figure 5.7c for an example) or did not ‘correctly’ compute the algorithm (e.g., Figure 5.7d). These examples suggest misunderstandings about the algorithm and perhaps a lack of understanding that the offspring receive one allele from each parent.

Of the respondents who indicated that they felt they could answer the question (75% in 2003; 78% in 2004), only 79% did so correctly in 2003 (n=104); and only 81% did so correctly in 2004 (n=92). This suggests that approximately 20% of students felt confident that they could answer the question, but then did not do so correctly. Students with more extensive prior biology study were more likely to provide a scientifically acceptable answer to the question (75% compared with 30% in the 2003 questionnaire; 83% compared with 58% in the 2004 questionnaire, both statistically significant at  $p < 0.01$ , based on a Chi-square test for independence).

To summarise, although approximately 80% of respondents indicated that they felt they could answer the question related to inheritance, about 20% of these did not do so correctly. This suggests that faculty views that some students “think they know it all, when they don’t” (see Section 4.5.1) may be justified. Given the extensive coverage of this topic at school it is perhaps not surprising that students with more extensive prior biology learning were more likely to answer the question correctly (statistically significant;  $p < 0.01$ , based on a Chi-square test for

independence). Since Mendelian genetics is one of the few biological topics where faculty indicated they specifically have some expectations regarding student prior knowledge (see Section 4.5.1), the responses to this probe have implications for how valid that assumption by faculty is.

#### **5.4 PRIOR BIOLOGY STUDY DOES NOT AFFECT UNDERSTANDING OF SOME CONCEPTS**

Data presented in the previous section suggests that students with a more extensive background in biology are more likely to provide what a panel of experts considered to be scientifically acceptable responses to several of the questionnaire items, in particular those related to some specific biological concepts. However, responses to a range of other questionnaire items did not appear to be related to the amount of prior biology study that had been undertaken. Examples include student responses to questions relating to hierarchical classification systems, energy requirements of living organisms, and questions relating to mathematical and chemical concepts. Each of these will be expanded on in the following sections.

##### ***5.4.1 Hierarchical Systems of Classification***

Students' views of organisms that are classified in the animal kingdom have already been explored (Section 5.3.1). In order to probe students' understanding of the hierarchical nature of the classification system,<sup>21</sup> question 14 of the 2003 questionnaire asked respondents to select the taxonomic grouping (phylum, class, order, family, genus, species) that "contains the greatest number of different varieties of organisms".

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<sup>21</sup> That is, organisms are grouped into kingdoms. Each kingdom contains several phyla. Each phylum is divided into classes. The classes are divided into orders, and so on.

Just over half the respondents (56%, n=144) correctly selected 'phylum'. There were no significant differences between the students with a more extensive biology background, and those with more limited prior biology study (58% versus 54%;  $p > 0.05$ , based on a Chi-square test for independence).

Twenty-six percent of respondents selected 'species' as the category containing "the greatest number of different varieties of organisms" and three of these students were subsequently interviewed and asked to explain their reasoning. Their responses suggest that they had misinterpreted the question, and reflected the view that there are more species than phyla, rather than the idea that phyla contain a greater number of different types of organisms. For example, Katie said: "There are only so many phylum [sic], but then there's heaps of species." However, she was the only one of the three students to indicate in the interview that she would change her selection from 'species' to 'phylum' saying: "When I think about it now, it [phylum] would include all the different species as well as all the other things." This ambiguity had not been picked up during the pilot study and the question was not included in the 2004 questionnaire. However, the findings do suggest that having completed Year 13 Biology or a bridging course did not appear to have made a difference to students' responses to this question.

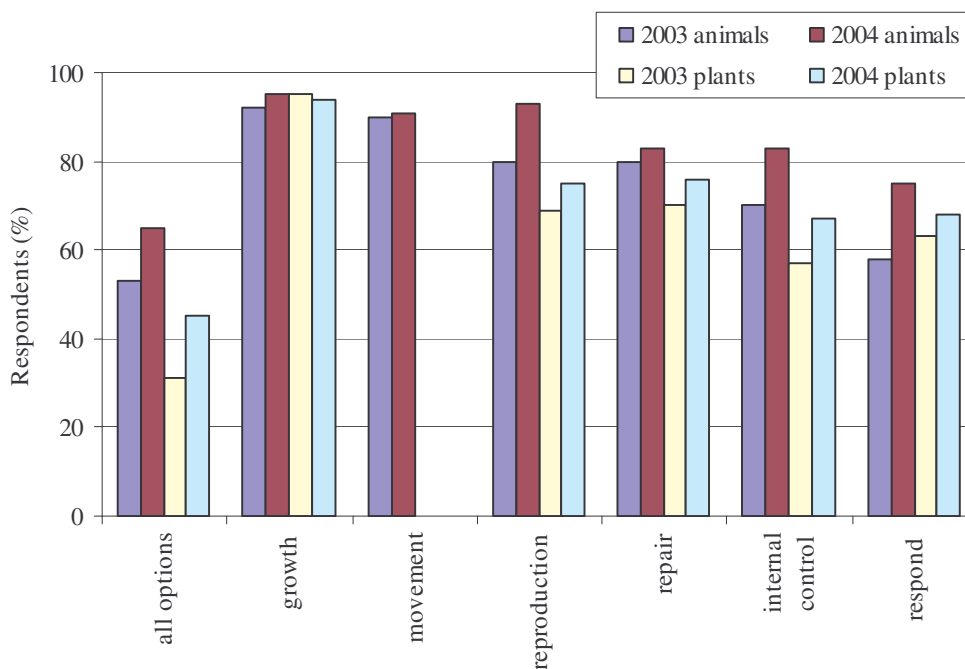
#### ***5.4.2 Living Organisms and Energy***

Cells need to carry out work in order to maintain their complex structure. Energy from external sources is required for cells to be able to do this. Energy enters most ecosystems in the form of sunlight, and plants and other photosynthetic organisms convert this energy into chemical energy via photosynthesis. The energy that is stored in the organic molecules that are produced by photosynthesis can then be released during cellular respiration, when it is used to generate ATP (the molecule that drives most cellular work).



The concept that living organisms require energy is thus fundamental to an understanding of photosynthesis and cellular respiration. In order to probe students' understanding of the plant and animal processes that require energy, students were provided with a list of processes (reproduction, growth, control of internal functions, movement, responding to the environment, and repairing the body). They were then asked to indicate which of these processes require energy (questions 2 and 4 in the 2003 questionnaire; questions 2 and 3 in the 2004 questionnaire).

The results, presented in Figure 5.8, suggest that student understanding of the range of processes requiring energy is limited: only 53% of the 2003 respondents and 65% of the 2004 respondents selected all the processes as requiring energy in animals, with even fewer (31% in 2003; 44% in 2004) indicating that plants require energy for all of the processes. There were no statistically significant differences in



**Figure 5.8**

Student views of animal and plant processes that require energy (n=147, 2003 questionnaire; n=126, 2004 questionnaire)

Note: 'Internal control' refers to the control of internal functions

responses between those who had a more extensive biology background and those who did not ( $p > 0.05$ , based on a Chi-square test for independence).

Subsequent interviews with six respondents revealed that in some cases the difference in responses to the animal and plant requirements was because some students did not think that plants actually carried out all the processes that had been listed. For example, Katie explained in an interview: “I thought because plants most times are in a fixed position so they can’t really respond to the environment.” She had not thought about tropisms (e.g., growth towards light/gravity/water) as examples of plant responses to the environment, or as processes that require energy.

In order to probe students’ understanding of the energy requirements of animals a little further, students were asked in the 2004 questionnaire to select from a list (skin, heart, lungs, eyes, muscles, brain) the parts of a person’s body that need energy (question 5). The results are presented in Table 5.5 and show that although more than 80% of respondents considered that the brain, muscles and heart require energy, fewer thought that the lungs, eyes and skin require energy. There were no statistically significant differences between students who had more extensive prior biology study and those with more limited prior study ( $p > 0.05$ , based on a Chi-square test for independence). This suggests that some students may have a limited view of where energy (and consequently cellular respiration) is required in the body.

**Table 5.5**

Student views of human body parts that require energy (n=125, 2004 questionnaire)

Human body part	Respondents (%)
Muscles	96
Brain	91
Heart	87
Lungs	78
Eyes	70
Skin	63

As well as being asked about the energy requirements of plants and animals, students were also asked whether bacteria need energy (question 6, 2003 questionnaire; question 4, 2004 questionnaire). The results show that just over a quarter of students (31% in 2003; 26% in 2004) either did not know, or were not sure. Subsequent interviews with four of these students suggested that this was because they did not think they knew much about bacteria. For example, when Rosie was asked whether bacteria need energy she said that she was not sure because “I’m not huge on bacteria. We haven’t really done anything on it, and I don’t really think I’ll have any clue until the end of the year after next semester’s bio [cellular and molecular biology]”.

Chi-square analysis for independence showed that there were no statistically significant differences between the ‘high bio’ cohort and those with more limited prior biology study (67% versus 69% in 2003; 78% versus 62% in 2004;  $p > 0.05$ ). This is perhaps not surprising given the limited focus on bacteria in the senior biology curriculum at secondary school.

Overall, the findings for questions related to the energy requirements of living organisms suggest that a large proportion of students do not have the view that energy is needed by all organisms (including animals, plants, and bacteria) and that it is needed for all life activities (including processes like maintenance, as well as growth and movement) and by all body parts. This is significant because it has the potential to affect student understanding of topics such as cellular respiration, why it important, and where it occurs in an organism (see Section 5.5.2).

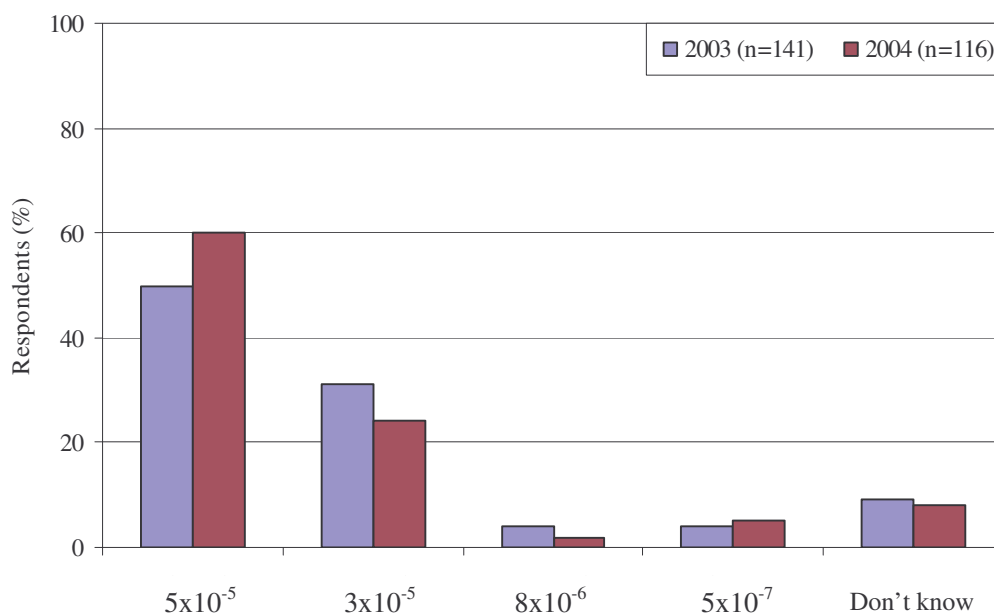
### **5.4.3 Mathematical Concepts**

The majority of faculty interviewed in Phase 1 of the study indicated the importance of mathematics in biology, and expressed concern that many students did not appear to have the mathematical skills or confidence that were required (Section

4.5.4). The prior knowledge questionnaires administered in both 2003 and 2004 thus included several questions designed to probe students' understandings of a range of mathematical concepts identified by faculty as being particularly important. These included: scientific notation, decimals, and conversion within the metric system (e.g., from millimeters to micrometres). Specific responses to these questionnaire items are discussed below.

### Scientific Notation

The questionnaire item designed to investigate students' understandings of scientific notation required students to select the largest number out of a list of four:  $5 \times 10^{-5}$ ;  $5 \times 10^{-7}$ ;  $3 \times 10^{-5}$ ;  $8 \times 10^{-6}$  (question 21, 2003 questionnaire; question 24, 2004 questionnaire<sup>22</sup>). The results are presented in Figure 5.9. As can be seen, just over 80% of the respondents in both 2003 and 2004 indicated that  $10^{-5}$  is greater than  $10^{-6}$  or  $10^{-7}$ ; however, 24% (2003 questionnaire) and 31% (2004 questionnaire) incorrectly



**Figure 5.9**  
Student selection of the largest number (presented using scientific notation) out of four

<sup>22</sup> A similar question was used by Tariq (2002) as part of a diagnostic test of basic numeracy skills, administered to students entering Stage 1 biology courses in Northern Ireland.

considered  $3 \times 10^{-5}$  (0.00003) to be greater than  $5 \times 10^{-5}$  (0.00005). The amount of prior biology study was not correlated with responses to this probe ( $p > 0.05$ , based on a Chi-square test for independence).

Subsequent interviews with students did not specifically enquire about their responses to this question, and it is thus not possible to speculate why a considerable proportion selected  $3 \times 10^{-5}$  as being bigger than  $5 \times 10^{-5}$  when some had even written the correct decimal equivalents next to the numbers on the questionnaire.

### Decimals

The 2003 questionnaire item designed to investigate students' understanding of decimals presented students with a list of cell sizes in millimeters (0.0507, 0.12, 0.012, and 0.2) and asked them to select the number representing the smallest size (question 22<sup>23</sup>). As can be seen from Table 5.6, more students selected the correct response than for the question on scientific notation (74% instead of 50%, see above). In addition, only 2% indicated that they did not know the answer, compared to 9% for the question relating to scientific notation. This suggests that students have a more scientifically acceptable understanding of decimals than scientific notation, although it seems noteworthy that more than a quarter still did not select the 'correct' answer. As with the question on scientific notation, there were no statistically significant

**Table 5.6**

Student views of the smallest decimal number, selected from a list of four numbers representing cell sizes in millimetres (n=143, 2003 questionnaire)

Number selected as being the smallest	Respondents (%)
0.012	74
0.0507	20
0.12	1
0.2	3
Don't know / not completed	2

<sup>23</sup> A similar question was used by Tariq (2002) as part of a diagnostic test of basic numeracy skills, administered to students entering Stage 1 biology courses in Northern Ireland.

differences in responses from students with more extensive prior biology study when compared with those with more limited prior study (74% versus 77%;  $p > 0.05$ , based on a Chi-square test for independence).

#### Conversion within the Metric System: Centimetres, Millimetres and Micrometres

A third mathematical probe included in the prior knowledge questionnaires concerned the expression of numbers as millimeters and micrometres. In the 2003 questionnaire, students were presented with a list of numbers (0.10mm, 150 $\mu$ m, 1.05mm, and 10 $\mu$ m) and asked to rank them in order of size, from largest to smallest (question 23). The scientifically acceptable response was: 1.05mm > 150 $\mu$ m > 0.1mm > 10 $\mu$ m. The results, presented in Table 5.7, show that only 23% of respondents gave this response.

Of the other responses, considering millimetres to be larger than micrometres, regardless of the actual value (i.e., 1.05mm > 0.1mm > 150 $\mu$ m > 10 $\mu$ m) was the most common (48%). Three of these students were subsequently interviewed and asked to convert 150 $\mu$ m and 10 $\mu$ m into millimetres. They were then given the four numbers from the question and asked to put them into order according to size. All three students converted 150 $\mu$ m into 0.15mm (Anne first multiplied by 1000, writing “150 $\mu$ m = 150,000mm”; when asked if millimetres were smaller than micrometres,

**Table 5.7**

Student ability to rank numbers (expressed in millimetres and micrometres) in order of size (n=143, 2003 questionnaire)

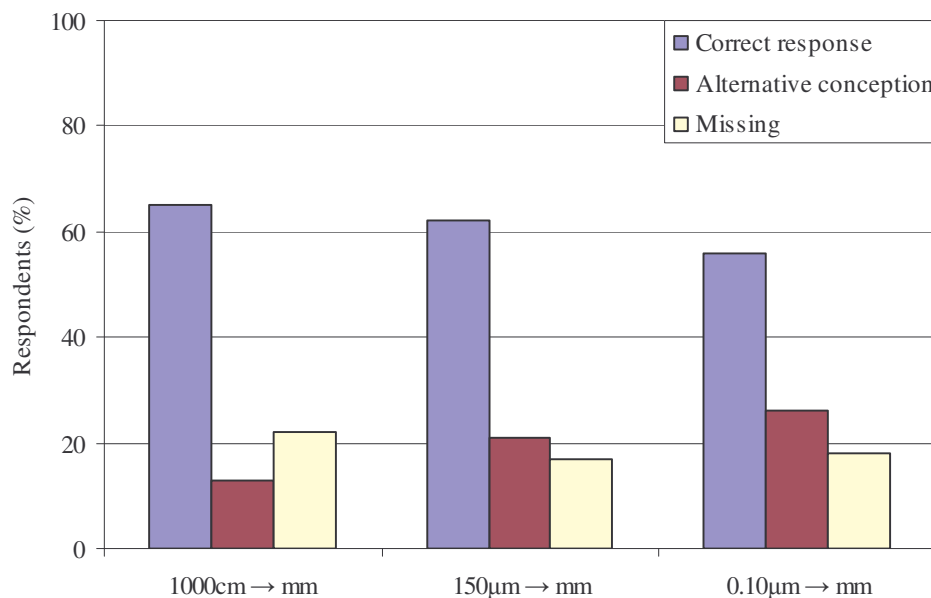
Ranking	Respondents (%)
1.05mm > 150 $\mu$ m > 0.1mm > 10 $\mu$ m <sup>†</sup>	23
1.05mm > 0.1mm > 150 $\mu$ m > 10 $\mu$ m	48
1.05mm > 0.1mm > 10 $\mu$ m > 150 $\mu$ m	14
150 $\mu$ m > 10 $\mu$ m > 1.05mm > 0.1mm	5
Don't know / not completed	9

<sup>†</sup> Scientifically acceptable response

she thought about it and then and rewrote her answer as 0.150mm). However, Sue was the only one of the three to then place the four numbers into the correct order, based on size. When asked whether 0.15mm is smaller than 0.10mm (as they had written), the other two students said that it was not, but that when putting the numbers into sequence they had “just looked at micrometres being smaller than millimetres”.

These interviews suggest that the students who did not place the four numbers in the correct size sequence may have been able to convert between millimeters and micrometres, but their final answer was based primarily on the conception that numbers expressed in micrometres are smaller than numbers expressed in millimetres.

To probe students’ ability to convert between micrometres and millimetres in more detail, the 2004 questionnaire was modified to include a question which asked students to convert  $150\mu\text{m}$  and  $10\mu\text{m}$  into measurements expressed in millimetres



**Figure 5.10**  
Student ability to convert within the metric system, from centimetres to millimetres and micrometres to millimetres (n=116, 2004 questionnaire)

(question 25). They were also asked to convert 1,000 cm into millimeters. The responses, presented in Figure 5.10, show that approximately 60% of respondents were able to complete some of these conversions correctly. However, cross-tabular analysis (see Table 5.8) showed that only 37% of students correctly completed all three conversions. Twelve percent correctly converted between centimetres and millimetres but not micrometres and millimetres, and 14% correctly converted between micrometres and millimetres, but not centimetres and millimeters.

These findings suggest that a large proportion of students are not able to accurately convert between centimetres, millimetres and micrometres. This is

**Table 5.8**

Cross-tabular analysis comparing students' responses to three questions related to conversion within the metric system (n=116, 2004 questionnaire)

1000 cm correctly converted			
	150 $\mu\text{m}$ correctly converted (%)	150 $\mu\text{m}$ incorrectly converted (%)	150 $\mu\text{m}$ not converted (%)
0.10 $\mu\text{m}$ correctly converted	37	3	3
0.10 $\mu\text{m}$ incorrectly converted	8	12	0
0.10 $\mu\text{m}$ not converted	0	0	0
1000 cm incorrectly converted			
	150 $\mu\text{m}$ correctly converted (%)	150 $\mu\text{m}$ incorrectly converted (%)	150 $\mu\text{m}$ not converted (%)
0.10 $\mu\text{m}$ correctly converted	14	2	0
0.10 $\mu\text{m}$ incorrectly converted	2	3	0
0.10 $\mu\text{m}$ not converted	0	0	2
1000 cm not converted			
	150 $\mu\text{m}$ correctly converted (%)	150 $\mu\text{m}$ incorrectly converted (%)	150 $\mu\text{m}$ not converted (%)
0.10 $\mu\text{m}$ correctly converted	0	0	13
0.10 $\mu\text{m}$ incorrectly converted	0	0	0
0.10 $\mu\text{m}$ not converted	0	0	0

Note: "Not converted" refers to missing responses



important, as faculty assume that students are able to do this, particularly in the context of laboratory activities.

### Conversion from cm<sup>2</sup> to mm<sup>2</sup>

In order to investigate students' ability to convert between cm<sup>2</sup> and mm<sup>2</sup>, a question requiring students to calculate the area of a rectangle (length 10 mm, width 4 mm) was included in the 2003 questionnaire (question 24).<sup>24</sup> The question asked for the final answer to be presented in cm<sup>2</sup>. Of the respondents, only 36% (n=142) provided a scientifically acceptable answer (0.4cm<sup>2</sup>) to the question (see Table 5.9). Of this 36%, the majority (76%) had converted the raw data from millimetres to centimetres prior to carrying out the area calculation.

Twenty percent of respondents provided an answer of 40. One of these students, Steve, indicated in a subsequent interview that he "just read the question partly and assumed that I knew the rest." This suggests that at least some of the 20%

**Table 5.9**

Student ability to calculate the area of a rectangle (10 mm x 4 mm), with the answer expressed in cm<sup>2</sup> (n=142, 2003 questionnaire)

Answer	Respondents (%)
0.4 <sup>A</sup>	36
40 <sup>B</sup>	20
4 <sup>C</sup>	24
Some other type of conversion <sup>D</sup>	9
Arithmetic errors <sup>E</sup>	4
Don't know / not completed	7

<sup>A</sup> Scientifically acceptable answer

<sup>B</sup> Possibly because students did not convert from mm<sup>2</sup> to cm<sup>2</sup>

<sup>C</sup> Possibly because students converted incorrectly from mm<sup>2</sup> to cm<sup>2</sup> by dividing by 10

<sup>D</sup> For example, 0.01 x 0.004; 40 / 1000

<sup>E</sup> For example, 1 x 0.4 = 1.4

<sup>24</sup> A similar question was used by Tariq (2002) in a diagnostic test to measure the numeracy skills of students entering Stage 1 biology courses in Northern Island.

who provided an answer of 40 had done so without recognising that a conversion of units was required. However, when Steve was asked what the answer would be in  $\text{cm}^2$  (from  $40\text{mm}^2$ ), he simply divided by 10 (rather than 100) to give an answer of “ $4\text{cm}^2$ ”. This type of conversion (dividing by 10, as though converting between centimetres and millimetres) had been carried out by 24% of the other questionnaire respondents, suggesting a lack of scientific understanding of the relationship between  $\text{cm}^2$  and  $\text{mm}^2$ . Several students (9%) gave responses based on some other type of conversion (e.g., multiplying by 10), suggesting that they did not understand how to convert accurately between millimetres and centimetres.

#### Summary of Student Understandings of Mathematical Concepts

In summary, a large proportion of students did not provide scientifically acceptable responses to the questionnaire items probing mathematical concepts such as scientific notation (50% in 2003; 40% in 2004), decimals (26% in 2003), and conversion between metric units (only 23% correctly ranked a series of four numbers in order according to size in 2003, and in 2004 only 37% correctly answered all the questions requiring conversion between mm and  $\mu\text{m}$ , and cm and mm). The question requiring conversion from  $\text{cm}^2$  to  $\text{mm}^2$  was also poorly answered (36% answered correctly in 2003), and this was reflected in a common topic test administered for course assessment purposes. Statistical analysis using Chi-square tests for independence showed no significant differences between students with more extensive prior biology study and those with more limited prior experience. This is perhaps not surprising given the lack of emphasis on mathematical concepts in the Year 13 biology curriculum.<sup>25</sup>

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<sup>25</sup> The exception is the inclusion of statistical analysis when carrying out a practical biological investigation, included in the Year 13 biology curriculum.

#### *5.4.4 Chemical Concepts*

During Phase 1 of the research, faculty indicated they assumed students have an understanding not only of some specific biological and mathematical concepts, but also of some basic chemical concepts. These included: atoms, molecules, chemical symbols and molecular formulae, chemical reactions including redox reactions, and osmosis and diffusion (see Section 4.5.3). An understanding of these chemical concepts is particularly important for topics such as movement across cell membranes (taught in relation to cell biology, nerve transmission, kidney function, and water and nutrient movement in plants); and biochemistry (cellular respiration and photosynthesis). The prior knowledge questionnaires thus included several questions designed to probe students' understandings of: diffusion and the particulate nature of matter; the meaning of chemical symbols (e.g., 'C' for carbon); and redox reactions. The responses to these questions are explored in more detail in the following sections.

##### Diffusion and the Particulate Nature of Matter

The questionnaire item designed to investigate students' understandings of the particulate nature of matter was set in the context of adding a drop of blue dye to a container of clear water (question 26, 2003 questionnaire). It was stated that all the water would eventually turn light blue, even without stirring, and students were asked whether the dye particles had at this point:

- stopped moving
- were still moving around randomly
- don't know / not sure

Respondents were then asked to select the best explanation for their answer:

- if the dye particles were still moving, the water would be different shades of blue
- if the dye particles stopped moving, they would settle at the bottom of the container
- particles are always moving
- other: \_\_\_\_\_
- don't know / not sure.<sup>26</sup>

Of the respondents (n=141), 87% indicated that the dye particles would still be moving randomly when the entire solution had turned blue. Of this 87%, just under three quarters (72%) indicated that the best explanation for this was that “particles are always moving”. A further 19% indicated that “if the dye particles stopped moving, they would settle at the bottom of the container”. The findings thus suggest that the majority of students have some understanding of the concept of particle motion, a key concept underpinning osmosis and diffusion (see Section 4.5.3).

When asked about the effects of temperature on the movement of the blue dye particles in the water solution (question 27, 2003 questionnaire), 95% of respondents (n=139) indicated that the water in a container at 40°C would turn light blue more quickly than the water in a container at 25°C, consistent with a scientific view. Of this 95%, the majority (90%) indicated that this was because “the dye particles move faster at higher temperatures”.

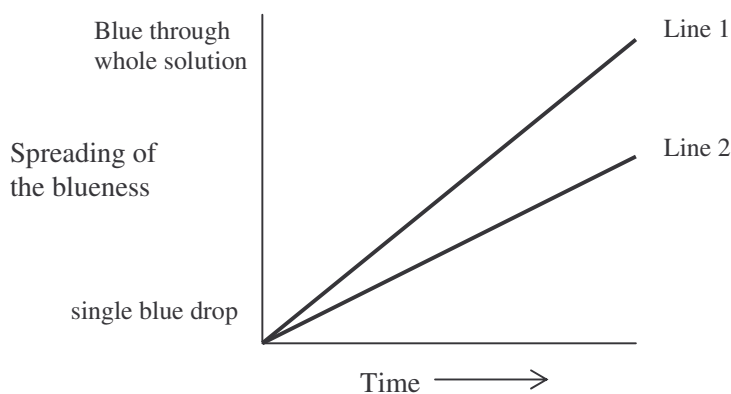
The questionnaire item also included a graph that represented the rate at which the blue colour spread through the water, which students were required to

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<sup>26</sup> This question was used by Odom and Barrow (1995), although minor changes were included. For example, the question used here explicitly pointed out that the solution would eventually turn blue, even if it was not stirred (to remove any confusion about the possible role of stirring in affecting the colour changes).

interpret (Figure 5.11).<sup>27</sup> A large proportion (86%) of the total cohort (n=139) could correctly interpret the graph. Of this 86%, the majority (83%) provided what appeared to be scientifically acceptable explanation for their choice. For example, Damian selected Line 2 as representing container A (25°C, i.e., the lower temperature) because “Line 1 has more blue spread in the same amount of time.” However, providing a title for the graph appeared to be more challenging, with only 46% of respondents referring to the effect of temperature on diffusion rates. A further 28% provided a title that repeated information contained on the axes of the graph (e.g., “Diffusion against time”) without reference to the effect of temperature; and 17% did not complete the question.

The majority of students (87%) therefore appeared to be able to provide scientifically acceptable descriptions of the movement of dye particles in water. More than 80% of students could also interpret the graph that was provided, although more guidance may be required to help students learn how to compose meaningful titles for graphs. Student ability to draw graphs was not investigated by this probe.



**Figure 5.11**

The effect of temperature on dye movement through two solutions (one at 25°C and the other at 40°C)

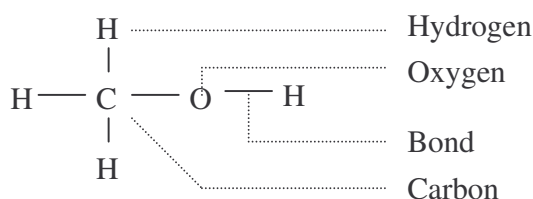
Note: Students were asked in the questionnaire to indicate which solution is represented by Line 2.

<sup>27</sup> Faculty indicated in Phase 1 of the research that they assumed students entering first-year biology courses could interpret graphs (see Section 4.5.4).

### Chemical Symbols

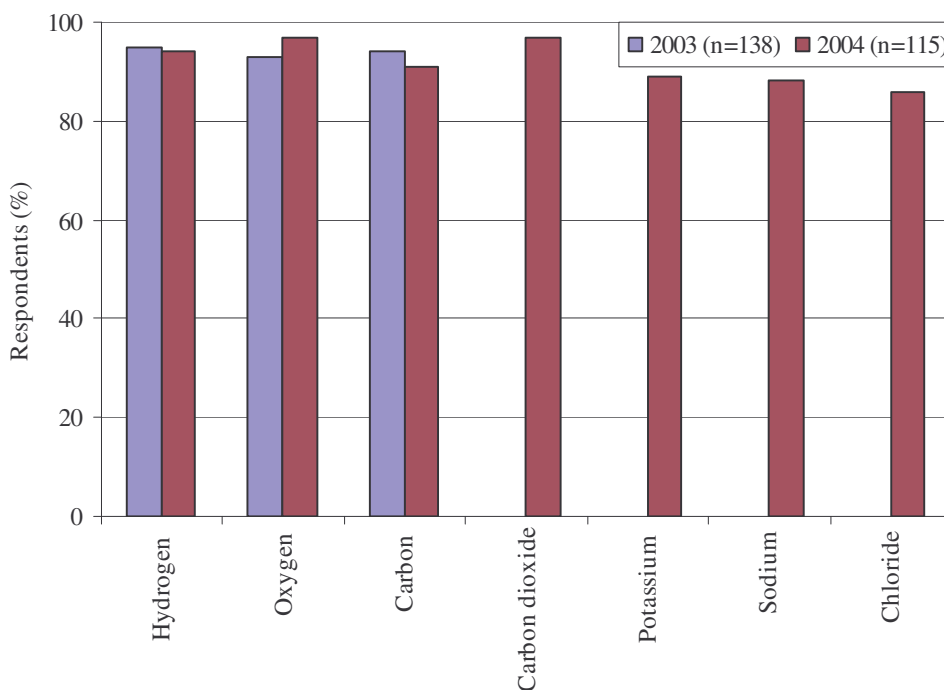
In order to investigate students' knowledge of common chemical symbols, the 2003 questionnaire included a diagram of a simple alcohol (methanol, see question 28). Respondents were asked to label the various components of the diagram, as shown in Figure 5.12. In 2004, students were provided with a table listing some of the more common chemical symbols referred to in first-year biology courses ( $\text{H}_2\text{O}$ , H, O,  $\text{CO}_2$ , C, Cl,  $\text{Na}^+$ ,  $\text{K}^+$ ), which they were asked to name (question 26). The responses to both questionnaire items are presented in Figure 5.13.

As can be seen, the majority of students (more than 85%) were able to correctly name the common chemical symbols for hydrogen, oxygen, carbon, carbon dioxide, sodium, potassium and chlorine. In addition, the latter three symbols were presented in 2004 as ions (i.e.,  $\text{Na}^+$ ,  $\text{K}^+$  and  $\text{Cl}^-$ ), and approximately half of the respondents who identified the symbols as representing sodium, potassium and chlorine/chloride respectively, also referred to them as ions (e.g., "chloride ion"). Over 70% (74%, 2003 questionnaire; 79%, 2004 questionnaire) were able to correctly identify all the symbols in either the figure or the table. Just less than three quarters (74%) referred to the line joining two atoms as a "bond" (see Figure 5.13), with 9% referring to it incorrectly as a hydrogen bond, and 4% referring to it as a peptide bond.



**Figure 5.12**

Labels required to complete the diagram of a chemical molecule (question 28, 2003 questionnaire)



**Figure 5.13**  
Student ability to provide scientifically acceptable names for common chemical symbols

The findings suggest that the majority of students (more than 74%) could identify the names given to common chemical symbols. However, nearly one quarter could not. Some alternative conceptions regarding the naming of chemical bonds (particularly where covalent bonds are considered to be hydrogen bonds if they involve a hydrogen atom) may be worth specific attention during teaching.

### Redox Reactions

Redox reactions, or oxidation-reduction reactions, are chemical reactions in which one or more electrons are transferred from one reactant to another. The reaction occurs at several steps in both the cellular respiration and photosynthetic pathways, producing oxidised and reduced intermediates. Some faculty who teach this section reported in interviews that they would generally assume that students were familiar with the terms 'oxidation' and 'reduction', although others said that they would also define the terms as part of their teaching (see Section 4.5.3).

In order to investigate students' understanding of oxidation and reduction, the prior knowledge questionnaires included an item relating to the reduction of NAD to form NADH, a common reaction within photosynthesis and cellular respiration.<sup>28</sup> The students were presented with the following reaction and told that it was part of a redox reaction:



Students were then asked to indicate “the reduced form of the molecule”, and presented with the following options (question 30, 2003 questionnaire; question 27, 2004 questionnaire):

- NAD
- NADH
- Neither NAD nor NADH
- Don't know / not sure

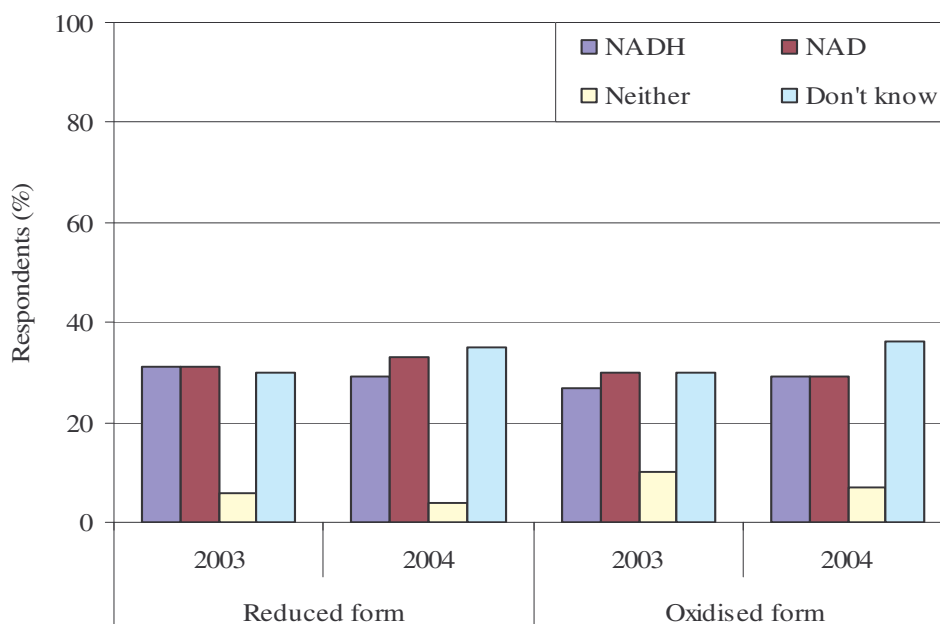
The second part of the question asked respondents to indicate “the oxidised form of the molecule”. Finally, respondents were asked, “What do you think it means if something is oxidised?”

The results, presented in Figure 5.14, show that very few respondents (less than one third) were able to correctly interpret the question and select NADH as the reduced form of the molecule, and NAD as the oxidised form. Of this small group of students, the majority (91% in both 2003 and 2004) had selected NADH as being the reduced form and NAD as being the oxidised form. However, for some students, ‘correctly’ selecting NADH as the reduced form and NAD as the oxidised form was a matter of chance. As Candace commented in a subsequent interview: “It had to be either one or the other, and it was lucky that I ticked the right ones. If you'd asked me to explain it I would have got it wrong.”

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<sup>28</sup> It should be noted that students may be familiar with redox reactions in general (e.g.,  $\text{K}^+$  being reduced to K), but not with this particular example. The probe therefore required students to apply their understanding of redox reactions to what may have been an unfamiliar context.





**Figure 5.14**

Student selection of the reduced and oxidised forms of NAD in the redox couple  $\text{NAD} \rightleftharpoons \text{NADH}$  (n=138, 2003 questionnaire; n=115, 2004 questionnaire)

Of the students who indicated that they did not know which molecule was the reduced form, the majority (91% in 2003; 95% in 2004) also indicated that they did not know which molecule was the oxidised form. This suggests that they were providing consistent responses, rather than guessing. There were no statistically significant differences in responses between students with more extensive prior biology study and those with more limited prior experience ( $p > 0.05$ , based on a Chi-square test for independence).

Students' explanations of what it means for a molecule to be oxidised varied considerably, as shown in Table 5.10. As can be seen, a reasonably large proportion (60%) provided what was considered to be a scientifically acceptable description of oxidation. This is perhaps surprising, given the lower number of respondents who correctly used this understanding to identify the oxidised and reduced forms of the NAD molecule (of the 62 respondents who provided a scientifically acceptable

**Table 5.10**

Student definitions of oxidation (n=138, 2003 questionnaire; n=115, 2004 questionnaire)

Category	Student definitions	2003 (%)	2004 (%)
Scientifically acceptable	Loss of electrons	18	24
	Loss of hydrogen	3	0
	Gain of oxygen	27	20
	Loss of electrons or gain of oxygen	4	7
	Loss of hydrogen or gain of oxygen	4	0
	Increase in oxidation number	4	3
	TOTAL:	60	54
Alternative conceptions	Release of oxygen	3	3
	Reaction with oxygen		8
	Either the loss or gain of electrons		1
	Gain of electrons	5	4
	Gain of hydrogen	5	3
	Gain of carbon		1
	Energy is created		1
	Atoms are changed	1	
TOTAL:	14	21	
Don't know	Don't know	27	26

explanation for oxidation in 2004, only 34% correctly selected NADH as being the reduced form of the molecule). One possible explanation for this may be the large number of respondents (35% in 2003, 27% in 2004) who considered oxidation to be associated with the addition of oxygen. Although this is a scientifically acceptable understanding in some contexts (e.g., the oxidation of iron), it is not directly relevant to the context of the NAD-NADH couple, in which there is a transfer of electrons and hydrogen ions but not oxygen.

The lack of integration between the explanation and the application of that explanation to the NAD-NADH problem was evident in a subsequent interview with Rosie. She had indicated in her questionnaire that if something is oxidised, its oxidation number has increased. However, when she was asked in the interview how she would decide which molecule in the NAD-NADH couple had been oxidised, she

answered: “I decided that possibly the NAD had been reduced because it no longer has an H on it. I didn’t know what the H was standing for exactly, but I decided it was less than what NADH was so it had been reduced.” When she was asked how this relates to the oxidation state, she did not appear to be able to provide a clear answer, saying instead: “I’m not sure ... I’m confusing myself now.” This expression of confusion was echoed by four of the five other students who were asked to explain their responses to this questionnaire item in subsequent interviews.

Taken together, the findings suggest that although a large proportion of students (60% in 2003, 54% in 2004) are able to provide a scientifically acceptable definition for oxidation, fewer are able to apply this information to identify the oxidised and reduced forms of the NAD-NADH couple. This suggests rote learning of the definition, and has implications for teaching biochemical pathways, particularly when faculty use statements such as “The *reduced NAD* goes into the next stage, called the electron transport chain”, or “fats are a better source of *reducing potential* than carbohydrates” as was observed during classroom observations. Similarly, the course lecture manual at one university similarly referred to ‘oxidation’ and ‘reducing potential’ with limited explanation, as in the following example (emphasis added):

NAD functions as a hydrogen carrier, picking up 2H removed in *oxidation* reactions. It thus carries potential energy in the form of *reducing* potential – it has the potential to *reduce* another chemical by giving up the 2H it is carrying.

#### Summary of Student Understandings of Chemical Concepts

The majority of respondents (more than 85%) seemed to have a scientifically acceptable understanding of aspects of the particulate nature of matter and the movement of molecules in liquid media (important for a scientifically acceptable understanding of concepts like diffusion and osmosis). A large proportion (more than 70%) also appeared to be able to provide names for common chemical symbols (like ‘C’ and ‘H’), although over a quarter did not. Students were less likely to be

able to interpret redox reactions, which has implications for teaching metabolic pathways like photosynthesis and cellular respiration.

The questionnaire did not probe student ability to engage with complicated chemical formulae or reactions used to describe metabolic pathways, although comments during tutorial classes that were observed at one university suggest that some students at least find the level of detail that is required to be somewhat intimidating (see Section 4.5.3). Not surprisingly, the amount of biology studied prior to enrolling in the first-year biology courses in which the questionnaires were administered had little impact on students' understanding of the chemical concepts that were investigated as part of the prior knowledge questionnaire.

Prior study in biology also appeared to have surprisingly little impact on students' ability to demonstrate an understanding of the 'bigger picture', or connections between concepts, as described in the next section.

## **5.5 UNDERSTANDING THE 'BIGGER PICTURE'**

Biology is a subject that consists of many interrelated concepts, but analysis of questionnaire responses showed that very few students were able to demonstrate an understanding of the links between certain concepts. This has already been discussed, for example, in the context of students' ideas that DNA is found in all cells, but not necessarily in all organisms (Section 5.3.3); and that living organisms require energy for some but not all internal processes (Section 5.4.2). Students' responses to questionnaire items related to photosynthesis and cellular respiration will be used to further demonstrate their apparent inability to demonstrate relationships between concepts.

### 5.5.1 Plant Needs and Photosynthesis

In the 2003 questionnaire, students were provided with a list of items (carbon dioxide, oxygen, water, ‘food’, light and minerals) and asked to select those that plants need, as well as explain what they are used for (question 10).<sup>29</sup> The results, presented in Table 5.11, show that the majority of respondents (over 95%) indicated that plants need light, water, carbon dioxide, and minerals. Responses to the ‘food’ probe appeared to be less reliable, due in part to different understandings of the term ‘food’. For example, eight of the students who indicated that plants don’t need food also indicated that this is because plants make their own. However, 37% of the 71% who indicated that plants do need food wrote that it comes from the soil. A further 9% wrote that the food comes from both the soil and photosynthesis. This is indicative of a commonly held alternative conception reported in the literature, that is, plants get their ‘food’ from the soil (e.g., Barker & Carr, 1989; Songer & Mintzes, 1994).

When asked to explain what the carbon dioxide is used for, only 51% of the respondents referred directly to photosynthesis. This suggests that there were a

**Table 5.11**  
Student views of substances needed by plants for survival (n=145, 2003 questionnaire)

Plants need ...	Respondents (%)
Light	100
Minerals	100
Water	98
Carbon dioxide	95
‘Food’	71
Oxygen	41

<sup>29</sup> This question was used in an open-ended form by Leach, Driver, Scott, and Wood-Robinson (1996a) to investigate high school students’ understanding of the cycling of matter. Here, the responses reported by Leach et al. were given to students to reduce the risk of respondents not referring to particular ‘needs’ simply because they did not think of them at the time of completing the questionnaire, as opposed to them believing that a plant does not need a particular substance.

significant proportion of students who indicated that plants require carbon dioxide, but who did not link it to photosynthesis in plants. A further 15% appeared to equate the use of carbon dioxide by plants with respiration in animals. For example, one student wrote that carbon dioxide is used for “respiration for energy”. There were no statistically significant differences in responses from students with more extensive prior biology study when compared with those with more limited prior study ( $p > 0.05$ , based on a Chi-square test for independence).

There also appeared to be some confusion of the role of oxygen in plants. Of the 41% of students who indicated that plants require oxygen, only 36% referred to its role in respiration or energy production. Ten percent indicated incorrectly that oxygen is needed for photosynthesis. The alternative conception that photosynthesis occurs during the day and respiration occurs at night was also apparent in several answers. For example, one student wrote that oxygen is needed for “respiration at night.” This confusion about the relationship between photosynthesis and respiration was also apparent in responses to a multiple choice question included in the 2004 questionnaire that specifically asked whether plants need oxygen (question 15): 20% of students indicated that plants require oxygen, but only at night, and a further 23% indicated that plants do not require oxygen at all (see Table 5.12).

Taken together with responses to the question regarding a plant’s need for carbon dioxide, the findings suggest that a large proportion of students have limited

**Table 5.12**

Student views of whether plants need oxygen (n=122, 2004 questionnaire)

Option selected	Respondents (%)
No, plants do not need oxygen	23
Yes, plants need oxygen, but only at night	20
Yes, plants need oxygen, during the day and night	46
Don’t know / not sure	12

understanding of plants' requirements for carbon dioxide and oxygen, and particularly the role of these molecules once in the cells. There were also several examples of students equating respiration in animals with photosynthesis in plants. This alternative conception is widely reported in the literature (e.g., Cañal, 1999; Songer & Mintzes, 1994). The findings thus suggest that the role of cellular respiration in plants (as distinct from photosynthesis) is not well understood. This is perhaps not surprising since cellular respiration tends to be taught only in the context of animals at secondary school.

In the 2004 questionnaire, the question about plant requirements was modified to specifically probe student understanding of the reactants required for photosynthesis. The question included a list of items (light, oxygen, carbon dioxide, carbohydrates, sugars, chlorophyll, water) and students were asked to select those that plants require in order to carry out photosynthesis (question 11). The results, presented in Table 5.13, suggest that many students have a limited knowledge of the

**Table 5.13**

Student views of substances needed by plants (n=145, 2003 questionnaire; n=124, 2004 questionnaire)

Plants need ...	Respondents (%)	
	2003 <sup>1</sup>	2004 <sup>2</sup>
Light	100	94
Carbon dioxide	95	79
Chlorophyll		76**
Water	98	66
Oxygen	41	24
Sugars		15
Carbohydrates		10

<sup>1</sup> The 2003 questionnaire asked which of the substances are needed by plants; the data are repeated from Table 5.8 to provide a comparison with 2004 data. As can be seen, the data suggest that students think plants need water (2003), but may not associate this need with photosynthesis (2004).

<sup>2</sup> The 2004 questionnaire asked which of the substances are needed by plants for photosynthesis.

\*\* Students with more extensive prior biology study were more likely to indicate that plants require chlorophyll for photosynthesis (84%) when compared with those who had more limited prior biology study (52%) ( $p < 0.01$ , based on a Chi-square test for independence).

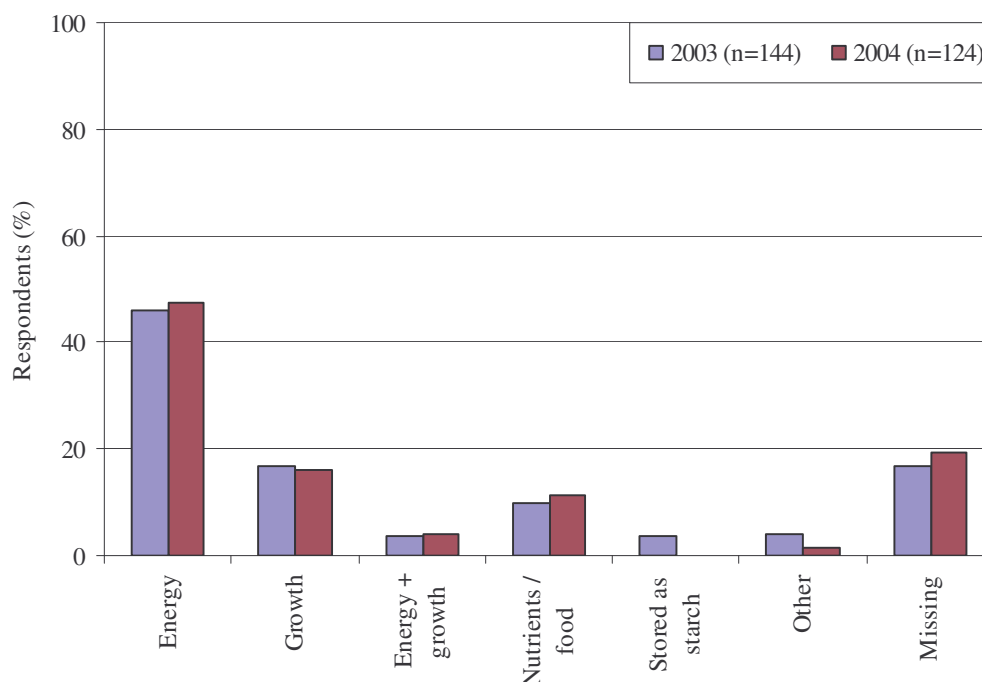
components required by plants for photosynthesis. For example, 21% of respondents indicated that carbon dioxide is not required, and 24% considered oxygen to be required (rather than produced). Between 10 and 15% consider sugars and/or carbohydrates to be required for photosynthesis (these are the products of photosynthesis).

Interestingly, there were no statistically significant differences in responses to the question related to plant requirements for photosynthesis ('high bio' versus 'low bio';  $p > 0.05$ ) except that those with more extensive biology prior study were more likely to indicate that chlorophyll is needed ( $p < 0.01$ , based on a Chi-square test for independence).

In order to investigate students' understanding of the significance of photosynthesis, the following item was included in both the 2003 and 2004 questionnaires (questions 13 and 12 respectively): "During photosynthesis, plants produce sugars. What do you think these sugars are used for?" The results, presented in Figure 5.15, show that fewer than half the respondents consider the products of photosynthesis to be an important source of energy for plants. Just over 15% referred to the role of the sugars in plant growth, and fewer than 5% indicated that the sugars were used for energy and plant growth. It was unclear from these responses what the remaining students considered to be the primary source of new organic materials required for plant growth.

In order to further investigate student understanding of the origin of organic molecules required for the building of cellular components, a question was included in the 2004 questionnaire that asked: "Where do plants get the materials that they need as building blocks to make new cells?" (question 14). As can be seen from the results to this multiple choice question (presented in Table 5.14), fewer than 50% of students indicated that the building blocks of cells are generated primarily from the





**Figure 5.15**

Student views of the function of sugars produced by plants during photosynthesis

Note: The ‘other’ category includes responses such as attracting pollinators, making DNA, and making chlorophyll

**Table 5.14**

Student views of the source of building blocks needed to make new cells (n=124, 2004 questionnaire)

Option selected	Respondents (%)
Mainly from the substances they make in photosynthesis, but low concentrations of minerals are needed from the soil	48
Mainly from the soil but they can use substances that they make in photosynthesis	27
From the substances they make in photosynthesis	10
From the soil	6
Don’t know / not sure	10

products of photosynthesis, with only small concentrations of minerals being absorbed from the soil. That a large proportion of students consider the soil to be an important source of “building blocks” for plants, whilst still demonstrating some knowledge of the reactants required for photosynthesis (i.e., they had some

understanding of the *process* of photosynthesis), suggests a lack of understanding of the significance of photosynthesis in plants. There were no statistically significant differences in responses between students with more extensive prior study in biology when compared with those who had more limited prior study ( $p > 0.05$ , based on a Chi-square test for independence). This suggests that even though photosynthesis is taught in Year 12 biology, the *significance* of the process (i.e., why it is needed by plants) is not explicitly taught or examined.

To summarise, the results for questionnaire items related to the reactants, products, and purpose of photosynthesis suggest that many students do not have a clear view of the overall process. Although the majority of students indicated some familiarity with the process (through answering the questions, rather than leaving them out), there was lack of clarity about the reactants that are required (e.g., in the 2004 questionnaire only 79% indicated that carbon dioxide is required, and 66% that water is required). Further, although a large proportion of respondents (nearly 70% for both the 2003 and 2004 questionnaires) indicated that the sugars produced by photosynthesis are needed for either energy or growth, many students concurrently indicated that components from the soil are an important source of the building blocks needed to make up the structures of cells. In addition, the role of oxygen (and consequently cellular respiration) in plants did not appear to be well understood. It is interesting to note that students with more extensive prior biology study did not appear to have a greater understanding of the ‘bigger picture’ than students with more limited prior biology experience.

Taken together, these findings suggest that faculty teaching first-year biology courses may find it helpful to make explicit not only the reactants and products of photosynthesis, but also the *purpose* and *significance* of photosynthesis in plants, as well as the relationship between photosynthesis and cellular respiration. There may also be some benefit in incorporating laboratory exercises that specifically target some of the common alternative conceptions revealed by students’ responses to the

prior knowledge questionnaires (e.g., that plants photosynthesise and animals respire).

### ***5.5.2 Oxygen, Nutrients, and Cellular Respiration***

Cellular respiration is a topic that is specifically taught in first-year biology courses that focus on cell biology and biochemistry, but the content contains considerable detail and several faculty indicated in Phase 1 of this research that they assume students have some understanding of the basic principles (see Section 4.5.1). Knowledge of cellular respiration is also important for a holistic understanding of other parts of first year biology courses, including understanding the importance of animals' gas exchange and circulatory systems.

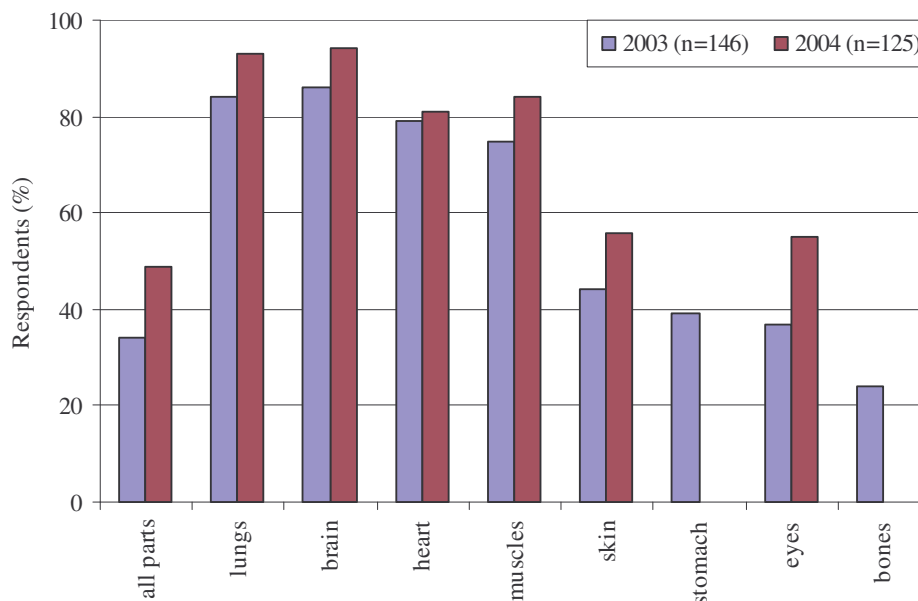
Several questionnaire items were included to probe students' understandings of some of the concepts underpinning cellular respiration, including animals' requirements for and use of oxygen, and the role of nutrients. Responses to these probes are discussed in detail below.

#### Animals and Oxygen

Several questionnaire items were designed to explore students' understandings of the role of oxygen in animals. In one of these items, students were presented with a list of human body parts (skin, heart, lungs, eyes, muscles, brain<sup>30</sup>) and asked to select the ones that need oxygen (question 7, 2003 questionnaire;

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<sup>30</sup> The 2003 questionnaire item also included stomach, hair and bones. These were omitted in the 2004 questionnaire because there appeared to be some confusion about whether these body parts are made up of living cells or not. For example, Derrick said in an interview, "I'm not sure if bones are alive." Anne similarly indicated in an interview that hair does not need oxygen because "hair is just dead cells". These responses suggest that the 2003 probe was two-fold, investigating not only whether all cells need oxygen, but also whether certain body parts are made up of cells.



**Figure 5.16**  
Student views of human body parts that require oxygen

question 9, 2004 questionnaire<sup>31</sup>). The results, presented in Figure 5.16, show that less than half the respondents (34% in 2003; 49% in 2004) considered oxygen to be required by all parts of the body. Seven of these students were subsequently interviewed, and all of them made a connection between oxygen and energy, although not all were clear on the details of the relationship. For example, when Brendan was asked to explain the role of oxygen, he replied: “When they are using energy they are using oxygen as well. For example the muscle cells – if they don’t get oxygen when they’re using the ATP to function then you get a build-up of lactic acid.” When he was asked to be more specific, he said that he was not sure of the details.

The body parts most commonly selected as requiring oxygen were the brain, lungs, heart and muscles (75% or more of respondents). Fewer respondents (less than 60%) considered the skin, eyes, stomach, and/or bones to require oxygen. In at least some cases this appeared to be related to a view that blood did not carry oxygen to

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<sup>31</sup> This question was used by Núñez and Banet (1997) to investigate secondary school students’ understanding of human nutrition.

these regions. For example, Kevin explained in a subsequent interview that he had not selected 'skin' because "blood doesn't go to the skin." This suggests a link between oxygen and the need for it to be circulated around the body, but not necessarily an understanding of what the oxygen is used for (and therefore all body parts require it).

Several responses also suggested a strong conceptual association between oxygen and muscles, with students not necessarily understanding that energy is needed for cellular activities other than movement (see Section 5.4.2). For example, Jenny was asked in a subsequent interview why she had selected the heart, lungs, muscles and brain. She replied: "Just general knowledge ... muscles always need oxygen or else you get lactic acid. The same for the lungs and the heart because they are muscles." Karl, who had initially ticked 'heart' and 'eyes' but then crossed them out and selected 'brain' and 'muscles', similarly explained in a subsequent interview: "Before I saw 'muscles' I thought that 'heart' and 'eyes' need oxygen, and then I saw 'muscles'." He went on to say that he did not know what muscles use the oxygen for, just that they need it. The students who were interviewed and who had selected only a few body parts as requiring oxygen therefore appeared to have a limited understanding of what the oxygen is used for, citing general knowledge (that muscles and the brain need oxygen to function, or that blood carries oxygen to the various body parts selected) to explain their selection.

Only 23% of respondents thought bones require oxygen (2003 questionnaire). Three of these students were subsequently interviewed, and all talked about bones as being living cells. However, other students indicated in subsequent interviews that they were not sure about whether bones are living. For example, Derrick considered that bones did not require oxygen, explaining: "I'm just not sure if the bones are alive ... they're just basically there for the cell walls to hold up the rest of the cells in the body." Nicole was also asked why she had not indicated that bones need oxygen and she replied, "I probably thought that bones are more of a structure than a function."

In summary, the findings suggest that a large proportion of students have an incomplete understanding that all living cells within a person require oxygen. This could be related to a lack of understanding that oxygen is required for cellular respiration (see below), and that energy (and consequently oxygen) is required for a range of cellular activities (see Section 5.4.2). Student background did not appear to affect student responses to this question ( $p > 0.05$ , based on a Chi-square test for independence).

### Why Oxygen is Required

After being asked which human organs require oxygen, students were asked to explain why the selected organs need the oxygen (i.e., what it is used for; question 8, 2003 questionnaire; question 10, 2004 questionnaire). The 2003 questionnaire also included a question asking whether animals like cows need oxygen (99% wrote that they did) and what they use the oxygen for (question 9, 2003 questionnaire).

Only 40% of the 2003 respondents ( $n=146$ ) and 28% of the 2004 respondents ( $n=125$ ) referred to oxygen as being needed for energy or respiration. Some of these responses also indicated alternative conceptions regarding the process of cellular respiration. For example, one student wrote: “Oxygen can be changed to energy when air goes into the heart of the human.” Subsequent interviews also suggested that the presence of alternative conceptions may be fairly widespread amongst those who recognise a relationship between oxygen and energy. For example, Harry had written in the questionnaire that the body parts selected (all except skin, eyes, and bones) need oxygen “to contribute to the process that energy is realised [sic].” When asked to describe this more specifically in an interview, he said: “It’s called aerobic ... something. Lactic acid is produced.” However, lactic acid is only produced in the absence of oxygen (i.e., during anaerobic respiration). Derrick also wrote that oxygen is used for “energy production”. When asked to elaborate on this in a subsequent interview, he said: “Well, they break starch down to glucose first of all and then the carbon from that and oxygen that you’ve breathed in join together and ...

that goes to CO<sub>2</sub> plus energy.” Although this seems like a plausible answer and explains the input of oxygen and output of carbon dioxide, it is not scientifically acceptable; the scientific view is that carbohydrate is oxidised to form CO<sub>2</sub> and oxygen is reduced to form water.

In another questionnaire item, students were asked to indicate the human organs that require energy (question 5, 2004 questionnaire, see Section 5.4.2). When these responses were compared with responses to the question asking which organs need oxygen (question 9, 2004 questionnaire, see above) there was little consistency (see Table 5.15). Overall, fewer than half the respondents indicated that all the organs listed required energy *and* required oxygen, suggesting that the majority of students either did not hold one or both of these concepts, or they had not made an explicit link between the requirement for energy and the requirement for oxygen (for cellular respiration, or the process of providing energy).

Other responses to the questionnaire item investigating students’ understanding of the role of oxygen were more general, with reference to oxygen being needed in order for the cells to function or to survive, whilst some referred to oxygen being needed by blood (14% in question 8 and 7% in question 9, 2003

**Table 5.15**

Student view of whether various body parts require energy *and* oxygen (n=125, 2004 questionnaire)

Body part	Respondents (%)
Brain	87
Muscles	83
Heart	74
Lungs	74
Skin	49
Eyes	50
All body parts listed	44

questionnaire; 9% in the 2004 questionnaire). A small proportion made a connection between oxygen and its role in breathing (2% for question 8 and 10% for question 9 in 2003). For example, Tina wrote that oxygen is needed because it “makes us breathe better.” She had also indicated that the lungs are the only human body parts that require oxygen. During a subsequent interview she was asked what happens to the oxygen once it is in the lungs, to which she answered: “I think it [oxygen] goes in the blood and then it comes to the heart and then it goes to everywhere else in the body.” She was then asked where in the body it goes to and she said she was not sure and that she had only learnt it goes to the body during the lectures on circulation (which she had attended as part of the first-year biology course). She added that she was uncertain what the oxygen was used for by the body. Although this student had completed Year 13 biology, she demonstrated no recollection of having learnt about cellular respiration, let alone linking it to the reason why the blood carries oxygen, or why it is then taken up by the tissues.

Many of the students therefore did not appear to have an understanding of *why* oxygen is needed by animals. This may be related to students’ somewhat limited understandings of how oxygen is involved in the production of energy, what animals use energy for, and the links between these concepts.

### Animals and Nutrients

In order to investigate students’ understanding of the links between nutrition and cellular respiration, a question was included in the 2004 questionnaire as follows (question 7):

Once a person has eaten food and it has been digested, the nutrients are absorbed into the blood. Which parts of the body are they carried to?

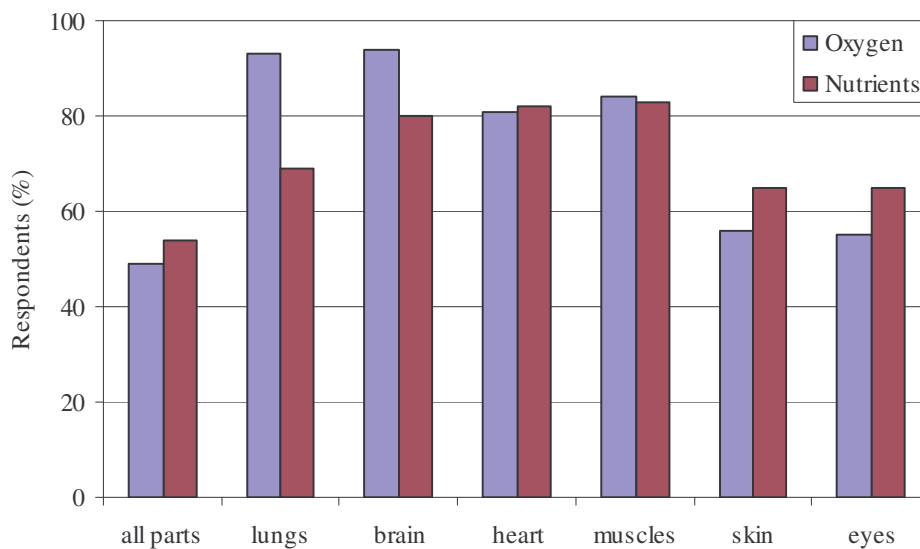
- |                                |  |
|--------------------------------|--|
| <input type="checkbox"/> skin  | <input type="checkbox"/> muscles               |
| <input type="checkbox"/> heart | <input type="checkbox"/> brain                 |
| <input type="checkbox"/> lungs | <input type="checkbox"/> don’t know / not sure |
| <input type="checkbox"/> eyes  |  |

Students were then asked “Why do you think nutrients are needed by the body part(s) selected?”



The responses, presented in Figure 5.17, were compared with responses that students had made to the 2004 questionnaire item which investigated students' views about human body parts that require oxygen (described above). As can be seen, approximately 80% of students indicated that the brain, heart and muscles require nutrients, with fewer (approximately 60%) indicating that the skin and eyes require nutrients. Fewer students indicated that the lungs require nutrients than had indicated that the lungs require oxygen, possibly because of the obvious role that the lungs play in gaseous exchange. Taken together with the finding that 85% of respondents considered all body parts to be composed of cells (see Section 5.3.3), it seems that there is a lack of understanding that all cells need nutrients.

Cross-tabular analysis was carried out to identify the proportion of students who indicated that each body part required both oxygen and nutrients, and the findings suggest that there was little consistency between responses (see Table 5.16 for a summary of the analysis). In particular, fewer than half the respondents



**Figure 5.17**  
Student views of human body parts that require nutrients and/or oxygen (n=125, 2004 questionnaire)

**Table 5.16**

Student views of whether various human organs require both oxygen *and* nutrients (n=125, 2004 questionnaire)

Body part	Respondents (%)
Brain	78
Muscles	74
Heart	69
Lungs	66
Skin	49
Eyes	49
All body parts listed	44

consider all the body parts listed as requiring both oxygen and nutrients. This has implications for the development of a holistic understanding of the role and significance of systems like the circulatory system within animals.

The function of nutrients in cells was investigated in a questionnaire item asking students to explain why nutrients are needed by the various body parts selected (question 8, 2004 questionnaire). Only 18% of respondents (n=125) referred to energy or cellular respiration (compared with 28% who indicated that oxygen is needed for energy creation). A further 16% referred to growth or cell reproduction, only 4% referred to both growth *and* energy. The remaining responses were more general and included references to cell survival and functioning (36%) or non-specific cell reactions (8%). Eighteen percent of respondents did not complete the question, with about half of these explicitly stating that they did not know the answer.

The findings suggest that a large proportion of students (just less than half) did not consider all the body parts referred to in the questionnaire item as requiring nutrients. Even fewer were able to provide a scientifically acceptable explanation for the role of nutrients in cells, and in particular to demonstrate links between nutrients, oxygen, and cellular respiration.

### Summary of Student Understandings of Cellular Respiration

The findings presented above suggest that a large proportion of students have limited understanding of the links between concepts such as cells' requirements of oxygen and nutrients, the function of these substances in cells, and the role and significance of the gaseous exchange, digestive, and circulatory systems in ensuring that cells are able to access these substances efficiently. This is perhaps exacerbated by the fact that animal systems and cellular biochemistry tend to be taught in separate courses at the first-year biology level, and there appear to be limited opportunities for students to be encouraged to develop a holistic understanding of organism functioning at both the organ and cellular level.

Some faculty reported in phase one of the research (see Section 4.5.1) that students do not need to have an understanding of cellular respiration prior to their study in first year biology papers since the topic is specifically taught. However, others reported that they do assume some understanding of the concept. Understanding of the underpinning concepts (e.g., the need for oxygen) also has the potential to affect student understanding of other topics, for example, gas exchange and circulatory systems in animals.

Some faculty may try to preface a new topic by placing it within a broader context, as was observed at one university when a lecturer introduced the topic of gas exchange by referring to the differences between aerobic and anaerobic respiration.<sup>32</sup> However, this was done only very briefly (in less than five minutes). Chemical equations were written up on the board, and students were required to have prior knowledge not only of aerobic and anaerobic respiration in general, but also ATP and its role as an energy carrier. Questions asked by students in subsequent tutorial classes suggest that this premise was not valid, a finding that is supported by the questionnaire responses reported above. Thus, although this faculty member did

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<sup>32</sup> Only two molecules of ATP are produced for every glucose molecule broken down during anaerobic respiration, compared with 36 ATP molecules produced for every glucose molecule broken down by aerobic respiration.

preface the lecture on gas exchange with an explanation that oxygen is used to generate energy, time limitations prevented him from going into detail, and some prior knowledge was thus vassumed.

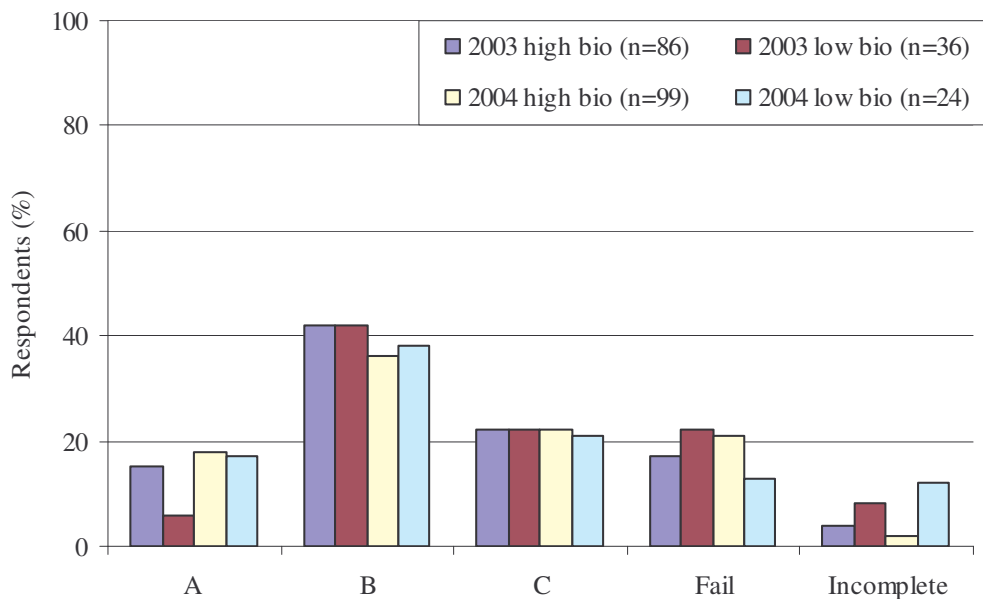
It seems that students' limited prior knowledge and the presence of alternative conceptions may affect their ability to understand the purpose, or significance, of processes like gas exchange and oxygen transport in the blood, and therefore their ability to see the 'bigger picture.'

## **5.6 BIOLOGY BACKGROUND AND COURSE ACHIEVEMENT**

The findings presented above suggest that students with more extensive prior biology study are more likely to have scientifically acceptable understandings of some, but not all, of the concepts that were investigated in the prior knowledge questionnaire. These differences, where they exist, are statistically significant. Further, many students (regardless of the amount of prior biology studied) did not demonstrate an understanding of the links between concepts.

In order to investigate the potential impact of prior knowledge of key biological, chemical and mathematical concepts (as identified in the prior knowledge questionnaires) on student learning, students' final course grades were compared with the amount of prior biology that was studied. Because of the nature of the data source, this could only be done for students who had completed the prior knowledge questionnaire (80% response rate in 2003; 61% in 2004). The course grade related to student achievement in a first-year course focusing on animal and plant biology.

The findings, presented in Figure 5.18, show that there was no statistically significant correlation between the extent of prior biology study and final course



**Figure 5.18**

Final course grades achieved by students who had completed the prior knowledge questionnaire

Note: An 'A' grade is equivalent to an end of course grade of 75% or higher; 'B' is equivalent to 60 – 74%; 'C' is equivalent to 50 – 59%; and 'Fail' is equivalent to a grade less than 50%. 'Incomplete' refers to students who did not complete the course.

grades ( $p > 0.05$ , based on a Chi-square test for independence). This suggests that prior biology study cannot be used as a reliable predictor for course achievement, despite the findings (presented above) that students with more extensive prior biology study were statistically more likely to have a scientifically acceptable understanding of some key biological concepts. However, it should be noted that the analysis was based on student grades for an animal and plant biology course, and not a cell biology course.

Since many of the concepts included in the prior knowledge questionnaires relate more directly to cell biology than to animal and plant biology, it could be that students' prior knowledge is more significant for success in these courses. The data were not available for this to be checked. In addition, responses to the prior knowledge questionnaire, reported above, suggest that the extent of prior biology

study affects student understanding of only some of the concepts assumed by faculty; in the case of other concepts, prior biology study did not appear to have had a significant impact on student understanding.

That the extent of prior knowledge does impact student learning was, however, evident in responses to selected assessment items. For example, in the first common topic test of a course on animal and plant biology,<sup>33</sup> students were presented with some of the terms used for classifying plant taxonomic groups (class, division, genus, species, kingdom) and asked to rank them in order from least inclusive to most inclusive. Only 44% of the class answered this question correctly. Students were also given a question which stated that *Zea mays* is the scientific name for sweet corn, and were asked to name the taxonomic group that ‘Zea’ belongs to (the scientifically acceptable response is ‘genus’). Only 63% of students answered this question correctly. Classroom observations revealed that the classification system was only briefly referred to in the second lecture, and there appeared to be the expectation that students were familiar with the concept (consistent with faculty reports that they assume students are familiar with this, see Section 4.5.1). However, the findings from the prior knowledge questionnaire (see Section 5.4.1, above), taken together with the data from the course assessment item, suggest that this assumption is not justified. In other words, although the extent of prior biology study did not appear to be correlated with course achievement in an animal and plant biology course, the impact of prior knowledge on student learning cannot be discounted.

## 5.7 CHAPTER SUMMARY

The findings presented in this chapter suggest that there are differences between what faculty expect students to know and what students do actually know. This was noticeable for a range of biological, chemical, and mathematical concepts.

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<sup>33</sup> This common topic test was the first of three tests administered for summative purposes as part of the course. A final exam, worth 60% of the total course assessment, was administered at the end of the course.

The differences are significant, since faculty had indicated that these concepts are ones that they assume students are familiar with, and that they are not explicitly taught in the first-year courses.

Perhaps not surprisingly, students with more extensive prior biology study were more likely to have a more scientifically acceptable understanding of some key biological concepts (e.g., the classification of animals, cells, DNA, chromosomes, genes, and patterns of Mendelian inheritance) but not others (e.g, the hierarchical system used to classify organisms, and the requirement of energy by living organisms). The differences in prior knowledge (as indicated by the extent of prior biology study) did not appear to be correlated with student achievement in the courses that were studied, although these findings may have differed if the analysis had been based on a cell biology course rather than an animal and plant biology course.

A further finding was that a large proportion of students appear to understand concepts in isolation, rather than as relating to each other, regardless of the extent of prior biology study. This lack of integration is important given faculty expectations that students will form connections between concepts and topics taught at different times during the first-year biology courses (see Section 4.5.1).

In an attempt to address these findings, an intervention using concept mapping was introduced during some tutorial classes. The details of the intervention and analysis of its usefulness are presented in Chapter 6.

# **Chapter 6**

## **Using Concept Mapping to Facilitate Teaching and Learning**

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### **6.1 INTRODUCTION**

Chapter 5 reported on the prior knowledge of students entering first-year biology courses at university. The findings showed, perhaps not surprisingly, that students who had undertaken more extensive prior biology study were more likely to demonstrate a scientific understanding of some, but not all, of the concepts that were investigated. The increasingly diverse academic background of students thus has implications for teaching in first-year biology courses. In particular, the more limited prior knowledge of some students may affect their learning in these courses. The findings from the prior knowledge questionnaire also suggest that very few students, regardless of their academic background, were able to make links between different concepts.



The work reported in this chapter sought to address these findings through the use of a concept mapping intervention implemented in tutorial classes. First, the nature of the intervention is justified in Section 6.2, and the specific research questions are listed. Section 6.3 provides details about how the intervention was implemented and evaluated. The findings are then reported, including: students' perceptions of the value of concept mapping as a teaching/learning tool (Section 6.4); the tutor's perceptions of the value of concept mapping as a teaching/learning tool (Section 6.5); and the influence of the concept mapping classes on student learning (Section 6.6).

## **6.2 JUSTIFICATION FOR THE CONCEPT MAPPING INTERVENTION**

A variety of 'pedagogical tools' are open to teachers to enhance student understanding of scientific concepts, including concept cartoons, analogies, and mental models (see Section 2.5). However, concept mapping has been promoted as "the most important meta-cognitive tool in science education today" (Mintzes, Wandersee, & Novak, 1997, p. 424), with numerous science educators and education researchers advocating its use in science classrooms. In particular, concept mapping is reported to help students learn more meaningfully (i.e., learn for understanding, as opposed to rote learning; see Adamczyk, Willison, & Williams, 1994; Fisher, Wandersee, & Moody, 2000; Novak & Gowin, 1984). Concept mapping has also been reported to aid collaborative learning (Roth, 1994; Sizmur & Osbourne, 1997; van Boxtel, van der Linden, Roelofs, & Erkens, 2002) and to improve students' problem-solving abilities (Okebukola, 1992).

As explained in Section 2.5.3, concept mapping is viewed as being able to promote meaningful learning because it helps the learner to identify relevant prior knowledge, recognise new concepts which need to be added, and make new connections between concepts (Novak, 2004; Taber, 1994; Trochim, 1989). Concept mapping is also a tool that enables misunderstandings and gaps in knowledge, which might lead to alternative conceptions, to be identified and addressed (Willson &

Williams, 1996). Used in this way, concept maps can thus act not only as a pedagogical tool, but also as a means of formative assessment. Other reported advantages include the visual nature of the resulting maps, seen to be inherently superior to more linear ways of organising information (Cliburn, 1987; Kinchin, 2000b); and the individualised nature of each concept map, reflecting individual constructions of knowledge (Freeman, 2004; Schmid & Telaro, 1990).

Because concept mapping provides students with a strategy to explicitly link and organise concepts, it was considered to be an appropriate tool to use in order to accommodate variations in first-year biology students' prior knowledge (identified in the earlier part of this research, see Chapter 5), and also to address the finding that few students were able to demonstrate links between concepts, regardless of the extent of their prior biology study. Specifically, the teaching intervention based on concept mapping was introduced to:

- encourage students to form explicit links between concepts
- assist students with more limited prior knowledge to recognise and address any gaps in their prior knowledge, and
- help students to become “active constructors of meaning” (Dawson, 1993, p. 74).

The research focused on whether the use of concept maps was appealing or a deterrent to students and what impact, if any, concept mapping had on student learning.

A large meta-analysis by Horton et al. (1993) suggests that concept mapping generally has positive effects on both student achievement and attitudes. However, there are few studies evaluating the usefulness of concept mapping in tertiary biology classes (Heinze-Fry & Novak, 1990; Kaya & Ebenezer, 2003; Smith & Dwyer, 1995; Yarden, Marbach-Ad, & Gersoni, 2004). Further, these studies tend to involve short-term use of concept mapping (one or two lessons), and data evaluating the effectiveness of concept mapping have been inconclusive (see Section 2.5.4). The paucity of evaluative data in the international science education literature thus provides further justification for the research.

Three research questions were used to guide this phase of the study:

1. What are students' perceptions of the usefulness of concept mapping as a teaching and learning tool?
2. What are the tutor's perceptions of the usefulness of concept mapping as a teaching and learning tool? and
3. What effect does the concept mapping have on student learning?

First, the nature of the intervention is described in detail. Later sections report on specific research findings.

### **6.3 THE NATURE OF THE CONCEPT MAPPING INTERVENTION**

The concept mapping intervention was implemented and evaluated in two successive courses during the periods July – November 2003, and March – July 2004. It occurred after the tutorials in each course had been observed as part of Phase 1 of the study (March – July 2003), and after the first prior knowledge questionnaire had been administered and analysed in Phase 2. This section describes the nature of the intervention, including the educational context in which it took place, and compares the intervention classes with the conventionally-run classes.

Whilst a variety of research tools were employed to evaluate the intervention, including classroom observations, interviews, quantitative instruments and the analysis of the results of common topic tests (see below), the study is not experimental in nature. Rather, it is exploratory and descriptive, seeking to uncover learners' experiences and to contextualise the work in the particular educational setting in which it was conducted. Hence, whether or not the findings are applicable in other educational settings is best judged by the reader (see Merriam, 2001; Peshkin, 1993).

### 6.3.1 Educational Context

The concept mapping intervention was implemented in two entry-level biology courses at a New Zealand university. The two courses focus on different content: *Course 1* includes topics related to cellular and molecular biology; *Course 2* emphasises animal and plant systems and diversity. However, they are similar in structure and pedagogy and include three 50-minute lectures each week, as well as a compulsory weekly, three-hour laboratory class. As at many other tertiary institutions (e.g., Dalgety & Coll, 2005; Laws, 1996; Ramsden, 2003), the lecturers tend to use a didactic teaching style based on a transmission model of instruction. Six different lecturers are responsible for delivering the lecture content for the two courses included in the study. The laboratory classes require students to complete a series of activities each week, including making observations using microscopes, performing dissections, and carrying out investigations designed to illustrate concepts covered during lectures.

In addition to the lectures and laboratory sessions, six tutorial sessions are offered each week. These run for 50 minutes and attendance is voluntary. The classes are taught by a range of staff, including a tutor employed specifically for this purpose, and the lecturer who is giving the lectures at the time (all are subsequently referred to as “tutors”). Because these classes are smaller, and at least potentially more interactive than large-scale mass lectures, they were considered to be the most appropriate educational vehicle for introducing concept mapping. Tutorial classes are also reportedly viewed by tertiary science students as being the most useful (when compared with laboratory classes and lectures) in terms of preparing for topic tests and examinations (Dalgety & Coll, 2005; Hobden, 2001; Jackman, Moellenberg, & Brabson, 1990).

Despite their potential to facilitate student learning, tutorials are often teacher-driven and based around a series of pre-set questions (Dalgety, Coll & Jones, 2003). This tended to be the case in the first-year biology courses prior to the intervention.

Questions and suggestions for discussion were included in the back of the course manual handed out to each student at the start of the courses. Although some of the tutors would start off by asking, “What would you like to discuss today?” the lack of immediate response from students meant that in the majority of cases the tutors would work their way sequentially through the pre-set questions (based on classroom observations carried out in the semesters prior to the implementation of the intervention, see Section 3.4.1).

In an attempt to use the tutorials to address some of the findings revealed by the prior knowledge questionnaires, concept mapping was introduced as a teaching and learning tool in two of the six tutorial classes offered each week for 11 teaching weeks (no tutorials were held during the first week of the 12-week teaching semesters). The other tutorial classes were run in the conventional manner and consisted mostly of the tutor going through pre-set questions. The two different classroom teaching approaches will be referred to as “concept mapping tutorials” and “conventional tutorials” respectively. One tutor, referred to as Angela (a pseudonym), took all the concept mapping tutorial classes as well as some of the conventionally-run tutorials. In *Course 2* she consistently taught at least two of the conventional tutorial classes each week in order to minimise any tutor-specific effects on the findings. A different cohort of students was enrolled in *Course 1* and *Course 2*.

The methods used to gather data are described in detail in Section 3.4.3 and included: classroom observations; informal discussions with students; a survey of student perceptions of the use of concept mapping as a pedagogical tool; interviews with the tutor; and analysis of student responses to selected questions in common topic tests administered for the purpose of course assessment. The following section provides a detailed description of the concept mapping tutorials, compared with the conventional tutorial classes.

### 6.3.2 Description of Tutorial Classes

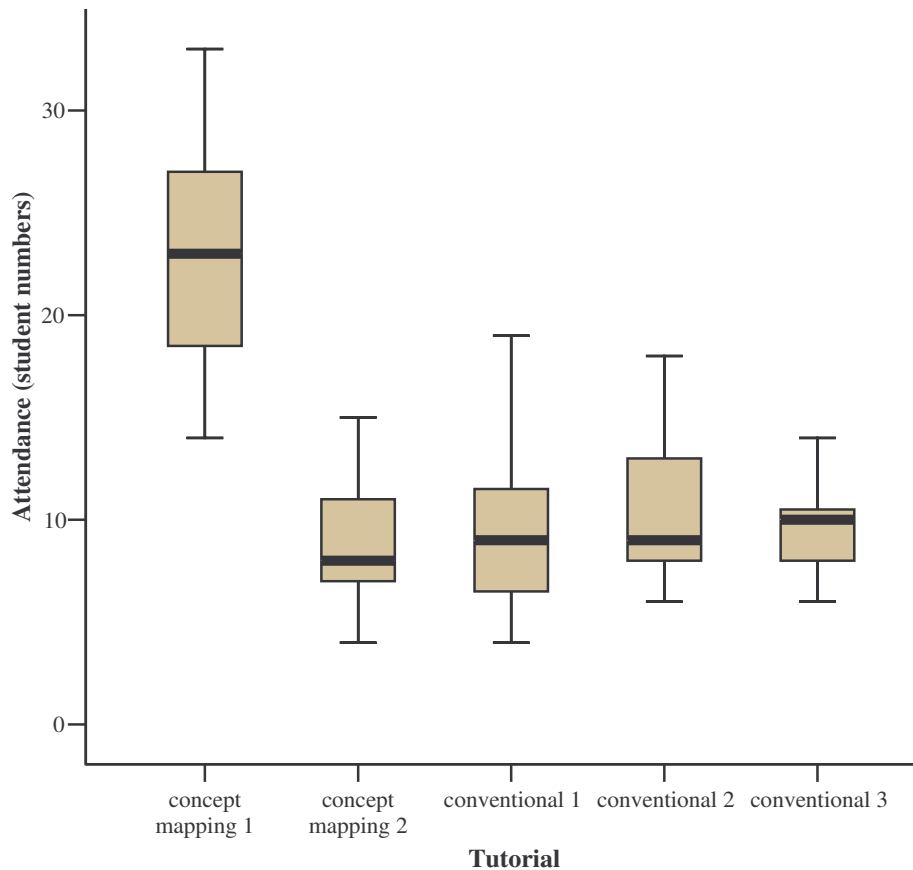
Because of the voluntary nature of the tutorial classes, student attendance fluctuates from week to week. Although attendance was not traditionally recorded in these classes, students were asked to write their student identification numbers on an attendance sheet for the purposes of the research (see Section 3.4.1). These data were used to identify patterns in attendance, and to check for any differences between cohorts attending the concept-mapping and the conventional classes. The data were also required in order to investigate any correlations between tutorial attendance and performance on specific assessment questions (see Section 6.6 below). The researcher did not have access to information that listed student names against their identification numbers, and was thus unable to identify individual students from the numbers.

Table 6.1 summarises the fluctuations in tutorial attendance in *Course 1*. Although the numbers may seem low, just over two-thirds of students attended at least one tutorial class during the 11-week teaching period, with nearly one third attending seven or more tutorials (an average of more than one tutorial every two weeks). Nearly 20% attended two or more different time slots, presumably due to other commitments in any given week. The results therefore demonstrate that attendance is erratic, both in numbers attending, and sessions which students attend in a particular week (i.e., they do not necessarily attend the same session each week).

**Table 6.1**  
Student attendance at tutorial classes in *Course 1* (n=166)

<b>Number of tutorials attended</b>	<b>Students (%)</b>
0	29
1-3	27
4-6	16
7-9	18
10-12	7
13 or more	2

Attendance at the concept mapping tutorials versus the conventional tutorials in *Course 1* is presented in Figure 6.1 and shows that there were no statistically significant differences in numbers of students attending either the concept mapping or the conventional tutorials ( $p > 0.05$ , based on a Chi-square test for independence). Similar patterns of attendance were recorded for *Course 2*. The slightly higher attendance for “concept mapping 1” seemed to largely be due to the timetabling of this tutorial directly before the course lecture, making it a convenient time slot for students to attend (based on informal interviews with the students). The fourth conventional tutorial was cancelled due to very low attendance during the first two weeks (four and two students respectively). This tutorial was held early on a Friday morning and may have clashed with other courses in which students were participating.



**Figure 6.1**  
Student attendance at weekly tutorial classes over the 11 teaching weeks associated with *Course 1*

Note: A box and whisker plot is used to show the spread of data.

The study was not experimental in nature, in the sense that tutorial attendance was voluntary and students were not randomly assigned to tutorial groups (either concept mapping or conventional). However, there did not appear to be any obvious differences between students self-selecting to attend the concept mapping tutorials and those who chose to attend the conventional tutorials (based on informal interviews with students). Specifically, more than half the students participating in *Course 1* of this study had already completed a first-year biology course during the preceding semester,<sup>34</sup> and end of semester grades from this latter course did not reveal any differences between students attending the concept mapping tutorials and those attending the conventional classes during the subsequent semester ( $p > 0.05$ , based on a Chi-square test for independence; see Figure 6.2). Data were not available to compare students who had not already completed a first-year biology course prior to participating in *Course 1* of this study.

Descriptions of the teaching and learning approaches adopted in each the concept mapping and conventional tutorial classes are provided in the following sections.

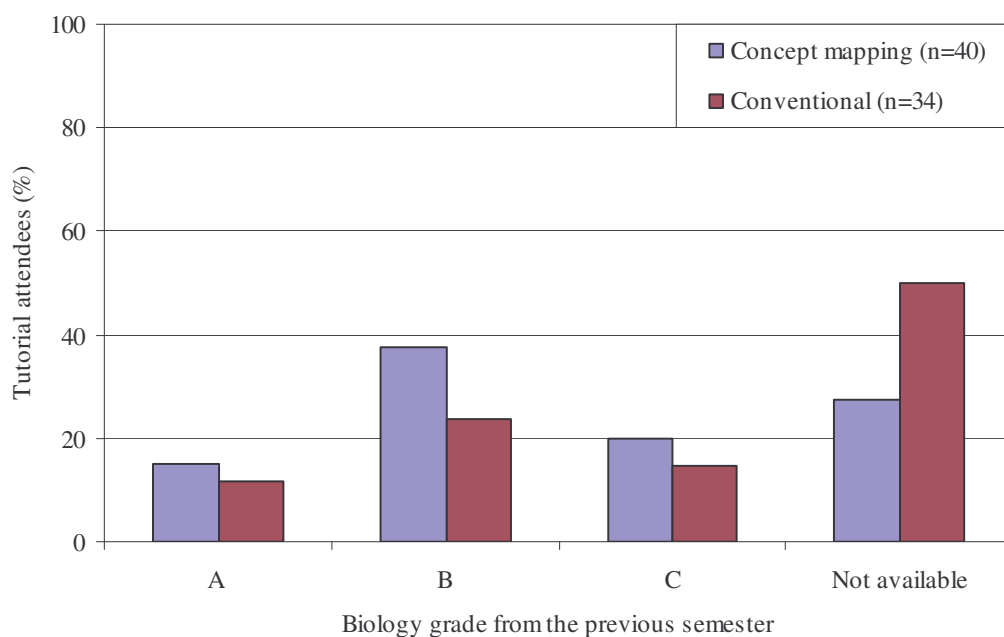
### Concept Mapping Tutorials

The potential benefits of concept mapping in learning science were presented in the first few weeks of tutorial classes, and the tutor modelled the construction of several different concept maps on the board. These maps were based on questions raised by students about topics that had been covered in the lectures (e.g., “Can we go over cell division?”) and the tutor used open-ended questions to encourage the class to contribute to the construction of the maps. Once concept mapping had been modeled in this way, students were encouraged to work as individuals or in groups to construct their own concept maps.

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<sup>34</sup> Course 1 of this study took place July – November 2003; more than half the students participating in this course had already completed a different first-year biology course offered at the same university during March – June of the same year.





**Figure 6.2**

Previous semester's biology grades (March – June 2003) for students participating in the concept mapping and conventional tutorial classes in *Course 1* (July – November 2003)

Note 1: Students were considered to have attended concept mapping or conventional tutorial classes if they attended those classes four or more times over the semester (because attendance is voluntary, very few students attended each week, see Figure 6.1).

Note 2: An 'A' grade is equivalent to an end of course grade of 75% or higher; 'B' is equivalent to 60 – 74%; and 'C' is equivalent to 50 – 59%.

Note 3: Data were only available for students who had completed a first-year biology course in the semester prior to *Course 1* of this study.

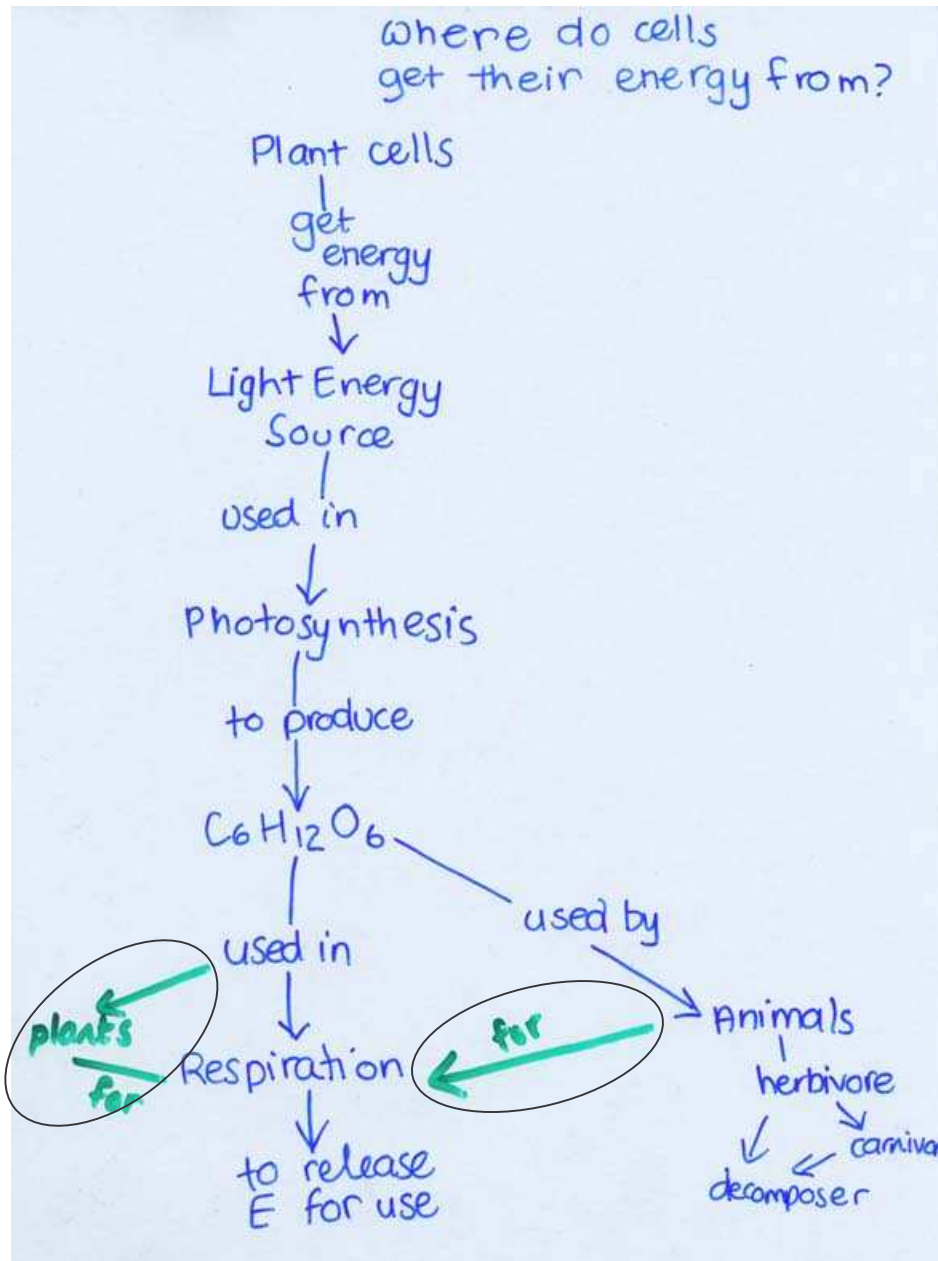
In *Course 1*, adhesive-backed notes were used by students during the first few sessions. A list of important concepts related to the topic being discussed was created on the board by the tutor and students, and the students were encouraged to write these down on their sticky notes and rearrange them to form a concept map. This method of introducing students to concept mapping has been described by Kinchin (2000b) as a useful way of letting students plan a map without having to rewrite the concepts.

Although students arranged the concepts using the sticky notes, they tended not to write down the linking terms between the concepts. Instead, they waited for the whole-class discussion when the tutor modeled a concept map using the concepts

that had been identified, and the students then rearranged their concepts to reflect this – despite the tutor taking care to point out: “There are no ‘right’ and ‘wrong’ maps; this is just one way of doing it.” For this reason, the sticky notes were not used beyond the fourth week, and students were instead encouraged to work as individuals or groups to prepare concept maps on overhead transparency sheets. While students were constructing their maps, the tutor moved around the class to discuss the technique and/or specific concepts with small groups of students. Students were also able to ask the tutor questions during this time. When it appeared that most groups had completed their maps all the overhead transparency sheets were collected and displayed, the tutor using them to facilitate whole-class discussion. During this discussion she was very affirming about the work that had been produced and pointed out, for example, the range of different maps constructed for a particular set of concepts, as well as additional links that could have been included. She also addressed any alternative conceptions that had been revealed in the maps, for example by pointing out changes that would make linking terms more scientifically acceptable. Finally, photocopies of all the concept maps were made available to those students who had attended the relevant tutorials through their laboratory classes.

Examples of two concept maps constructed by students are presented in Figures 6.3 and 6.4. These maps were constructed by the same group of students in *Course 1* and show that the earlier map (Figure 6.3), whilst appearing hierarchical in structure and including linking words, was very linear. In contrast, the later map (Figure 6.4) shows more cross-links between concepts. In general, the greater the number of valid links between one concept and others, the more sophisticated the map is considered to be (Novak & Gowin, 1984). These maps, and others like them, therefore suggest that the skill of students in constructing concept maps improved over the 11 weeks of tutorial classes.

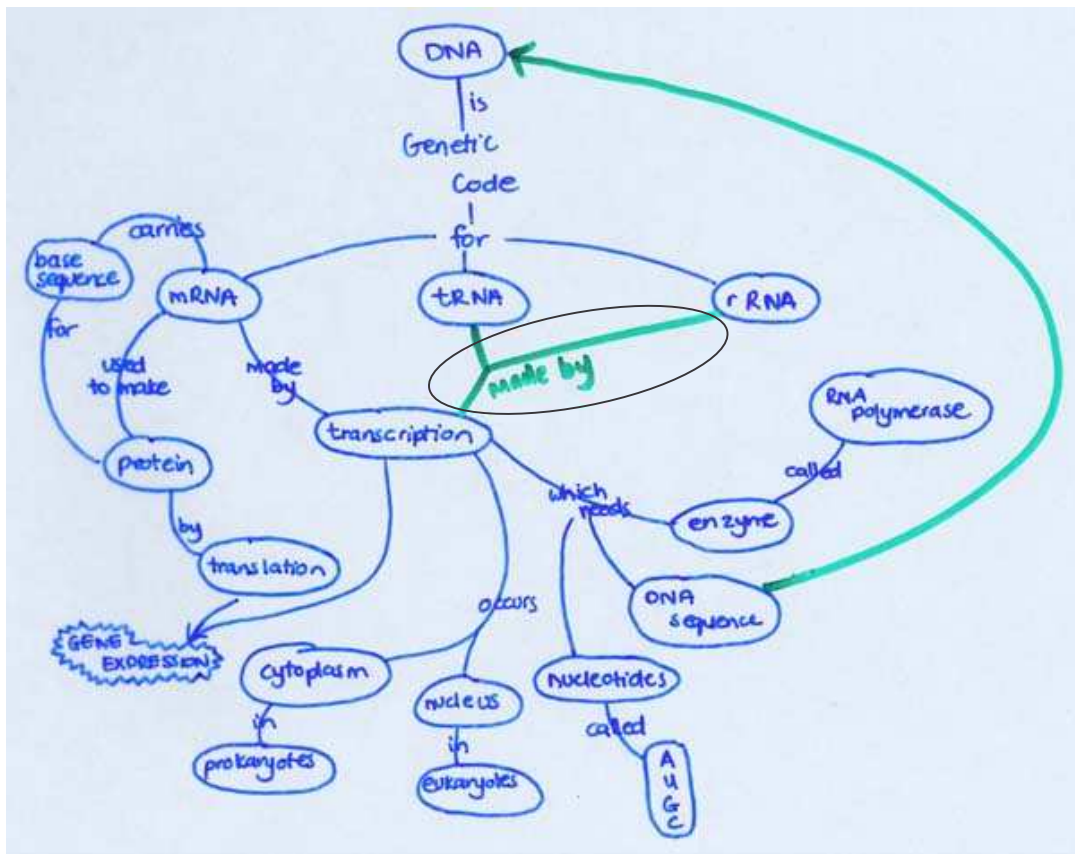
The strategy described above is time-intensive and only two or three conceptual themes could be developed in this way within one 50-minute class.



**Figure 6.3**  
 Student concept map showing energy sources for cells

Note 1: This concept map was constructed on an overhead transparency sheet by a group of three students early in *Course 1*.

Note 2: Links that have been circled were added by the tutor as part of the whole-class discussion to emphasise that the carbohydrates produced by photosynthesis are used by both animals and plants for cellular respiration.



**Figure 6.4**  
Student concept map showing the role of DNA in cells

Note 1: This concept map was constructed on an overhead transparency sheet by a group of three students late in *Course 1*.

Note 2: Linking lines that have been circled were added by the tutor as part of the whole-class discussion to emphasise that tRNA and rRNA are also made by transcription. The linking line joining 'DNA sequence' with 'DNA' at the top of the concept map was also added by the tutor, saying: "This is why we talk about DNA being the genetic code."

Students were encouraged to ask their own questions, and sometime these covered a range of themes, particularly before tests. In these cases, the tutor tended to construct a general concept map on the board, using student input from the class all the way through, rather than spending time on just one or two of the questions and allowing time for students to construct their own concept maps. The concept mapping classes therefore included a mix of both teacher and student-generated maps. The tutor believed that this was important so that all students' questions could be adequately addressed. The approach is also consistent with the social-constructivist nature of the study. As described in Section 2.2.3, this view of learning posits that whilst learning is an individual activity in that each individual constructs

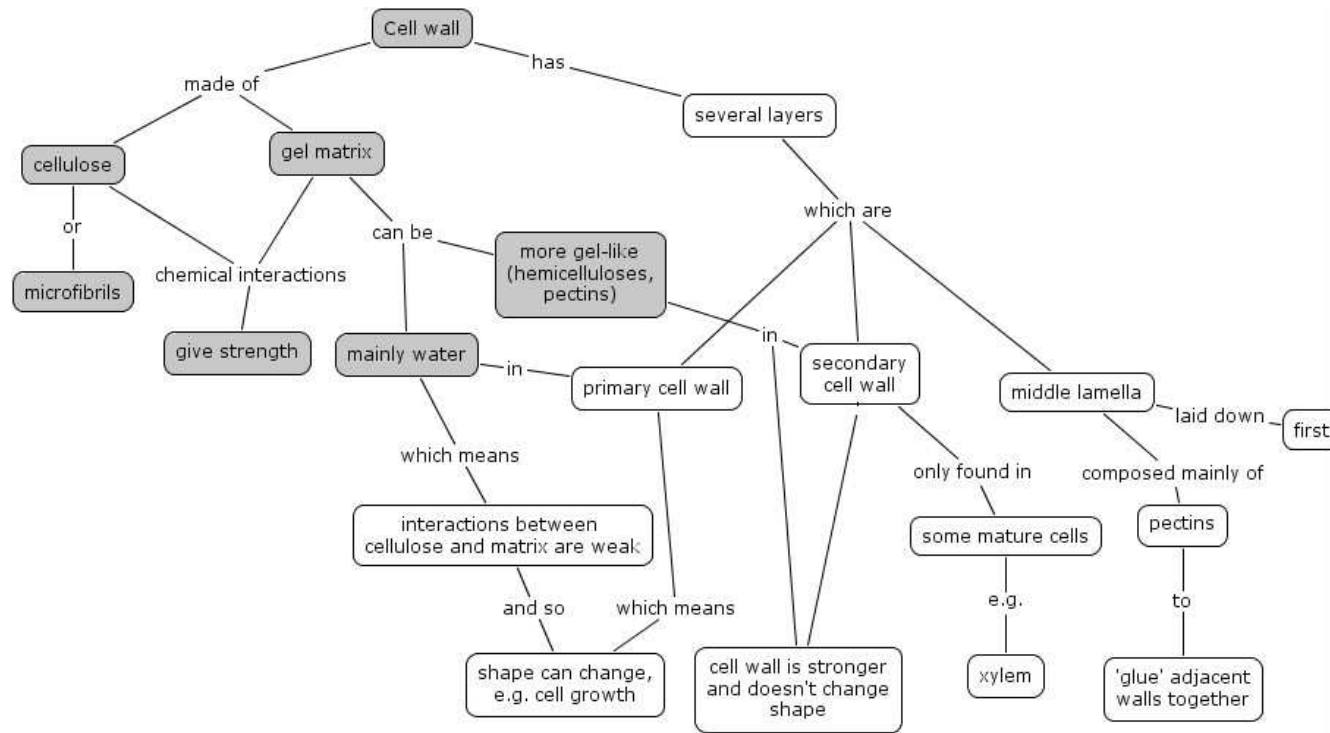
meaning in his or her own mind, the learning is carried out within a particular social context. The intention was thus to help students to co-construct knowledge, facilitated by the tutor as the more knowledgeable peer (Vygotsky, 1962).

An example of the dialogue between the tutor and students as the tutor modeled the construction of a concept map on the board is presented below. A copy of the concept map that was constructed during the conversation is presented in Figure 6.5 (shaded concepts relate directly to the discussion excerpt).

- Student 1: I have a question about the cell wall and microfibrils – how can they bend?
- Tutor: Your question relates to the structure of the plant cell wall.
- Student 1: I don't understand how they change their hydrogen bonds, and how they change their shape or something?
- Tutor: What Katie<sup>35</sup> is referring to is the way that the primary cell wall can expand, allowing the cell to grow, but when the secondary cell wall is laid down then the shape of the cell becomes fixed. So let's think about cell walls [*writing cell wall on the board*]. What are they composed of?
- Student 2: Cellulose.
- Tutor: Good [*writing cellulose on the board and joining it to cell wall using the linking term made of*]. What else? What holds it together?
- Student 3: Peptidoglycan?
- Tutor: No, that's found in bacterial cell walls. We're talking about plant cell walls.
- Student 2: The gel matrix?
- Tutor: Yes. So there's the cellulose, which is held in place in the gel matrix [*writes gel matrix on the board and joins it to the cell wall concept*]. And it's the interactions between the two – the cellulose and the matrix – that give the cell wall its strength [*adds chemical interactions and give strength to the developing concept map*]. Now, what is the gel matrix made up of?
- Student 4: Hemicelluloses and pectins? [looking in course notes]
- Tutor: Yes, you could say the hemicelluloses and the pectins. Those are the gelling part. But in primary cell walls, the matrix is mainly water. The hemicelluloses and the pectins are more concentrated in the secondary cell walls [*writes that the gel matrix can be mainly water, or more gel-like*]. So now we're introducing some new concepts. The primary cell wall and the secondary cell wall ...

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<sup>35</sup> Pseudonyms have been used throughout.



**Figure 6.5**  
Class concept map showing concepts related to cell wall structure

Note: This concept map was constructed as part of a whole-class discussion, with the tutor incorporating students' responses to her guided questions. It was copied from the board and reproduced here using IHMC software available from <http://cmap.ihmc.us/>. Shaded boxes represent concepts referred to in the discussion excerpt presented in the text.

This dialogue is typical of the discussion between the tutor and students (both as individuals and as a whole class), and shows how the tutor tried to elicit student ideas when building up the concept map. Recording the ideas in a concept map on the board meant that students had a visual representation of the concepts being discussed, and the linking terms made the relationship between concepts explicit.

### Conventional Tutorials

Discussion in the conventional tutorials tended to be driven primarily by a list of pre-set questions available to students prior to the tutorials in their course lecture manual. The level of student input into the discussion seemed to be largely determined by the teaching style of the tutor (several different tutors were responsible for these sessions, see Section 6.3.1) and ranged from being fairly interactive, where the tutor would ask students for the answers to the questions; to very teacher-directed, where the tutor would write the answers up on the board with very little student input. Writing on the board, if it was done at all, tended to focus on the construction of linear lists generated in response to the tutorial questions.

Angela, who took all the concept mapping tutorials and some conventional tutorials, had the most interactive style of all the tutors taking the conventional classes, and preferred that students ask their own questions rather than automatically working through the pre-set tutorial questions. Because of her participation in the current study (comparing learning outcomes for concept mapping tutorials versus conventional tutorials) her manner of responding to the questions in the conventional classes was limited to more linear presentations of information on the board.

## **6.4 STUDENTS' PERCEPTIONS OF THE VALUE OF CONCEPT MAPPING AS A TEACHING/LEARNING TOOL**

Three research questions were used to evaluate the concept mapping intervention (see Section 6.2), the first being: What are students' perceptions of the usefulness of concept mapping as a teaching and learning tool? This question was

deemed necessary since unfamiliar pedagogies may have a negative influence on tertiary-level students, who quickly become accustomed to lectures in which they can ‘turn off’ and become passive learners (Dalgety & Coll, 2005). Hence, a new teaching approach – whatever its potential learning benefits – needs to be introduced with caution.

Student responses to the tutorial classes were collected using ‘tutorial experience questionnaires’ administered during the tutorial sessions in the last teaching week of each course. In *Course 1*, an open-ended questionnaire was used (see Appendix G) and included questions such as:

- What do you like about the way this tutorial session is normally run?
- What would you change about the way this tutorial session is normally run?
- Please comment specifically on the use of concept mapping in this tutorial session.

The responses to this questionnaire were analysed according to themes that emerged from the data (Patton, 2002), and these are presented below. The analysis was also used to develop a questionnaire incorporating Likert scales (Appendix H), which was administered to students in *Course 2*. Thus, data obtained from the first cohort of students were largely qualitative, whilst more quantitative data were obtained from the second cohort. The response rate was 100% for both courses as a result of the captive nature of the questionnaire administration (n = 27, *Course 1*; n = 35, *Course 2*). A modified form of the questionnaire was also administered to students attending conventional tutorial classes in *Course 2* (Appendix I; n = 17). This was intended to provide a comparison with the concept mapping tutorials (i.e., to check whether responses could be correlated specifically with concept mapping, or tutorial attendance in general). The validity of the instruments was enhanced through follow-up interviews (n = 12, *Course 1*; n = 8, *Course 2*) which probed students’ responses to questionnaire items, and confirmed that what had been written reflected their opinions about the tutorials.<sup>36</sup>

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<sup>36</sup> Students were asked at the end of the questionnaires to indicate if they were willing to participate in a follow-up interview and, if they were, to provide their names and contact details.



A summary of responses to the tutorial experience questionnaire administered in *Course 1* is presented in Table 6.2; responses to the questionnaires administered in *Course 2* are presented in Table 6.3. As can be seen, students considered the concept mapping tutorials to be helpful, both in terms of understanding the material and highlighting areas that they needed to revisit in their learning. Students who attended the conventional tutorials reported similar outcomes, suggesting that attendance at either form of tutorial was considered by the students to be useful. Students also reported that they felt relaxed in tutorial classes, and that they had to think, regardless of whether they had attended the conventional or the concept mapping tutorials. Although all students indicated that the tutorials had helped them to see links between concepts, the concept mapping cohort were more likely to strongly agree with this statement (69% versus 29%,  $p < 0.01$  based on a Chi-square test for independence).

A more detailed description of the following themes is presented below: concept mapping as a tool to summarise and learn course content; concept mapping as a tool to help students form links between concepts; concept mapping as a tool to encourage active participation of students; concept mapping as a tool to facilitate cooperative learning; and classroom management strategies.

**Table 6.2**

Responses to the tutorial experience questionnaire administered in the concept mapping classes during the last week of *Course 1* (n=27)

Response themes	Response frequency (%)
Concept mapping is helpful for summarising, revising and recalling lecture content	67
Concept mapping is helpful for linking concepts	33
Constructing concept maps as individuals or small groups is helpful	37
It would have been more useful to focus directly on past test and exam questions in tutorials	15
Concept mapping is time consuming	7

Note: Responses were grouped by themes that emerged from the data.

**Table 6.3**

Responses to the tutorial experience questionnaire administered during the last week in *Course 2* (n=35, concept mapping tutorials; n=17, conventional tutorials)

Questionnaire items	Agree / strongly agree response (%)	
	Concept mapping tutorials	Conventional tutorials
Concept mapping seems to be a good way to study biology	100	
The tutorials helped me to understand the material	100	100
The tutorials helped me to see the links between concepts	100	100
It is easy to learn how to do concept mapping	74	
I found it useful to be able to work on making a concept map on my own or with other students	91	
I felt that there was enough time for me to ask questions during the tutorials	83	100
I found that I had to think during tutorials	100	100
I felt relaxed in the classroom environment	94	94
I would have preferred it if the tutor had answered questions <i>without</i> using concept mapping	6	
The tutorials are helpful because they show me what I know and what I need to learn more about	94	100
I have sometimes used concept mapping for studying biology outside of the tutorials	77	
I have sometimes used concept mapping for studying in my other courses	49	

#### ***6.4.1 Concept Mapping as a Tool to Summarise and Learn Course Content***

A common theme to emerge from the data from both courses was that students considered that tutorials (both conventional and concept mapping classes) helped them to understand course material (see Tables 6.2 and 6.3). However, students who attended the concept mapping tutorials tended to specifically link the ‘usefulness’ of the classes with the use of concept mapping. For example, Sally wrote on the tutorial experience questionnaire: “I have attended other tutorials, but I find the concept mapping tutorials more informative and you learn the content better.” Andrew reported: “I like concept mapping. It’s a good way to present information, and makes it easier to remember ideas.” Alice liked the way that “concepts are covered step by step.”

In particular, concept mapping was considered by students to be a useful tool for summarising the large mass of material that undergraduate biology students tend to encounter in first year classes. As Angus wrote: “Concept maps are very good at summarising the material, as the lecturers often go into detail but it is sometimes hard to put it all together.” This comment was echoed by Alister, who wrote: “I really like the concept mapping because it helps eliminate the clutter and ‘fluff’ terminology,” and Ben reported: “It’s a lot easier to understand than just reading from the notes.”

A large proportion of students also reported using concept mapping for other topics in their biology courses (77% in *Course 2*) and other science courses (49% in *Course 2*). As Candice explained: “The mindmaps are very helpful and allow me to create ‘quick study’ notes of my own ... It has made me use them for other subjects and for other topics in biology.” Other students met with the tutor outside of tutorial classes to discuss concept maps that they had constructed during or after lectures. Several students also used concept maps to answer test questions and construct essay plans in their responses to course assessment tasks (these summative assessment tasks were part of normal course teaching). This suggests that a large proportion of students viewed concept mapping as a useful general learning strategy, and that they applied it to their learning outside of the tutorial classes.

In contrast, a few students indicated that concept mapping would not be their learning style of choice. As Heather explained in an interview: “I’m more of a bullet point person. That’s simply because that was the way I was taught at high school ... I’ve gotten more familiar with it [concept mapping] now and I can actually follow it, but I can’t say that I would actually use it.” Similarly, two other students indicated that they “would prefer to do notes.” These students also indicated during subsequent interviews that they felt more comfortable using their traditional learning strategies, and that these strategies had been sufficient in terms of enabling them to reach their academic goals. They therefore did not see a reason for adopting a new study strategy.

Concept mapping, by its nature, also requires students to have an understanding of each of the concepts before they can be incorporated into a concept map. As one student was heard to comment during a tutorial class: “You need to know what you’re doing in those [concept mapping] tutorials.” When she was asked to elaborate on this, she explained that she found it difficult to link the concepts together when she was still trying to work out what each concept on its own represented. Rachel similarly commented in the tutorial experience questionnaire: “I am a mature student and I found this type of learning [i.e., using concept maps] difficult as I am not familiar with the terminology and my knowledge of the subject isn’t good enough.” On the other hand, Molly (an NESB<sup>37</sup> student) reported: “I always have trouble with new terms ... the concept mapping style is helpful especially for me as things are written down simply.” Brian, another mature student, wrote: “You can work out what you know and don’t, and then it makes sense when the gaps in knowledge are filled in.” These responses suggest that although some students with more limited prior knowledge found it difficult to construct concept maps for the topics raised during tutorial classes, others found the tool helpful in clarifying concepts as well as ‘gaps’ in their knowledge.

A handful of students also reported that they would have preferred it if the tutor had not answered questions using concept mapping, apparently because concept mapping did not directly help them to answer assessment tasks correctly. For example Chin, an NESB student, wrote: “It will be helpful to get ideas how to answer test questions.” Pan, another international NESB student, wrote: “Concept mapping has helped me learn the material more effectively. However, it didn’t help much on how we should answer the test questions.” These students indicated that they would have preferred to have spent less time on concept mapping, and more time focusing directly on past test and exam questions.

In summary, the majority of concept mapping students who completed the tutorial experience questionnaire indicated that they found concept mapping to be a

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<sup>37</sup> Non-English speaking background.

useful method for studying biology, and many reported using the technique as a learning tool outside of tutorial classes. This was also evident in the responses to a range of tasks administered for summative assessment purposes in the courses. However, negative case study analysis (Roth, 1994) showed that some students elected not to adopt the technique in their learning outside of tutorial classes, apparently because they preferred to use their existing study strategies. Some also found it frustrating that concept mapping did not seem to directly give them the 'right' answers to test questions that they could then copy down.

#### ***6.4.2 Concept Mapping as a Tool to Help Students Form Links Between Concepts***

The concept mapping intervention was introduced specifically to encourage students to consider the interrelationships between different concepts. At the start of each class, the tutor emphasised out the need for students to develop the ability to integrate information and to see the "big picture", and that concept mapping is a tool to help them do that.

It is interesting that students who attended the concept mapping tutorials, and also those who attended the conventional tutorials, indicated on the tutorial experience questionnaire that the classes had helped them "to see links between concepts" (see Table 6.3). However, the concept mapping cohort was more likely to *strongly agree* with the statement "The tutorials helped me to see links between concepts" (69% versus 29%,  $p < 0.01$  based on a Chi-square test for independence). This was consistent with responses to the open-ended questionnaire administered in *Course 1*. For example, Sue reported: "The concept maps have helped me as it is easier to understand the way bits of a topic link together." Renee similarly reported that concept mapping "helps you piece things together and include all the data you need," and Alan wrote: "Concept mapping is good for tieing [sic] many processes together."

Other students indicated that they found that the concept mapping tutorials helped them to understand the lecture content more clearly because the links between concepts are made explicit. For example, Diana wrote on the tutorial experience questionnaire: “Concept mapping has definitely helped because in the lectures the concepts were quite muddled,” and Paula wrote: “Concept mapping shows the interrelations between groups of ideas.”

In summary, students seemed to consider concept mapping to be a helpful strategy to determine the relationships between concepts, and between different conceptual themes. The actual impact of concept mapping on student learning is explored in more detail in Section 6.6.

#### ***6.4.3 Concept Mapping as a Tool to Encourage Active Participation by Students***

An important feature of the intervention strategy was that there was opportunity in most classes for students to construct their own concept maps, either individually or in small groups. This was specifically referred to by a number of students at the end of *Course 1* (see Table 6.2), and at the end of *Course 2* the majority of participants reported that they found it useful to construct their own concept maps, either individually or in small groups (91%, see Table 6.3).

There seemed to be several reasons why students valued the opportunity to construct their own maps. One of these was that they felt the activity actively engaged them in the learning process. The other appeared to be the opportunity for collaborative learning (see Section 3.4.4).

All students, regardless of whether they attended the conventional tutorials or concept mapping tutorials, indicated on the tutorial experience questionnaire administered in *Course 2* that the classes had helped them to think (see Table 6.3). A number of students had also specifically linked this with the opportunity to construct their own concept maps. For example, Martin wrote that he liked the way “there is

time to do our own problem-solving” and Alice wrote that she liked the way the tutorials were “hands on instead of just listening.” This suggests that one of the aims of the intervention, namely, to use concept mapping to help students become ‘active constructors of meaning’ (see Section 6.2), may have been met.

In contrast to the more common positive views of concept mapping, a few students (7% at the end of *Course 1*) reported that they felt concept mapping was too time-consuming. For example, Chris wrote: “A lot of time is wasted. [The tutor] asks the class to do things which she could do in two minutes.” Allan similarly commented when interviewed: “If you knew it, you didn’t have to think about it. And if you had to think about it, it was too hard for you to know it.” These comments suggest that a few students did not value the opportunity to extend their own thinking about the links between concepts.

It is also worth noting that not all students wanted to actively participate in tutorial discussions. As Tammy commented in response to the questionnaire related to the conventionally-run tutorial classes: “You can just listen if you don’t want to ask questions.” Ellen, who first attended concept mapping tutorials but then switched to attend a more conventionally-run tutorial class, reported: “I started going to non-concept mapping tutorials ... [The tutor] just feeds you the information.”

It seems that the majority of students valued the opportunity to construct some of the concept maps on their own or in small groups, and that they felt that this helped them to engage in their own learning. However, a few students indicated that they did not see much value in the activity, and some explicitly reported that they preferred tutorials where they could adopt a more passive role.

#### ***6.4.4 Concept Mapping as a Tool to Facilitate Cooperative Learning***

Another significant advantage of the approach that was taken during the concept mapping tutorials appeared to be the opportunities for collaborative learning.

These opportunities included both teacher-student interactions (during whole-class discussions, and as the teacher moved amongst the students while they constructed their own concept maps); and student-student interactions (as students worked together to construct concept maps, and when students answered each other's questions within the whole-class setting).

During the early sessions students who already knew each other (e.g., they had come into the class chatting together) tended to work together to construct concept maps. However, in later tutorials the formation of new learning groups was observed, suggesting that students became more comfortable with the idea of working together with other students whom they likely knew less well. In addition, students did not necessarily participate in the same learning groups in each session, but tended to work with whoever was sitting closest to them. The interactions that were observed between the students in these groups suggested that there was a lot of 'peer-coaching,' with each student having to justify to their peers why they would place concepts in particular positions on the concept map being constructed. There was also discussion about which concepts to include, and whether any additional concepts were needed.

Students specifically appeared to value the interaction with the tutor. Questions were asked both within the whole-class setting (e.g., to clarify a statement that either the tutor or another student had made) and within small groups as the tutor moved around the class when students were working on their own concept maps. Students used this opportunity to check details (e.g., definitions) related to the task, and to ask the tutor questions that were unrelated to the discussion topic but that had come up during their own private study. As Marcia wrote on the tutorial experience questionnaire, she liked the way Angela "always comes round to every group to make sure everyone understands." This suggests that the tutor-student interactions were considered by the students to be helpful to their learning.



The interaction between the tutor and small groups of students additionally meant that there was opportunity for all students to have their questions addressed, even if the questions were not related to the topic being formally discussed. This was not always possible in a whole-class setting when students might have been embarrassed to ask their questions in front of the rest of the class, or where time may have limited the number of questions that would be answered in-depth. Further, the skill of the tutor in responding to students' questions was considered to be important. For example, Heather commented that Angela "has the ability to make you think for yourself while at the same time guiding you to the correct answers if there is a misconception."

The concept mapping approach used during the intervention tutorials therefore appeared to provide useful opportunities for cooperative learning, both between students, and between students and the tutor. The skill of the tutor in facilitating dialogue appeared to have a significant influence on the usefulness of the interactions.

#### ***6.4.5 Concept Mapping and Classroom Management Strategies***

Students commented specifically on several classroom management strategies related to the application of concept maps as a teaching and learning tool. Students' views of the usefulness of self-constructed maps and opportunities for cooperative learning have already been described above. Other features of the intervention that received comment from students included the importance of taking time to teach students to construct concept maps, and the role of whole-class feedback.

The research literature expounding the use of concept maps in science education takes care to point out the need to teach students how to construct concept maps (e.g., Novak & Gowin, 1984). This was reflected in comments from several students. For example, Heather wrote: "Concept mapping is not a technique that I have been taught or used and at first I found it very confusing." It therefore appeared to be important for the tutor to introduce the technique by modeling the construction

of several concept maps, explaining the key points of the process as she did so (e.g., that linking terms are used to show the relationships between concepts). The tutor then circulated among the students as they constructed their own maps in class, checking informally that they knew what they were expected to be doing. Because the tutor taught the concept mapping classes each week she was also able to pick out the ‘newcomers’ and ensure that they had understood the instructions and knew what to do. Displaying students’ maps on the overhead transparency projector and commenting on their construction within a whole-class setting provided further opportunity to reinforce the importance of making the relationships between concepts explicit through using of relevant linking terms. Displaying the students’ maps in this way also provided visual examples of differences between concept maps constructed using the same set of concepts, showing that there is no one ‘right’ way of constructing a map. At the end of *Course 2*, nearly three quarters of students (74%) indicated that they felt concept mapping had been easy to learn.

The whole-class feedback using the maps that had been constructed by students on overhead transparency sheets appeared to be particularly appreciated by some of the class. For example, Alice commented: “I thought it was very effective by starting us off – giving us time to do it on our own and go over them as a whole at the end and explain the concepts.” Another advantage of having a ‘summing-up’ was that the tutor could address common questions, and in some cases alternative conceptions, that had arisen as she had moved around the class. As has already been pointed out, the skill of the tutor in responding to students’ questions during this process was valued.

#### ***6.4.6 Summary of Students’ Perceptions of Concept Mapping***

Comments made during the concept mapping tutorials, as well as student responses to the tutorial experience questionnaires suggest that concept mapping as a teaching and learning tool was generally positively received. Specifically, the majority of students indicated that the approach helped them to summarise and learn

content required for their biology courses, and in some cases for their other science courses. They also strongly indicated that they felt concept mapping helped them to develop an understanding of the links between concepts, although several students (notably those who were likely to have more limited biology-specific prior knowledge) pointed out that you first had to have an understanding of the individual concepts before they could be linked to other concepts.

The way that the teaching and learning was managed during the concept mapping tutorials appeared to have worked well. In particular, the majority of students valued the opportunity to construct their own concept maps (individually or in small groups). Tutor feedback as part of this process was considered by the students to be very important – both while the maps were being constructed, and within the whole-class setting. The use of overhead transparency sheets provided the tutor with an opportunity to manage the feedback without having to rewrite everything. She could also point out key characteristics of concept maps, for example, the importance of meaningful linking terms and that there is no one ‘right’ concept map for any particular group of concepts.

However, not everyone was enamoured with the concept mapping technique. A few students reported that they would prefer to use their existing learning strategy (e.g., using bullet points), or that they preferred a more passive approach to tutorials. Others felt that concept mapping had not directly helped them to respond to course assessment tasks.

The next section details the tutor’s perceptions of the value of concept mapping as a teaching and learning tool, and her role in implementing the intervention. Finally, the impact of concept mapping on actual student learning is explored in Section 6.6.

## **6.5 THE TUTOR'S PERCEPTIONS OF THE VALUE OF CONCEPT MAPPING AS A TEACHING/LEARNING TOOL**

A key characteristic of an interpretive methodology is that the perspectives of a range of participants are obtained in order to gain a more holistic understanding of the research context. The tutor's perceptions of the intervention programme were therefore investigated through informal interviews with her, as well as more formal interviews (see Section 3.4.3). The tutor's perceptions are also important because they will influence whether or not she will adopt concept mapping as part of her own pedagogy, and thus affect the long-term impacts the study has on her practice.

A number of themes emerged from the discussions with Angela, and are described below: the tutor's personal teaching philosophy; the role of reflective practice; and the likely impact of the intervention on the tutor's future pedagogical practice.

### ***6.5.1 Concept Mapping Fitted with the Tutor's Own Teaching Philosophy***

One of the significant outcomes of the research presented in this thesis was that the tutor, Angela, perceived concept mapping to be congruent with her own teaching philosophy, and this kept her actively and enthusiastically engaged in the project. As she commented: "I kept doing it because my personal philosophy anyway is that I think it's very important that students learn to see the big picture; that they don't just focus on the minutiae ... Concept mapping gives you the opportunity to do that."

In particular, Angela felt that concept mapping provided her with an "extra tool for explaining things to students ... it lets you show the relationships between concepts far better than simply writing a list of words on the board." She also commented that she enjoyed trialing a new teaching strategy: "I find it stimulating

because it's different ... It's given me very welcome experience in a technique that I was aware of but hadn't consciously used before."

The classroom management approaches used to incorporate concept mapping in the relevant tutorial classes also suited Angela's own teaching preferences. Specifically, it was important to her that students had the opportunity to ask questions. Although this had been part of her teaching practice prior to implementing the concept mapping intervention, she felt that she had "probably become, not more confident in doing that, but stronger in my use of doing that." It was therefore important to her that concept mapping could be flexible enough to accommodate a range of students' questions. Being able to interact with students as they worked on constructing their own maps was thus valued by Angela as well as by the students (see Section 6.4.4).

Active participation by students in the classroom discussions is another aspect of teaching that Angela values highly. She commented that the concept mapping approach (particularly having students work in small groups to construct their own maps) appeared to have facilitated this: "With concept mapping and the fact that they had to work together, they probably participated more than they did in some of the other tutorials I was taking." She indicated that the use of overhead transparencies as part of this process was a very effective way of collecting students' ideas and providing immediate feedback. However, at first she had been a bit apprehensive about using the overhead transparencies and reflected:

I thought about why I felt uncomfortable with it. I decided it was because I must be a bit of a hidden control freak, because I didn't know what was going to happen ... When you're giving the students something open-ended like that, I wasn't sure whether they'd do it.

Angela was also concerned that "Some students won't like it ... Having to play an active role is something that some of them are not going to feel comfortable or confident about doing." The intervention was therefore not always something that Angela felt particularly comfortable with. She acknowledged that at times she was "out of [her] comfort zone" but at the same time she was willing to try new strategies.

Student feedback seemed to be very important in terms of encouraging her to continue with the intervention, and particularly with the practice of allowing time for students to construct their own maps. For example, after the first tutorial class where the overhead transparencies had been used she commented: “I think it’s going well. I was flabbergasted so many [concept maps on transparency sheets] came back. And the students are very positive.” By the end of *Course 1* she reported feeling a lot more comfortable with giving students the opportunity to construct their own concept maps, saying:

It’s an important part of tutorials ... I think that if it’s a technique that they’re going to use for their own learning then they do need to practice it ... And it’s a good situation for them to do that because then you can circulate and talk about what they’re doing and you can point out that there are umpteen different ways of doing it. So you’re constantly giving positive feedback.

However, Angela did not feel that she would expect students to construct their own maps in every tutorial class:

Students do have expectations of tutorials that differ from mine, to the extent that they do want to know how to handle, for example, past year’s test questions. For reasons of efficiency, I suppose, you don’t really want to spend the whole of a tutorial on, say two questions, when the students would quite like it if you handled more than that.

This was particularly true in the latter parts of each course, when she said:

You’ve got students beginning to worry about, ‘What’s coming up in the exam?’ ‘How can we cope?’ ‘How can we answer the questions?’ I just had this nagging concern the whole time that if you focused on one thing then you’re going to get a lot of students feeling, ‘Well, why did I come? I had these other questions.’

In classes where students did not construct their own maps, Angela used the opportunity to construct a ‘whole-class map’ on the board, using student input. She commented:

Although they’re not practicing in the sense of building their own maps, they’re still going to be involved in developing it. That, I hope, would reinforce to them what’s going on – their grasp of the concepts and their ideas of the links between them. They’re not just sitting there writing down what I’m saying.

Angela therefore found value in implementing the concept mapping intervention, particularly because it fitted with her own understanding of her role as a teacher as 'guide'. The structure of the intervention programme also meant that she was able to incorporate two practices that she considered to be particularly important: students had the opportunity to ask questions, and they actively participated in the resulting activities and discussions. A second key feature of the intervention, according to Angela, was the opportunity to reflect on her own teaching practice.

### ***6.5.2 The Role of Reflective Practice***

At the start of the intervention programme, Angela indicated that her main objective for participating was "seeing if there was a tool I could use that would improve my own teaching." The reflective processes that were built in as part of the programme appeared to be significant in this. They included receiving copies of the classroom observations made by the researcher, and also reflective discussions between Angela and the researcher, both formal and informal. As she commented at the end of *Course 1*:

I think when you're developing a new teaching technique it's enormously helpful to have feedback on what you're doing – or even if you're using a normal technique. I think there's an important role in teaching for something with peer review or peer feedback.

Earlier in the course she had been even more specific about the benefits of reflection: "It lets me focus on what I did – and why I did it! – and, I would hope, improve what I'm doing. This is still very much a learning curve for me." Angela therefore viewed herself as a learner, and obviously enjoyed the opportunity to try something new. In particular, she appeared to gain enormous satisfaction as her own confidence with using concept mapping grew. She said after one class, for example: "I did like the little map I made up. I was quite chuffed with that." On another occasion, when asked what she had enjoyed about using concept mapping, she responded: "The real buzz I got out of doing them. I know that sounds silly, but it's quite neat to get asked a question that is unpredictable, and to be able to think, 'Oh gosh, I can actually put all that down in that particular form [i.e., a concept map].'"

The growth in Angela's ability to construct concept maps 'on the spot' was also evident. Initially, she and the researcher met together prior to the tutorials to construct concept maps that they thought would relate to questions that the students might ask. This gave Angela the opportunity to practice the technique prior to modeling it with a class. After a few weeks this practice no longer appeared to be necessary, and Angela commented at the time: "I'm glad I'm at the stage where I'm confident and I can depart from the script. It's nice to have that flexibility." By the time the intervention was implemented in *Course 2*, she reported:

It was probably a lot easier [than *Course 1*] because I was a lot more comfortable using the technique ... you saw, they could ask just about anything ... but I could usually come up with something fairly coherent. That suits my teaching style, because I prefer to be able to answer any questions that they throw at me.

Angela's enthusiasm for trying a new teaching approach and her reflective nature thus made a significant contribution to the nature of the intervention programme. Her growing confidence and skill at using concept mapping was also very evident and allowed her the freedom to adjust the content of tutorial discussion to meet the needs of particular students on the day.

### ***6.5.3 Potential Impacts on Future Pedagogical Practice***

In order to gauge the likely long-term impact of the intervention on Angela's own pedagogical practice, she was asked on several occasions to comment on her likely future use of the approach. In all these instances, she reported feeling very positive about the incorporation of concept mapping as a teaching and learning tool in her classes, commenting at the end of *Course 2*: "I'll use it more extensively next year in tutorials, and possibly for explaining stuff in labs. It's certainly not a case of me thinking, 'Well, I've done that. I'm going back to what I was doing before'."

Angela also indicated that she "used the technique probably more widely than I thought I would – like for planning talks." However, she pointed out that concept mapping was not something that she would begin to use exclusively "because we



know other methods work.” This was consistent with her teaching practice during the concept mapping tutorials, in which she had sometimes used annotated diagrams to show a process, for example, cell division, in addition to constructing a concept map. She was also aware of the need to “meet several different requirements of the students” and that concept mapping would be “just one of the techniques I will use.”

Overall, Angela appeared to feel very positive about the experience and the opportunity to try something new and receive feedback, and reported that she intended to continue using concept mapping as part of her teaching practice. In terms of long-term uptake of the approach within the department, she commented:

I suspect it’s a technique that isn’t going to suit all teachers. It’s probably outside the comfort limits of some of them ... teaching this way requires that the lecturer be open to the students asking questions, and it requires that they be open to the students playing quite an active role. Not everybody is going to be happy with that, because their own teaching style is quite different.

Angela also commented on another occasion: “I think you’d need to be confident in your own teaching before you jumped into making a change.” Her advice to other teachers interested in exploring the use of concept mapping in their own classes was to read some of the literature that explains the philosophy behind concept mapping “so you can see how and why they’re developed and how and why they’re used.” She further suggested that teachers might find it valuable to discuss their intentions with someone who has already used the technique. These comments of course reflect her own perception that concept mapping fitted with her own teaching philosophy, and that reflective practice was an important aspect of implementing the intervention.

## **6.6 THE INFLUENCE OF CONCEPT MAPPING CLASSES ON STUDENT LEARNING**

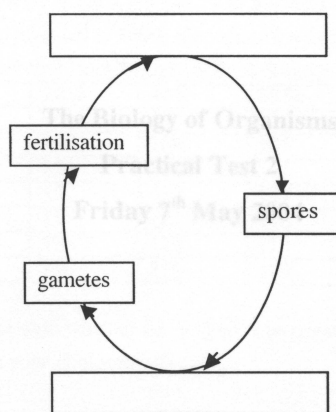
To investigate the effects concept mapping had on actual student learning, data were collected from selected questions from course tests administered to the whole class for assessment purposes (see Section 3.4.3). The test questions were

examined thematically and classified by a panel of experts into two types. The first type of question, it was considered, could be answered by repetition of information provided in the course lecture notes (i.e., rote learning; see Table 6.4). These questions were either very descriptive in nature (e.g., “What is metagenesis?”), or the information required to answer the question was provided directly in the course notes (e.g., to complete a diagram, available in the lecture notes, by filling in the appropriate terms).

**Table 6.4**

Questions from course assessment tasks that required factual recall from the lecture notes

Item	Question
1	Why are C4 plants able to continue to photosynthesise even in hot dry conditions when the photosynthetic rate of a C3 plant would be severely limited? a) They use PEP carboxylase to initially fix CO <sub>2</sub> b) They conserve water more efficiently c) They exclude oxygen from their tissues d) They do not participate in the Calvin cycle
2	Briefly describe a cellular DNA molecule in terms of the units of which it is composed, hydrogen bonding, and structure.
3	Asexual reproduction requires less energy than sexual reproduction and allows the population to increase much faster. However, most animals use sexual reproduction. Explain why this is so.
4	What is metagenesis?
5	Fill in the general name of the life stages in the following diagram of a fern life cycle.



Note: The expected answer required a repetition of facts presented to students in their lecture notes.

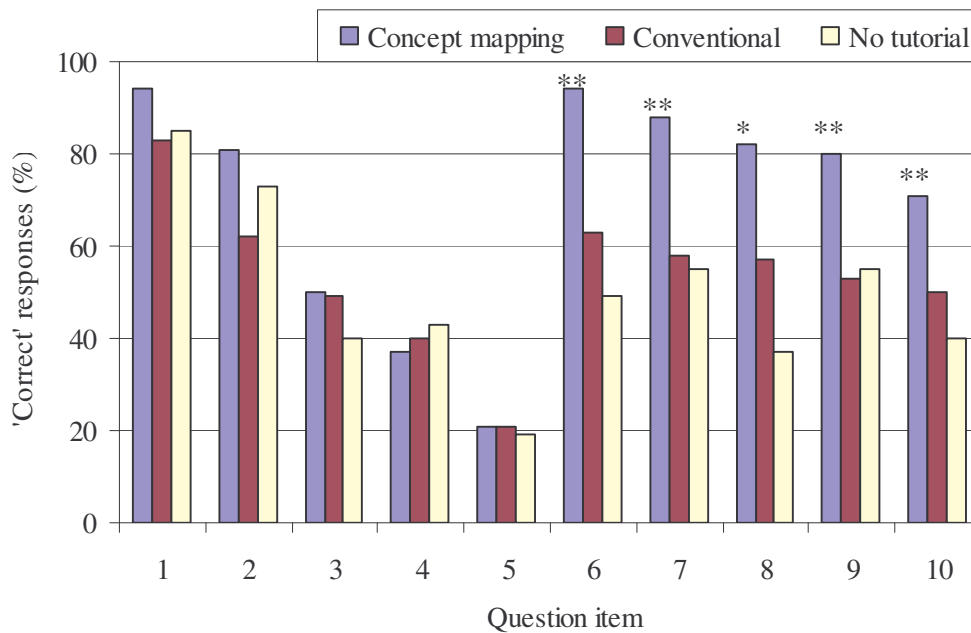
The second type of question was considered by the panel of experts to require students to have an understanding of a range of biological concepts, and to meaningfully demonstrate the links between them. An example of such a question is: “Briefly describe the maternal and paternal homologous chromosomes in terms of the DNA molecules and genes that they contain.” At first sight such a question might also appear to be rewarded by rote learning. However, although each of the concepts had been introduced in lectures, the link between homologous chromosomes as a concept, and the relationship with the positioning of genes along chromosomes, had not been made explicit. Hence, students were required to demonstrate understanding of the links between the concepts in order to answer such a question satisfactorily. Other examples of this type of question are provided in Table 6.5.

Student achievement in the selected test questions was correlated with tutorial attendance (using information about topics covered in tutorials, and tutorial attendance sheets) and analysed for differences using Chi-square tests for independence. The results (see Table 6.6 and Figure 6.6) show statistically significant differences in student achievement for questions that required students to

**Table 6.5**  
Questions from course assessment tasks that required conceptual understanding

Item	Question
6	Distinguish between the middle lamella, primary wall and secondary wall in a plant cell wall.
7	In C4 photosynthesis, carbon fixation takes place in the _____ cells, and then is transferred as malic or aspartic acid to _____ cells, where carbon dioxide is released for entry into the Calvin cycle.
8	Explain how immunoglobulin G interacts with the proteins of the complement system to kill invading bacteria.
9	In the prokaryotic bacterium <i>E. coli</i> , why is the lac operon <u>not</u> transcribed when the cell is growing in a lactose-free environment?
10	Briefly describe the maternal and paternal homologous chromosomes in terms of the DNA molecules and genes that they contain.

Note: The expected answer required students to have an understanding of a range of concepts which they had linked together. The answers were not presented explicitly in the students’ lecture notes.



**Figure 6.6**  
Student responses to selected assessment items

Note 1: Question items relate to questions presented in Tables 6.4 and 6.5.

Note 2: Statistically significant differences between students who attended a relevant concept mapping tutorial and those who attended either a relevant conventional tutorial or no tutorial are represented by asterisks (\*  $p < 0.05$ , \*\*  $p < 0.01$ , based on Chi-square tests for independence; see Table 6.6 for details).

Note 3: Sample sizes varied for each question (concept mapping and conventional tutorial samples ranged from 12 – 49; no tutorial sample ranged from 90 – 163; see Table 6.6 for details).

have an understanding of a range of concepts and the links between them, with students who attended the relevant concept mapping tutorials achieving higher marks than those who attended either a conventional tutorial, or no tutorial. In contrast, there were no statistically significant differences in responses to questions that did not require a sophisticated level of conceptual organisation, but that could be answered by repeating facts found in the course lecture notes. In other words, differences in student responses only applied to questions that required students to demonstrate links between concepts beyond those that were made explicit in lectures.

The content had been discussed in all the tutorials associated with the relevant lectures, although this had been done in a linear fashion in the conventionally-taught tutorials and in a way that encouraged conceptual linking in the concept mapping

**Table 6.6**  
Student responses to selected assessment task items

Item <sup>†</sup>	Concept mapping tutorial		Conventional tutorial		No tutorial	
	(N)	'Correct' answer <sup>††</sup> (%)	(N)	'Correct' answer <sup>††</sup> (%)	(N)	'Correct' answer <sup>††</sup> (%)
1	16	94	12	83	134	85
2	42	81	26	62	100	73
3	64	50	49	49	117	40
4	30	37	35	40	157	43
5	24	21	14	21	163	19
6**	16	94	16	63	176	49
7**	16	88	12	58	134	55
8*	33	82	23	57	108	37
9**	40	80	15	53	115	55
10**	28	71	46	50	90	40

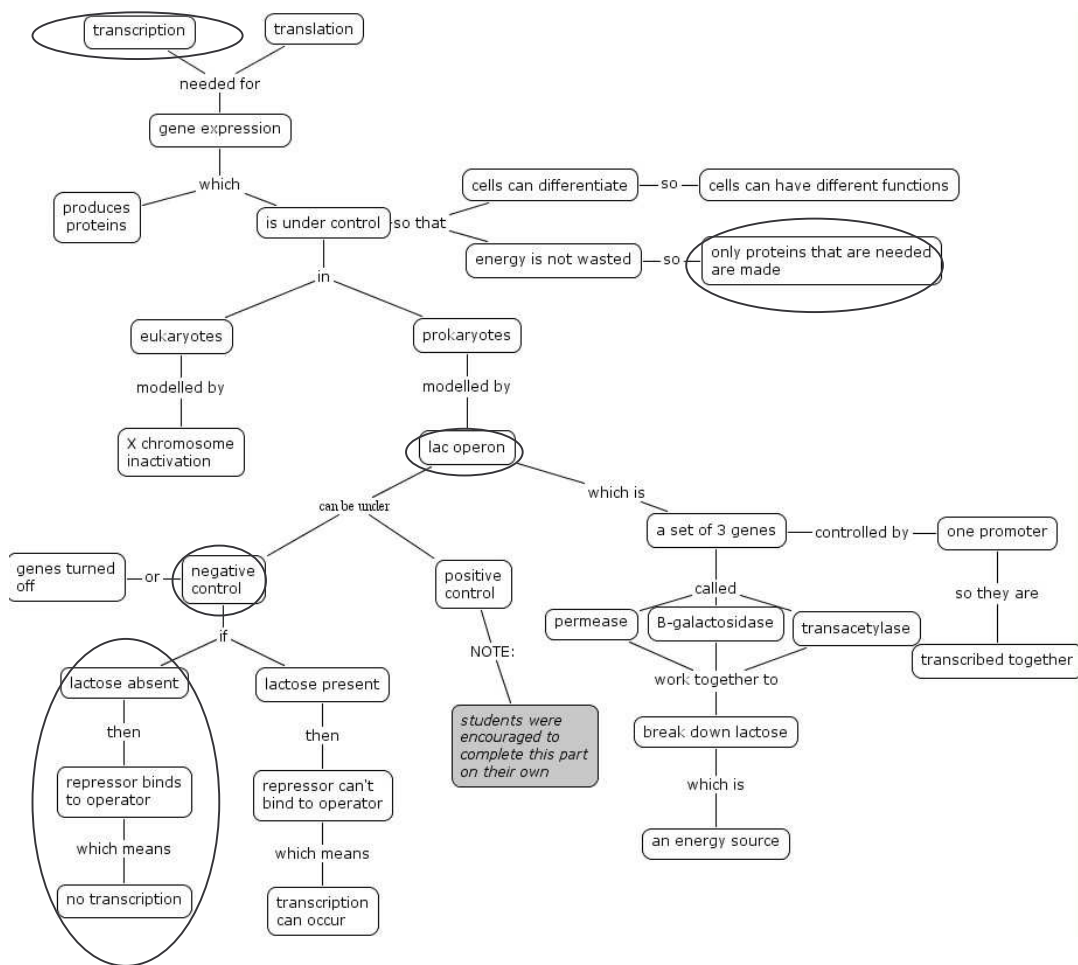
<sup>†</sup> See Tables 6.4 and 6.5 for specific questions.

<sup>††</sup> Based on the marking scheme for the assessment task.

\* Difference between 'concept mapping tutorial' and both the 'conventional tutorial' and 'no tutorial' is statistically significant ( $p < 0.05$ , based on a Chi-square test for independence).

\*\* Difference between 'concept mapping tutorial' and both the 'conventional tutorial' and 'no tutorial' is statistically significant ( $p < 0.01$ , based on a Chi-square tests for independence).

tutorials. An example of a concept map constructed by the tutor (with student input) that related to the question on genetic control of the lactose operon (question item 9, see Table 6.5) is presented in Figure 6.7 to show the linking of the concepts required to answer that particular question. The question related to the cell walls (question item 10, see Table 6.5) required linking of some of the concepts identified in the concept map presented earlier (see Figure 6.5). In the conventional tutorials, these concepts had been covered using simple diagrams drawn by the tutor and used as the basis for a verbal explanation that was presented in a linear fashion ("Then this happens ... Next this happens...").



**Figure 6.7**  
Class concept map related to the control of gene expression

Note 1: Concept map was constructed as part of a whole-class discussion; it was copied from the board and reproduced here using IHMC software available from <http://cmap.ihmc.us/>.

Note 2: Concepts needed to answer question item 9 in Table 6.3 have been circled.

Although it may seem strange that only 10 questions were analysed in detail, this was largely because the test questions tended to test knowledge of isolated concepts only (concept mapping is designed to highlight the links between two or more different concepts). In other cases the conceptual themes that were addressed had not been discussed in all of the tutorial classes, rendering analysis of tutorial effects inappropriate because of small sample sizes. The observation that the tutorial discussions often did not relate to assessment items raises the question about how relevant the tutorial discussions are to the rest of the course (or to look at it another

way, how relevant the assessment tasks are to the learning objectives of the course). This will be explored further in Chapter 7.

## **6.7 CHAPTER SUMMARY**

The concept mapping strategy was introduced to help students develop an understanding of how different concepts are related. The tutor emphasised during the concept mapping classes that this was an important skill for students to develop. She then modeled the construction of concept maps, using input from students, and there was the opportunity for students to spend time in class constructing their own maps. The intervention took place over 11 teaching weeks.

The first-year biology students involved in the concept mapping tutorial sessions were generally positive about the experience, reporting that concept mapping helped them to link concepts together as well as summarise and recall course content. Consistent with the findings reported by others (e.g., Esiobu & Soyibo, 1995; Roth, 1994; Roth & Roychoudhury, 1993; Sizmur & Osbourne, 1997), the majority of students indicated that they had found it useful to construct the concept maps on their own or in small groups. The classroom management strategies used in this study also seemed to be significant. The tutor moved around the classroom discussing with students the concept maps as they were being constructed, and this formative feedback was valued by the students. The tutor also had positive views of the incorporation of concept mapping into the tutorial sessions and indicated that she intended use concept mapping as part of her teaching in the future. She felt that concept mapping fitted with her own personal philosophy of teaching, and valued the fact that students were able to participate actively in the tutorial sessions.

The quantitative data suggest that students who attended concept mapping tutorials were more likely to score higher on traditional assessment tasks that required an understanding of the links between a range of concepts. Concept mapping did not appear to help students perform better on assessment tasks that could be answered

using rote-learning strategies. This raises the question about whether the type of questions that were more dominant in the assessment tasks (i.e., where rote learning could be used to effectively answer the majority of questions) match the learning intentions of the course.



# **Chapter 7**

## **Discussion, Conclusions and Recommendations**

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### **7.1 INTRODUCTION**

The work presented in this thesis explores the increasingly diverse academic backgrounds of students entering first-year biology courses, and the educational implications for teaching and learning in these courses. Specifically, the work seeks to understand how the diverse prior knowledge of students is, and can be, taken into account during teaching. The thesis is based on a social-constructivist view of learning, that is, learners construct new conceptual frameworks by relating new concepts to relevant prior knowledge. The social context in which this process occurs is also considered to be important (Guba & Lincoln, 1994; Tobin 1993).

The first phase of the research explored faculty assumptions regarding the prior knowledge of students participating in entry-level tertiary biology courses. In the second phase, research findings from phase one were used to develop a prior knowledge questionnaire to investigate students' subject knowledge on entering tertiary study. The third phase consisted of a teaching intervention based on concept mapping. The purpose of this chapter is to discuss the findings and interpret them in the context of the research literature. Methodological constraints and limitations related to the work are also considered. Finally, implications of the findings and recommendations for further work are presented.

## **7.2 DISCUSSION OF THE FINDINGS**

### ***7.2.1 Faculty Assumptions Regarding Student Prior Knowledge***

#### Faculty Views of the Importance of Prior Knowledge

In order to explore faculty assumptions regarding the prior knowledge of students entering first-year biology courses, an extensive survey was carried out which involved 35 faculty from six New Zealand universities in semi-structured interviews. In addition, course documents including student lecture and laboratory manuals were analysed, and classroom observations were carried out at one university. The aim was to identify specific concepts that faculty assume students understand prior to participating in first-year biology courses. Faculty views of the role of prior knowledge in student learning were also explored.

The findings indicate that faculty are aware that students participating in first-year biology courses come from diverse academic backgrounds, and consequently have different levels of biology-specific prior knowledge. Many believe that this has implications for their teaching and feel they have to “start from scratch” in order to accommodate students with very little prior knowledge. At the same time, they are concerned that other students in the class, who consider themselves to be familiar with some of the more basic concepts, will “switch off”. Some faculty reported

trying to address this tension by using different examples (or emphasising different aspects) from those typically referred to in school biology classes.<sup>38</sup> Other faculty reported that they try to aim for “somewhere in the middle”, but feel that this approach still means that students with more extensive prior knowledge are likely to be bored, whilst those with more limited prior knowledge are still likely to feel overwhelmed (see Section 4.3).

Tension between accommodating tertiary students with more limited prior knowledge, and disenfranchising or alienating the ‘high achievers’, has been reported by Bishop and Eley (2001). Similarly, Tariq (2002) reported faculty concerns about reductions in subject-specific teaching time in order to take into account the needs of students with more limited prior knowledge. However, few studies appear to have investigated faculty assumptions about specific prior knowledge required by students entering tertiary biology courses. Those that do exist explore the mathematical skills required for these courses (Bishop & Eley, 2001; Lake, 1999), with faculty expressing concern regarding the mathematical backgrounds of students entering life science degree courses (Phoenix, 1999a; Tariq, 2002), as well as students’ apparent fear of mathematics (Bishop & Eley, 2001; Lenton & Stevens, 1999).

Although ostensibly trying to accommodate students with more limited prior knowledge, faculty in the current study indicated that prior biology study is likely to help students cope with both the jargon and the high level of content included in introductory biology courses. However, language skills and motivation also were considered to be important. Mature students in particular were highlighted by faculty as being able to do well despite often not having much biology-specific prior knowledge. The general view seemed to be that such students are sufficiently motivated to “catch up” and acquire the concepts needed in order to scaffold their understanding (see Section 4.4).

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<sup>38</sup> However, it was not clear how many faculty are sufficiently familiar with the senior school curriculum to be able to do this effectively.

The view that verbal ability and motivation are important factors influencing student success is supported by a considerable body of research investigating factors that affect student learning. For example, Archer, Cantwell, and Bourke (1999) reported that verbal ability was the strongest indicator of academic success (as measured by grade point average) for students participating in first-year university courses across a range of disciplines. Other studies have demonstrated a link between motivation and student achievement (e.g., Ames, 1992; Astin & Astin, 1992).

Consistent with faculty views expressed in the current study, the literature indicates that mature students in particular tend to be highly motivated and success-oriented (Forgasz, 1996), and that mature students generally report deep learning intentions on self-report questionnaires (Archer, Cantwell, & Bourke, 1999; Richardson & King, 1998). However, being motivated to learn for understanding does not necessarily translate into the behaviours required to realise this goal, partly because students who want to develop a deep understanding of a subject do not always have the prior knowledge or cognitive skills to do so (Archer, Cantwell, & Bourke, 1999). However – and this is what the faculty who were interviewed in the current study appeared to believe – the goal of wanting to understand the material is likely to cause some students to persist with their studies even when difficulties arise (Ames, 1992).

It seems that motivation to understand course content has to be translated into effective study strategies and be accompanied by relevant prior knowledge if the student is to be academically successful. Further, students' self-efficacy will affect the way they tackle the learning task (Dalgety, Coll, & Jones, 2003).

#### Faculty Assumptions Regarding Specific Biological, Chemical and Mathematical Concepts

Faculty interviewed as part of the current study reported that they assume very little biology-specific prior knowledge when teaching introductory-level biology courses. However, many did indicate that prior knowledge of some 'basic' biological

concepts is taken for granted. These concepts include: the hierarchical system used to classify living organisms; the cellular basis of life; the significance of photosynthesis and respiration; the presence and function of DNA, chromosomes and genes in cells; and patterns of Mendelian inheritance (Section 4.5.1). Other concepts, like evolution, are specifically taught in some courses, but form part of the assumed prior knowledge in other courses. It also seems that once a topic is taught in one part of a first-year biology course, however briefly, faculty assume that students are able to make connections between this content and content taught either later in the same course, or in other first-year biology courses (i.e., the concepts are not re-visited). This means that students are in effect required to integrate their knowledge across different topics, and across different first-year courses.

Another important finding is that although faculty reported that they assume very little biology-specific prior knowledge, ostensibly because of the diversity in academic backgrounds of the students, they do expect students to be able to competently use a range of mathematical and chemical concepts (Sections 4.5.3 and 4.5.4 respectively). For example, faculty teaching cellular respiration indicated that students are required to be able to follow (and not be overwhelmed by) the chemical symbols and written reactions used to represent different steps in the pathway. Chemical concepts like oxidation and reduction are referred to without explanation. Similarly, mathematical skills are required, particularly for laboratory-based tasks. These mathematical skills include: drawing and interpreting graphs and tables; calculating means, percentage, area, volume, and scales in drawings; working with units of measurement and scientific notation; and using fractions, square roots, and algebraic formulae.

Faculty reported using several strategies to try to address what they consider to be inadequacies in the academic background of many of their students. For example, some of the course manuals available to students include a glossary associated with particular sections of the course (e.g., genetics). Two universities offer one-off tutorial classes to address content that is considered to be particularly

problematic for students with more limited prior biology study, such as Mendelian genetics, and a third university offers a regular tutorial programme which students are expected to attend in order to clarify questions they have regarding course content. In the case of mathematical skills required for laboratory activities, detailed examples of statistical calculations are provided for students to work through when this sort of analysis is required, although the examples assume that they can compute algebraic equations. The tutor at one university had also constructed a 'help sheet' explaining the manipulation of algebraic formulae.

Classroom observations at one university suggest that faculty may sometimes assume prior knowledge of a greater number of concepts than they realise. For example, one faculty member who teaches diffusion and osmosis specifically reported in the interview these concepts are taught "from scratch". Classroom observations indicated that he did indeed refer to the concept that these processes are the result of *random* movement of molecules, but this explanation was based on the assumption that students are familiar with the concept that molecules move (several students asked about this in tutorial classes that were observed, indicating that they were not familiar with this latter concept).

This finding, that faculty may assume more prior knowledge than they realise, is supported by the literature suggesting that an expert is seldom explicitly aware of the knowledge he or she is using (Eraut, 2000). As a consequence, the expert may assume more underlying knowledge than he or she realises (Duggan & Gott, 2002), taking the most fundamental aspects for granted (Bowden & Marton, 1998). In addition, novices and experts process information differently (Pennington, 2001) so that although concepts might be 'explained' by the experts, novices without the necessary mental frameworks may have difficulty interpreting and assimilating the explanation (Passer & Smith, 2001).

In summary, faculty reported that they assume very little prior knowledge of specific biological concepts, although some are referred to without explanation.

Students are also expected to be familiar with a range of chemical and mathematical concepts, and to be able to form links between related concepts covered in different topics and even different first-year courses (i.e., once taught, the concepts are not revisited). This was supported by an analysis of course documents, including student study manuals and laboratory manuals. Classroom observations also suggested that faculty may assume more prior knowledge than they realise.

### ***7.2.2 Students' Prior Knowledge***

Students' actual prior knowledge was explored in phase two of the study. A prior knowledge questionnaire, based on the findings from phase one, was administered to two successive cohorts of students entering a first-year biology course at one New Zealand university.

Not surprisingly, students with more extensive prior biology study were more likely to demonstrate a scientific understanding of some concepts than students with more limited prior biology study (see Section 5.3). These included concepts such as: the classification of animals, cells, DNA, chromosomes, genes, and patterns of Mendelian inheritance. Students with more extensive prior biology study also were more likely to feel more confident about their understanding of some of these concepts, although in some cases this confidence appears misplaced.

The amount of prior biology study did not appear to affect students' understanding of other concepts, including: the hierarchical system used to classify organisms; the fact that living organisms require energy for a range of activities; and mathematical concepts and chemical concepts (Section 5.4). This is more surprising, since these concepts, including the chemical and mathematical concepts, are encountered in the senior secondary school biology curriculum. It is also significant that a low proportion of students demonstrated a scientifically acceptable understanding of these concepts, as faculty assume students are familiar with them prior to teaching.

A third finding from the prior knowledge questionnaire was that very few students could make links between concepts, regardless of the amount of prior biology that they had previously studied (Section 5.5). This was exemplified by the responses that students provided to questions on topics related to why living organisms need energy, the significance of photosynthesis and cellular respiration, and the requirements and products of each of these processes. For example, very few students demonstrated understanding of the links between concepts such as a cell's requirements for oxygen and nutrients, the role of these substances in cells, and the role and significance of the gaseous exchange, digestive, and circulatory systems in ensuring that cells are able to access these substances efficiently. This finding, that students do not appear to form conceptual links between concepts, seems particularly significant in light of faculty assumptions regarding the need for students to form connections between concepts taught as part of different topics (see 7.2.1 above).

The lack of integration between concepts revealed in the current study has also been reported by others investigating senior secondary and tertiary students' understandings of specific biological concepts (e.g., Anderson & Grayson, 1994; Brumby, 1984; Núñez & Banet, 1997) and may explain why learning complex topics like genetics and ecology (Okebukola, 1990) and anatomy and physiology (Cliburn, 1987) seem to be particularly problematic for students. Specifically, poor integration of concepts points to lack of coherence in students' conceptual frameworks (Taber, 1995, 1998), with separate concepts considered to be isolated and unrelated (Brandt et al., 2001; Schmid & Telaro, 1990). The disciplinary approach to science knowledge, as well as sequencing of topics in courses in a way that encourages conceptual compartmentalisation, may be partly to blame (Carlsson, 2002; Cliburn, 1987). In particular, Okebukola (1990) argues that presenting students with concepts in isolation and expecting them to learn these concepts in an unconnected sequence is likely to result in rote learning and isolated memorisation of facts. This may lead to students "failing to construct a coherent picture of the subject, its methods and its practices, leaving them with fragmented pieces of knowledge" (Osborne & Collins, 2000, p. 30).



Although specific alternative conceptions were not analysed in depth during this study, many of the findings are consistent with those reported by others in the science education literature. For example, senior secondary and tertiary biology students have been reported to hold alternative conceptions related to:

- *the identification and function of DNA, genes and chromosomes* (e.g., Banet & Ayuso, 2000; Fisher, 1985; Friedrichsen, Stone, & Brown, 2004; Lewis & Kattmann, 2004; Marbach-Ad & Stavy, 2000; Wood-Robinson Lewis, & Leach, 2000);
- *problem-solving in the context of Mendelian inheritance* (e.g., Browning & Lehmann, 1988; Johnson & Stewart, 2002; Kinnear & Simmons, 1990; Moll & Allen, 1987; Stewart, Haffner, & Dale, 1990);
- *classification of living organisms* (e.g., Brumby, 1982; Trowbridge & Mintzes, 1988; Yen, Yao, & Chiu, 2004); and
- *sources of energy for living organisms* (e.g., Barak, Gorodetsky, & Chipman, 1997; Boyes & Stanisstreet, 1991)
- *photosynthesis and cellular respiration, and the relationship between them* (e.g., Anderson & Grayson, 1994; Barker & Carr, 1989; Carlsson, 2002; Haslam & Treagust, 1987; Hazel, 1994; Songer & Mintzes, 1994).

The number of “don’t know” responses in the current study may be indicative of gaps in student understanding of some concepts, rather than the existence of strongly-held alternative conceptions.

The poor mathematical skills of a large proportion of students, highlighted in the current study, are also of concern considering the strong emphasis placed on mathematics, particularly in the laboratory component of many first-year biology courses. Other researchers have also reported on tertiary science students’ difficulties with questions requiring an understanding of fractions, indices (i.e., powers of 10), units of measurement, logarithms, area and volume, and tables and graphs (Lake, 1999; Marsh & Anderson, 1989; Tariq, 2002). These studies, as well as findings presented in this thesis, suggest that many students entering undergraduate biology courses are not adequately equipped with the basic mathematical understanding and skills required for these courses. As Lake (1999) argues, science students are required to not only master the structure of scientific writing, but also the non-textual, quantitative conventions.

Although the mathematical concepts required for introductory biology courses have been explored in the literature, there appears to be a paucity of research investigating specific chemical concepts that are required for developing a scientifically acceptable understanding of concepts taught in first-year biology courses. Those studies that do exist highlight key chemical concepts underpinning an understanding of biological concepts like osmosis and diffusion (e.g., Odom & Barrow, 1995) and cycling of matter (e.g., Leach, Driver, Scott, & Wood-Robinson, 1996a).

The current study suggests that student understandings of basic chemical concepts (e.g., the use of chemical symbols and equations) are of concern, with one quarter of respondents unable to provide the chemical names for a list of chemical symbols commonly referred to in first-year biology courses (e.g., carbon, sodium, and potassium). Reduction-oxidation (redox) reactions appeared to be particularly problematic, with less than one third of respondents able to correctly identify NADH as the reduced form of NAD, and less than two thirds able to provide a scientifically acceptable definition for oxidation. This has implications for teaching metabolic pathways like photosynthesis and cellular respiration, where statements such as “The reduced NAD then enters the next part of the cycle ...” are common.

In summary, the findings from the prior knowledge questionnaires, administered as part of the current research to two different cohorts of students entering first-year biology courses, suggest that there is widespread variation in students’ understanding of key biological, chemical and mathematical concepts. Not surprisingly, students with more extensive prior biology study are more likely to have a scientifically acceptable understanding of some, but not all, of the concepts that were investigated. There also were differences between what faculty assume students know, and what students do actually know. Finally, a large proportion of students appeared to understand concepts in isolation, rather than as relating to each other. This lack of integration is particularly significant given the faculty expectation that

students will form connections between concepts and topics taught at different times during the first-year biology courses.

### ***7.2.3 Concept Mapping as a Teaching and Learning Tool***

An intervention using concept mapping was planned and implemented as a result of the findings from phases one and two of the research. Specifically, the aim of the concept mapping intervention was to encourage the explicit formation of links between concepts, thereby enhancing student understanding and learning. Because each concept map is a personal representation of an internal mental model (Freeman, 2004) suited to individualised learning as opposed to individualised teaching (Schmid & Telaro, 1990), concept mapping was also considered to be an appropriate strategy to use with students with diverse prior knowledge.

#### The Use of Concept Mapping in Tertiary-level Introductory Biology Courses

Despite numerous references to concept mapping in the science education literature, particularly as a research tool, few studies have evaluated the effectiveness of concept mapping in tertiary-level biology classrooms (see Section 2.5.4). Work by Heinze-Fry and Novak (1990), with college students completing an autotutorial course that was self-paced and incorporated concept mapping tasks, reported no statistically significant differences in understanding as a result of concept mapping. However, the authors suggested that this could be because the sample size was small and students had had limited exposure to concept mapping as a learning tool.

Other studies at the tertiary level in biology have also tended to be based on short-term use of concept mapping by students and again findings have been inconsistent. For example, Smith and Dwyer (1995) report on students given a short training session in the use of concept mapping and then asked to read a text on the human circulatory system. One group of students was given an instructor-prepared concept map to study alongside the text; students in another group were asked to construct their own concept maps; and a third group of students was not asked to

consider concept mapping at all. When students' understanding of the text was evaluated, there were no statistically significant differences between the groups. Similarly, Yarden, Marback-Ad, and Gersoni (2004) reported on a class of freshman biology students who constructed concept maps as part of one week's tutorial activities. Again, no statistically significant differences were found between students who had attended concept mapping tutorials and those who had not, based on final exam performance on selected questions related to the concept mapping tasks.

The current study differs from these other studies in that students were exposed to the use of concept mapping for a considerable length of time, that is, 11 teaching weeks in each of two courses. The longer implementation period is much more consistent with Novak, Gowin, and Johansen's (1983) view that long-term exposure to and use of concept mapping is necessary for the realisation of significant gains in meaningful learning.

The findings from the current research suggest that concept mapping can be introduced into tertiary-level tutorial classes and that students are on the whole very positive about its use. This is significant, as the satisfaction of users of a new technique is an important criterion in the overall evaluation of the intervention (Vennix & Gubbels, 1992). Dalgety and Coll (2005) point out that unfamiliar pedagogies may have a negative influence on tertiary level students, who quickly become accustomed to lectures in which they can 'turn off' and become passive learners. However, in the research presented here, the majority of students appeared to value the opportunity to engage in learning activities during tutorials. For those who did not, there was the option of attending conventional tutorials where they could "just sit and listen".

Specifically, students participating in this study reported that concept mapping helped them to see the links between concepts (Section 6.4.2), and to understand and learn the biology content being covered in lectures (Section 6.4.1). These findings are consistent with work by Fonseca, Extremina, and da Fonseca (2004) who reported

on the use of concept mapping in a third-year microbiology class, although the authors did not provide details of how the intervention was evaluated, or indeed how the concept maps had been used.

Students in the current study further reported that they found the concept maps “easier to follow” when compared to the linear presentation of concepts in lectures and in the textbook (Section 6.4.1). These findings support comments by Novak and Gowin (1984) that concept mapping helps students to navigate between linear text and the hierarchical organisation of information in the brain, and that the visual nature of concept mapping is “inherently more superior to verbal ways of organizing information” (Cliburn, 1987, p. 426). Consistent with the findings reported by others (e.g., Esiobu & Soyibo, 1995; Roth, 1994; Roth & Roychoudhury, 1993), the majority of students involved in the study presented here indicated that they had found it useful constructing the concept maps in small groups. This opportunity for collaborative learning was specifically valued by both the students and the tutor, as was the way the tutor interacted with the students while they constructed their maps (Section 6.4.4).

An additional finding from the present study is that a thorough understanding of the individual concepts is required before they can be linked together in a concept map (Section 6.4.1). This is of particular relevance since concept mapping was introduced partly to address the different needs of students who had a wide range of prior learning experiences and prior knowledge. Stewart, van Kirk, and Rowell (1979) suggest that it “might be wise to ask only students who have a good grasp of the subject to try and construct maps of it ... a student with sketchy knowledge is likely to be overwhelmed and confused by the task” (p. 175). However, the current study indicates that students with more limited prior knowledge also were able to engage in the task, and several specifically reported that concept mapping had helped them to “make sense of the concepts.” The role of collaborative discussion (student-student and tutor-student) was considered by the students to be an important facilitator of this process. This is consistent with other reports in the literature

regarding the role of the teacher in fostering collaborative learning (e.g., Brown & Campione, 1994; Halloun & Hestenes, 1985). The development of positive relationships between students and between students and faculty have further been shown to reduce student attrition (Daempfle, 2003; Zepke et al., 2005).

Both the students and tutor involved in the current study highlighted classroom management strategies as contributing to their positive views about the use of concept mapping (Section 6.4.5). In particular, it was found that there was a need for the teacher to model the construction of concept maps, but that students valued the opportunity to spend time constructing their own maps. The role of the teacher in guiding discussions with the students (both as a whole class and with individual students or small groups of students as they constructed their own concept maps) was also valued, as was whole-class discussion at the end of each tutorial session in which a range of student-constructed maps could be discussed and feedback (both from the tutor and other class members) could be given. A few students commented negatively on the time required to construct a concept map, although the majority of students reported that they felt the time involved was worthwhile. Whole-class concept maps were constructed on the board in some tutorial sessions, notably those before course tests (the tutor wanted to have the flexibility to cover a larger range of content during these sessions). Cliburn (1987) suggests that an alternative strategy is to provide students with a map outline that they are required to complete (e.g., by adding in the linking terms for horizontal, integrative links).

Not surprisingly, the views of the tutor responsible for implementing the concept mapping intervention described in this study also were identified as being significant, both in terms of the way that she used concept mapping in the tutorial classes, and in her perceptions of the usefulness of concept mapping (Section 6.5). In particular, the tutor valued (in theory and in practice) opportunities to engage students in meaningful discussions about their learning; she was skilled at using open-ended questions to explore students' current understandings of concepts; and she was reflective of her own practice. She also reported feeling increasingly more confident

about using concept mapping over the two 11-week implementation periods. This suggests that the introduction of new pedagogy requires learning by the tutor, as well as the students, and it seems significant that the characteristics of the tutor implementing the intervention described in this study fits with the social constructivist view of learning that was used to underpin the research.

There is strong support in the literature for such ‘constructivist teacher development’ in which the teacher views himself or herself simultaneously as a learner, teacher, and researcher (Kinchin, 2001b; Kroll & LaBoskey, 1996). As Brookfield (1995) points out, such a teacher “experiments creatively with approaches ... in response to the unique demands of the situations in which they work” (p. 216).

#### The Role of Concept Mapping in Facilitating Meaningful Learning

As well as showing how concept mapping can be successfully introduced in tertiary biology classrooms, the findings from the current work contribute to the broader literature in concept mapping by distinguishing between the cognitive effects of concept mapping for different types of tasks (i.e., those that require rote memorisation, or shallow learning, versus those that entail deeper learning and the cognitive linking of several different concepts; see Section 6.6). Similar findings were reported by Schmid and Telaro (1990) evaluating the effect of concept mapping use by 9th and 10th grade biology students in Canada. However, the majority of studies evaluating the effectiveness of concept mapping as a teaching/learning tool do not report findings at this fine-grained level. Indeed, some of the studies that report no significant differences as a result of concept mapping might be the result of questions focusing on rote reproduction of responses, rather than tasks that require more sophisticated understanding of concepts.

The findings from the current work suggest that although concept mapping is a strategy that can effectively be used alongside other strategies in tertiary tutorial classes, this is more worthwhile if the type of deep learning that is encouraged through the concept mapping strategy is also the focus of assessment tasks (and

ultimately the course objectives).<sup>39</sup> In other words, students are likely to value strategies that encourage deep learning only if this kind of learning is in fact rewarded by the assessment regime. As Ames (1992) argues, deep learning, or learning for understanding, is made salient when this sort of learning is required for success in assessment tasks.

A few students in this study alluded to this by reporting that although they felt concept mapping had helped them to learn the material, it did not help them to answer test questions (Section 6.4.1). A small proportion of students also appeared to resist adopting an approach that differed from their customary approach to learning. This is consistent with other reports in the literature, which note that some students may resist using a new learning tool, particularly if: it is considered to limit or interfere with the student's customary approach to learning (Slotte & Lonka, 1999); the student has had prior success with his or her customary approach to learning (Chapman, 2001); or the student is heavily focused on high-stakes assessment regimes that reward rote learning (Novak & Gowin, 1984). Novak (1990) thus argues that concept mapping is "no 'magic bullet', no 'quick fix' for classrooms where rote learning predominates" (p. 947).

A further finding of the current research is that assessment tasks did not seem to correlate very strongly with questions discussed in tutorial classes (see Section 6.6). This raises the question of the relevance of the tutorial discussions to the learning aims of the courses, particularly as other research has shown that students consider tutorials to be the most relevant (out of tutorials, lectures and laboratory classes) in terms of preparation for topic tests and examinations in tertiary science courses (Dalgety & Coll, 2005; Hobden, 2001; Jackman, Moellenberg, & Brabson, 1990) as well as in other disciplines (Abbott-Chapman, Hughes, & Wyld, 1992; Mulligan & Kirkpatrick, 2000). Further, students with more limited prior knowledge

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<sup>39</sup> Coll (1997) suggests that there is not necessarily a strong link between the stated course aims and objectives, and the assessment regimes associated with the courses.



appear to particularly value their experiences in tutorials (Bennett, Rollnick, Green, & White, 2001; Mulligan & Kirkpatrick, 2000).

### **7.3 METHODOLOGICAL CONSIDERATIONS**

Shulman (1997) points out that any educational inquiry possesses some constraints and limitations. What is important is that they are recognised, and that appropriate care is taken when interpreting the meaning of research findings.

The current study sought to investigate teaching and learning in introductory-level tertiary biology courses as a whole, rather than specific content areas. These courses typically include extensive coverage of content (including diversity of organisms, animal and plant anatomy and physiology, and cellular and molecular processes). As a result, the depth of coverage of the range of concepts to be included in the prior knowledge questionnaire was necessarily limited. This means that student understanding of all these concepts could not be explored in great depth. Rather, the findings represent broad themes that emerged from the data:

1. Differences in prior knowledge assumed by faculty and actual student prior knowledge;
2. Differences in prior knowledge depending on prior biology study for some but not all concepts that were investigated; and
3. Difficulty in forming links between concepts.

The prevalence of specific alternative conceptions was not explored in any detail.

A second methodological constraint that existed concerned the first phase of the study, in which the prior knowledge assumed by faculty was explored. Although efforts were made to use multiple methods of data gathering (interviews with faculty, classroom observations, and document analysis), the classroom observations were carried out at one university only. As a result, individual faculty become more readily identifiable and ethical issues prevent the researcher from reporting the findings too specifically. Discrepancies between what faculty say they assume, and what they actually assume in practice, are thus not explored in detail.

A third methodological constraint concerns the implementation of the concept mapping intervention in tutorial classes. These classes were selected as the most appropriate vehicle for implementing a teaching intervention (see Section 6.3.1). However, attendance at these classes was voluntary and fluctuated each week. Further, students could not be randomly assigned to a particular class to ensure equivalence (in terms of prior knowledge, student motivation, etc.) amongst those intending the intervention ('treatment') and conventional ('control') classes. The study was thus not experimental in nature. Rather, it was exploratory and descriptive, seeking to uncover learners' experiences and to contextualise the findings in the particular educational setting in which it was conducted.

Further, this study was conducted in a particular educational context and is thus somewhat limited in scope. While the first phase of the study (i.e., an inquiry into faculty assumptions regarding students' prior knowledge) sought to include the views of academic staff from several institutions, phase two and phase three were carried out at one institution only. This potentially limits the transferability of the research findings and conclusions. However, the demographics at other New Zealand universities and comparable institutions overseas are likely to be similar, and faculty at other New Zealand universities did refer in interviews to the diverse academic backgrounds of students. Further, rich descriptions of the research context are provided to help readers to determine the extent to which the findings relate to their own educational contexts (Cohen, Manion, & Morrison, 2000; Maykut & Morehouse, 1994; Merriam, 2001; Peshkin, 1993). As Tobin and Tippins (1993) point out:

The purpose of reporting is to inform others of what has been learned from a study ... not to convince readers of the generalizability of what has been learned but to provide sufficient details of the contexts in which the theory is embedded and to enable readers to decide on the extent to which what has been learned can help them meet their goals. (p. 19)

The educational context of the current study, like many others, is dominated by didactic teaching methods and assessment regimes which seem to reward rote learning (Laws, 1996; Ramsden, 2003). There was some evidence in the current study that some students were made uncomfortable with differences between the

concept mapping intervention and the normal teaching approach. Hence, an important consideration when introducing concept mapping is that teaching faculty may encounter student resistance to the use of this tool if students are heavily focused on high-stakes assessment regimes that reward rote learning (see Section 7.1.3). Teachers are thus advised to carefully consider if concept mapping is necessary and appropriate for their own educational setting, or alternatively allow for student choice in the types of teaching that is offered. (In this case concept mapping tutorials were offered alongside more conventionally run tutorial classes, and students could attend the sessions that they felt best suited their learning styles.)

## **7.4 IMPLICATIONS FOR TEACHING AND LEARNING**

The findings presented in this thesis have several implications for the design and teaching of first-year biology courses at university, particularly regarding the diversity of students' academic backgrounds and relevant prior knowledge. These implications are discussed below.

### ***7.4.1 Matching Faculty Expectations with Students' Reality***

First, the findings from the research suggest that there are significant gaps between the understandings students have of key biological, chemical and mathematical concepts, and the understandings faculty assume they have.<sup>40</sup> This is partly due to the diverse academic backgrounds of students and the consequent variation in students' prior knowledge (some students have more limited understanding of key concepts than others). Faculty may also assume more prior knowledge than they realise. A further important finding is that although faculty ostensibly expect students to make connections between concepts, students appear not to do this.

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<sup>40</sup> In some cases faculty reported that they were aware students did not understand some of the concepts, but time constraints prevented detailed explanations from being provided during class.

Although the level of biology-specific prior knowledge did not appear to be directly related to the final assessment grades of students participating in a plant and animal biology course, it does have the potential to impact workload and student self-efficacy, both of which can influence student attrition (Abbott-Chapman, Hughes, & Wyld, 1992; Dalgety & Coll, 2005; Leder & Forgasz, 2004; Zepke et al., 2005). Variations in students' prior knowledge also have implications for teaching, particularly if a social constructivist view of learning is adopted and if faculty support calls in the science education literature for teachers to consider students' prior knowledge when developing their teaching programmes. However, there is the perception amongst a number of science education researchers that many tertiary educators are not aware of the constructivist paradigm (Barrow, 1994; Davis, McCarty, Shaw, & Sidam-Tabbaa, 1993) and that a dramatic change in their own perceptions of the role of the tertiary teacher may not be easily accomplished (Brookfield, 1995; Coll & Taylor, 2001).

Faculty can investigate students' prior knowledge either indirectly by referring to the relevant science education literature, or by using a questionnaire format as adopted in this study (the questionnaire used in this study could be used directly). Informal interviews with students, for example in a laboratory setting, may also prove to be useful. An additional advantage of this latter approach is that students have greater opportunity to interact with faculty. This sort of interaction between faculty and students has been shown to be valued by students (Dalgety & Coll, 2005), and may reduce attrition (Astin & Astin, 1992; Daempfle, 2003; Zepke et al., 2005).

An alternative strategy to narrow the gap between faculty perspectives and those of the students is for faculty to make their expectations more clear (Pennington, 2001). Specifically, the current study suggests that faculty expect students to be able to form connections between concepts, including those which are taught in other parts of the course, and often by other lecturers. On the other hand, students appear to have difficulty forming these connections. Thus, there seems to be scope for faculty to

make a conscious effort to make connections more explicit. This could be done as part of the teaching process, and also through course lecture manuals. Additionally, subject matter should be sequenced in a way that requires the “continual recycling and consolidation of previous learning” (Keats & Boughey, 1994, p. 62). Finally, assessment tasks should reflect faculty expectations about conceptual understanding and conceptual linking if these skills are to be valued by students. As Ramsden (2003) has argued: “From our students’ point of view, assessment always defines the actual curriculum.” This theme will be revisited later in Section 7.4.3.

A further finding of the research is that although faculty reported that they specifically try to assume very little prior knowledge of specific biological concepts, they do expect students to have some understanding of basic chemical and mathematical concepts. However, findings from the prior knowledge questionnaires administered to students suggest that a large proportion of students do not meet these requirements. This issue, particularly regarding the mathematical skills of students entering first-year courses, has also been raised by others (see Section 7.1.2).

The science education literature refers to a range of strategies that have been implemented to address students’ mathematical skills, including: using the results of diagnostic tests to structure revision tutorials; providing a drop-in, ‘surgery’ facility; using workbooks or computer-based learning packages designed to address specific skills in subject-specific contexts; and developing additional course modules in which key skills are taught (Bishop & Eley, 2001; Phoenix, 1999b). However, Tariq (2002) points out that not only are these interventions highly demanding in terms of staff time, but many fail to provide an integrated yet flexible programme that allows for the effective and efficient delivery of skills tuition to all students. There is also the tension between providing support to those who need it, and at the same time motivating and encouraging the high achievers (Bishop & Eley, 2001; Tariq, 2002) as boredom can contribute to students’ decisions to drop out of university (Abbott-Chapman, Hughes, & Wyld, 1992). Additionally, faculty are generally resistant to

approaches that are likely to reduce subject-specific teaching time (Astin & Astin, 1992; Phoenix, 1999b).

The university in which the majority of the current research took place offers weekly tutorial classes as part of the first-year biology courses, and there is scope for some of these classes to be specifically set aside to address relevant chemical and mathematical concepts. The university also has a drop-in facility to help students with mathematical questions, but this service currently appears to be little used by biology students. Perhaps advertising the service after the first test, as well as at the start of the year, may prompt more students to seek assistance once they realise the importance of mathematics in the first-year biology courses.

#### ***7.4.2 Using Concept Mapping to Facilitate Meaningful Learning***

The current research demonstrates the diversity of prior knowledge of students entering first-year biology courses, as well as the wide-spread lack of ability to link concepts in a meaningful way. The findings suggest that concept mapping is one strategy that can be used to address both these concerns, and the introduction of concept mapping into first-year biology tutorial classes was shown not only to be feasible, but also to be valued by students. Further, the method is flexible and can be used alongside other teaching and learning approaches. However, the research presented in this thesis highlights two important aspects that need to be considered before implementing concept mapping as a teaching and learning tool.

First, concept mapping appears to only be worthwhile if the assessment tasks reward the type of deep learning that is facilitated by the construction of concept maps. Those considering using the technique are thus advised to first consider the overall objectives of the course, the type of learning that students are required to do, and the assessment regime. If the course objectives and assessment regimes do actually require linking of concepts, then the current work suggests this may be enhanced by the use of concept mapping. If the course objectives and assessment

practices do not require students to link concepts then there is probably little point in engaging in what is a fairly time-consuming task of developing a new teaching approach.

Second, the implementation of the teaching intervention was influenced by the characteristics of the tutor. Specifically, her reflective approach, as well as her own social constructivist views of learning and ability to engage students in conversations about their own ideas, appeared to have a significant impact on the delivery of the intervention programme. This has implications for others who are interested in using concept mapping as part of their teaching. Perhaps more importantly, it also has implications for faculties that are considering encouraging a number of different staff members to adopt a concept mapping (or other) approach in their teaching.

#### ***7.4.3 Bridging Biology Courses***

As well as informing the design and delivery of introductory-level biology courses, the research presented in this thesis has several implications for the design of bridging biology courses. These courses, variously called preparatory courses, pre-degree courses, access courses, and enabling programmes (Archer, Cantwell, & Bourke, 1999), are offered by several New Zealand universities and target a range of students, including mature students as well as younger students who did not complete senior science subjects at secondary school.

In terms of course design, the current research provides a list of biological concepts that should be included in such courses because faculty assume that students are familiar with these concepts when they enrol in first-year biology classes. Interestingly, the list is not extensive, providing bridging course tutors with the opportunity to focus on in-depth coverage of fewer topics, rather than superficial coverage of many topics. This in-depth coverage is a cornerstone of a constructivist-based view of teaching and learning (Eylon & Linn, 1988) and tends to encourage

deep, or meaningful, learning (Deniz & Harwood, 2003; Keats & Boughey, 1994; Ramsden, 2003). Also consistent with a constructivist view of learning, the questionnaire developed in this study could be used to identify students' prior knowledge when enrolling in a bridging course. The findings could be used to ensure that the course is targeted to the particular group of students enrolled in the course.

As well as biological concepts, the research reported in this thesis suggests that a range of mathematical and chemical concepts should also be learned prior to participating in introductory-level degree courses. Including these concepts in a subject-specific bridging course (rather than a generic 'skills' course) means that the concepts can be grounded in relevant contexts.

Having said all this, the findings from the current work do raise questions about the need for bridging biology courses, particularly since students with more extensive prior biology study did not appear to necessarily do better than those with more limited prior biology study, at least in the animal and plant course that was evaluated. However, it would be interesting to know how successful students who attended a bridging biology course would have been had they not participated in the bridging courses. In particular, many students who are directed to participate in a bridging course may have low self-efficacy and be concerned that they lack the critical background knowledge and skills required for successful participation in first-year biology courses (Dalgety & Coll, 2005; Leder & Forgasz, 2004). Low self-efficacy has been reported in the literature to influence student motivation (Archer, Cantwell, & Bourke, 1999) and consequently attrition (Leder & Forgasz, 2004; Willson, Ackerman, & Malave, 2000). Attendance at bridging courses per se may enhance students' perceptions of their ability to cope with tertiary study, as well as improving their subject-specific knowledge.



## 7.5 RECOMMENDATIONS FOR FUTURE RESEARCH

The research presented in this thesis focused on first-year biology courses, and specifically the diverse prior knowledge of students and the implications of this for teaching and learning. Although faculty from six universities were involved in phase one of the work, the prior knowledge questionnaires and teaching intervention took place in one university only. Future work could be extended to explore the diversity in science and mathematical prior knowledge of students enrolling in first-year biology courses at other universities, and in other first-year science courses. Correlations between students' relevant prior knowledge, their self-efficacy, motivation, learning approaches, and course achievement are also of interest.

The National Certificate for Educational Attainment, introduced as the new senior secondary school qualifications framework in New Zealand in 2002 (see New Zealand Qualifications Authority [NZQA], 2001) also has the potential to impact students' understandings of concepts when they leave school. For example, even though schools are still required to teach the content outlined in the curriculum (which is unchanged at present, but also under review), comments made by teachers attending professional development meetings suggest that many schools are encouraging students to complete only some of the assessment standards. As a result, senior biology students may have been assessed on their understanding of the role of DNA in relation to gene expression (Achievement Standard 90715; see NZQA, 2005a), but not processes and patterns of evolution (Achievement Standard 90717; NZQA, 2005b). The implications for prior knowledge that students bring with them to the tertiary classroom are worthy of further investigation (students are likely to have a better understanding of concepts that have been taught and assessed, than concepts that may have been taught, but that were not assessed).

Another area worthy of further investigation is the need for and role of bridging or preparatory courses. This is particularly relevant given the increased pressure on universities to justify their courses (Scott, 2005). It would also be of

interest to incorporate the findings from this research into curriculum design for bridging biology courses (e.g., specifically including topics on chemical and mathematical concepts), and to evaluate the usefulness of the resultant curriculum modifications.

Finally, future tertiary-level research in science education could explore the role of concept mapping and other interactive learning tools in enhancing student learning. Specifically, the role of the tutor's teaching philosophy and pedagogy in facilitating concept mapping classes could be explored, as could the use of concept mapping and other pedagogical tools in science courses other than biology, or at higher levels in biology. Faculty perceptions of the need for such an intervention (and their views of who should provide it should there be a need) would also be of interest. In addition, many science education researchers advocate the use of concept mapping as an assessment tool (e.g., Moreira, 1985; Ruiz-Primo, Schultz, Li, & Shavelson, 2001; Shavelson & Ruiz-Primo, 2000; Stoddart, Abrams, Gasper, & Canaday, 2000) and this was not explored in the current work.

## **7.6 FINAL COMMENTS**

Ramsden (2003), in his book "Learning to teach in higher education", argues that good teaching involves finding out from students and other sources about the difficulties students experience in learning the subject matter. Further, he suggests that the continually growing numbers of students entering higher education from non-traditional backgrounds imply that increasing attention has to be paid to studying the variety of understandings and skills with which students begin a course in higher education. Laws (1996) similarly points out that strategies are needed for tertiary teachers to be able to take into account the broad range of students' prior learning in their teaching.

The research presented in this thesis examined the teaching and learning in introductory-level tertiary biology courses. Consistent with Ramsden's (2003) comments, a key focus for the research was the diversity in academic backgrounds of

students, and the consequent diversity in students' prior knowledge. To this end, the prior knowledge assumed by faculty was compared with the actual prior knowledge of students. A teaching intervention using concept mapping was subsequently implemented and evaluated. The findings suggest that concept mapping is well received by students as a teaching and learning tool, although it appears to be more worthwhile when assessment tasks require conceptual linking, rather than rote memorisation of isolated facts. The continued use of concept mapping in tutorial classes since the completion of the research confirms both the relevance and significance of the work.

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**APPENDIX A**  
**SEMI-STRUCTURED INTERVIEW PROTOCOL USED TO SURVEY**  
**FACULTY**

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1. Which first-year biology course(s) do you teach in?
2. What specific topics do you teach?
3. Approximately how many years have you been teaching these topics?
4. Are there specific topics which you teach that students seem to find particularly difficult?
5. Why do you think students have difficulty with these topics?
6. Is there any way in which you try to address this?
7. What concepts do you assume students are familiar with when teaching your section of the course?
8. What school subjects (if any) do you think are helpful for students to have completed prior to participating in first-year biology courses?
9. Do you think a bridging course would be helpful for students who have not completed senior biology at school?
10. (If yes...) What topics do you think should be included in a bridging course?
11. What mathematical skills do you think students need for your first-year biology course?
12. Please select the specific mathematical skills students need (but are not taught) from the following list:<sup>41</sup>
  - Calculating rates
  - Understanding statistical distribution (mean, median, mode, standard deviation, normal curves)
  - Interpreting tables and diagrams
  - Interpreting correlations
  - Interpreting graphs
  - Using significant figures
  - Using algebraic formulae
  - Using square roots
  - Conversion within the metric system (e.g., millimeters to micrometres)
  - Calculating and interpreting probability
  - Calculating permutations and combinations
  - Calculating area and volume
  - Using a log scale for graphing
  - Using scientific notation (e.g.,  $3 \times 10^6$ )
  - Using scales in drawings
  - Identifying dependent and independent variables
  - Calculating percentage
  - Calculating ratios and proportions
  - Using fractions in calculations
  - Calculating means
  - Drawing graphs
  - Using sets and Venn diagrams

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<sup>41</sup> Mathematical competencies identified by Marsh and Anderson (1989) as being desirable for students to possess when they enrol in introductory biology courses in the United States.

## APPENDIX B INFORMED CONSENT FORM FOR FACULTY INTERVIEWS

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Cathy Bunting  
Centre of Science and Technology Education Research  
The University of Waikato  
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Phone: 838 4466 ext 8453  
Email: [bunting@waikato.ac.nz](mailto:bunting@waikato.ac.nz)

*[Letter to biology chairs of department]*

November 2002

Dear \_\_\_\_\_,

I am a PhD student at The University of Waikato where I am investigating teaching and learning in introductory biology courses.

For this project, I am seeking permission to involve staff members who lecture in first year biology papers at your university. The focus of this part of my study is to determine what lecturers assume that students know on entry to introductory biology papers. This may include specific biological concepts as well as more generic understanding, for example how to manipulate mathematical equations.

Participants in the study will be asked to provide course handouts (this will only apply to course co-ordinators of introductory biology courses) and to participate in a short interview (30-45 minutes) at a time and place of mutual agreement.

The results of the interviews will be used to develop a questionnaire which will be administered to students at the University of Waikato at the start of their introductory biology courses.

***For one university only [re. course observations and the prior knowledge questionnaire administered to students]:***

In a later phase of the research I am planning to ask all first year biology students to complete a questionnaire during a scheduled laboratory session in which there is extra time. This will be discussed with the course co-ordinator. It would also be valuable if I could then interview a cohort of students to probe student understanding even further.

Effort will be made to ensure that the educational progress of students is not hindered in any way. The right of students to decline participation will be protected. No coercion will be employed. It will be emphasised that the formal assessment of the course is completely independent of participation in the research.

I will also be grateful for the opportunity to be an unobtrusive observer of lectures, tutorials and laboratory sessions.

A tutorial intervention will then be developed to try to address any gaps in student understanding revealed by analysis of questionnaire responses.

Staff members who are interviewed will be provided with a transcript of the interview and will have the opportunity to clarify anything that was said, or to request that all or part of the interview is not used for the study. Results of the interviews will be reported only in a way that prevents identification of individuals. Confidential information about participants will not be made available to other researchers without the participant's permission. The research has been approved by the School of Science and Technology Human Research Ethics Committee, University of Waikato.

Participating staff members will also be provided with a written summary of the research, and will be notified with details of publications based on the project.

I am excited about the potential outcome of this work, and hope that you will agree to allow me access to the staff in your department.

If you are happy for me to interview your staff and ask course co-ordinators for copies of their course study manuals, I would appreciate it if you could please sign the form below. Please also feel free to contact me or my supervisor [name and contact details provided] if you have any questions about this research.

Sincerely,  
Cathy Bunting

**CONSENT FORM:**

I am happy for Cathy to approach staff in my department.

I understand that:

- 1 Staff will be involved in a study on teaching and learning in first-year Biology courses
- 2 Data gathered for this project will not be made available to any third party and will be subject to the provisions of the New Zealand Privacy Act (1993)
- 3 Staff will not be identified in any way other than a code number or pseudonym in data records or reports of the research findings
- 4 Staff may withdraw from parts of this study at any stage and, if they wish, they may withdraw from the project completely
- 5 If I or my staff have any concerns about participation in this research project we may approach either Cathy Bunting, or her supervisor [name and contact details provided]

Signature: \_\_\_\_\_

Name: \_\_\_\_\_

Date: \_\_\_\_\_



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The University of Waikato  
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*[Letter to faculty contributing to introductory biology courses]*

November 2002

Dear \_\_\_\_\_,

I am a PhD student at The University of Waikato where I am investigating teaching and learning in introductory biology courses. The focus of the first part of the study is to determine what lecturers assume students know when they enrol in introductory biology courses. This may include specific biological concepts, as well as more general concepts, for example, how to manipulate mathematical equations.

I would be grateful if you would agree to participate in the study by being interviewed for 30 – 45 minutes. I have also contacted [the Chair of Department], who has given permission for me to approach staff and invite them to participate. The interview will be conducted at a time and place that is convenient to you.

With your permission, the interview will be tape-recorded. You will be provided with a transcript of the interview and have the opportunity to clarify anything that was said, or to request that all or part of the interview not be included in the study. Findings from the interviews will be reported in a way that prevents identification of individuals. Confidential information about participants will also not be made available to other researchers without the participant's permission. The research has been approved by the School of Science and Technology Human Research Ethics Committee at the University of Waikato.

You will be notified with details of publications based on the project.

If you are happy for me to interview you, I would appreciate it if you could please sign the form below. Please also feel free to contact me or my supervisor [name and contact details provided] if you have any questions about this research.

Sincerely,  
Cathy Bunting

**CONSENT FORM:**

I am happy to be interviewed by Cathy.

I understand that:

- 1 I will be involved in a study on teaching and learning in first-year Biology courses
- 2 Data gathered for this project will not be made available to any third party and will be subject to the provisions of the New Zealand Privacy Act (1993)
- 3 I will not be identified in any way other than a code number or pseudonym in data records or reports of the research findings
- 4 I may withdraw from parts of this study at any stage, and if I wish I may withdraw from the project completely
- 5 If I have any concerns about my participation in this research project I may approach either Cathy Bunting, or her supervisor [name and contact details provided]

Signature: \_\_\_\_\_

Name: \_\_\_\_\_

Date: \_\_\_\_\_

## APPENDIX C

### INFORMED CONSENT FORM FOR CLASSROOM OBSERVATIONS

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February 2003

Dear \_\_\_\_\_,

As you know, I am currently investigating the teaching and learning in introductory biology courses as part of my PhD research. In particular, I am interested in student prior knowledge and how this may affect their learning.

As part of this research, I would be grateful for your permission to observe the lectures and tutorial classes you offered as part of the first-year biology course. The aim of the observations is to investigate the content that is taught, and specifically to identify concepts that students are assumed to be familiar with (i.e., that are not explained).

Students will also be informed of my presence as an observer, and only four of the six weekly tutorials will be observed to enable students to attend a non-observed class if they wish. Any reporting of the classes will be done in a way that ensures that individual students will not be identified. I may also want to describe the general format of the classes. In this case, every effort will be made to ensure that specific staff members are not identifiable.

If you are happy for me to observe your classes, I would appreciate it if you could please sign the form below. Please also feel free to contact me or my supervisor [name and contact details provided] if you have any questions about this research.

With kind regards,  
Cathy Bunting



**CONSENT FORM:**

I am happy for my first-year lectures and tutorial classes to be observed by Cathy.

I understand that:

- 1 I will be involved in a study on teaching and learning in first-year Biology courses
- 2 Data gathered for this project will not be made available to any third party and will be subject to the provisions of the New Zealand Privacy Act (1993)
- 3 I will not be identified in any way other than a code number or pseudonym in data records or reports of the research findings
- 4 I may withdraw from parts of this study at any stage, and if I wish I may withdraw from the project completely
- 5 If I have any concerns about my participation in this research project I may approach either Cathy Bunting, or her supervisor [name and contact details provided]

Signature: \_\_\_\_\_

Name: \_\_\_\_\_

Date: \_\_\_\_\_

**NOTICE ON THE OVERHEAD PROJECTOR TO INFORM STUDENTS OF THE RESEARCHER'S PRESENCE IN TUTORIAL CLASSES**

**STUDENTS**

Cathy Bunting is a PhD student who is looking at ways to improve teaching and learning on introductory biology courses.

She will be observing this classroom session. Although she may record what is said during this session, any comments will be coded to make sure that individuals cannot be identified. Please do not let her presence cause you to change your behaviour in any way.

If you feel uncomfortable about her presence in your classroom, please feel free to leave and to attend an alternative tutorial session [alternative times provided]. You may also contact [the course co-ordinator] to discuss any concerns that you have.

**APPENDIX D**  
**PRIOR KNOWLEDGE QUESTIONNAIRE, MARCH 2003**

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Student ID: \_\_\_\_\_

**THIS IS NOT A TEST.**

What you write will not affect the way your performance in the course is assessed.

The reason for asking you these questions is to determine your background understanding so that we can see how we might teach difficult topics better.

Please answer all questions to the best of your ability.

**A BIOLOGY BACKGROUND**

Please indicate only the *highest* level of biology that you have studied.

- |                                |                                  |   |                                |                                |                                |
|--------------------------------|----------------------------------|---|--------------------------------|--------------------------------|--------------------------------|
| <input type="checkbox"/>       | Year 11 science                  | <table border="1"><tr><td>Year 11 = 5<sup>th</sup> form</td></tr><tr><td>Year 12 = 6<sup>th</sup> form</td></tr><tr><td>Year 13 = 7<sup>th</sup> form</td></tr></table> | Year 11 = 5 <sup>th</sup> form | Year 12 = 6 <sup>th</sup> form | Year 13 = 7 <sup>th</sup> form |
| Year 11 = 5 <sup>th</sup> form |                                  |   |                                |                                |                                |
| Year 12 = 6 <sup>th</sup> form |                                  |   |                                |                                |                                |
| Year 13 = 7 <sup>th</sup> form |                                  |   |                                |                                |                                |
| <input type="checkbox"/>       | Year 11 human biology            |   |                                |                                |                                |
| <input type="checkbox"/>       | Year 12 science                  |   |                                |                                |                                |
| <input type="checkbox"/>       | Year 12 biology                  |   |                                |                                |                                |
| <input type="checkbox"/>       | Year 12 human biology            |   |                                |                                |                                |
| <input type="checkbox"/>       | Year 13 science                  |   |                                |                                |                                |
| <input type="checkbox"/>       | Year 13 biology                  |   |                                |                                |                                |
| <input type="checkbox"/>       | Year 13 human biology            |   |                                |                                |                                |
| <input type="checkbox"/>       | Bridging course: _____           |   |                                |                                |                                |
| <input type="checkbox"/>       | University biology course: _____ |   |                                |                                |                                |
| <input type="checkbox"/>       | Polytech biology course: _____   |   |                                |                                |                                |
| <input type="checkbox"/>       | Other: _____                     |   |                                |                                |                                |

Please indicate when you completed the course selected in (A) above.

Year: \_\_\_\_\_

**B OTHER BACKGROUND**

Please indicate only the *highest* level of the subjects listed below that you have passed.

- |                        |                          |         |                          |         |                          |         |                          |        |
|------------------------|--------------------------|---------|--------------------------|---------|--------------------------|---------|--------------------------|--------|
| <b>Any maths</b>       | <input type="checkbox"/> | Year 11 | <input type="checkbox"/> | Year 12 | <input type="checkbox"/> | Year 13 | <input type="checkbox"/> | Other: |
| <b>General Science</b> | <input type="checkbox"/> | Year 11 | <input type="checkbox"/> | Year 12 | <input type="checkbox"/> | Year 13 | <input type="checkbox"/> | Other: |
| <b>Chemistry</b>       | <input type="checkbox"/> | Year 11 | <input type="checkbox"/> | Year 12 | <input type="checkbox"/> | Year 13 | <input type="checkbox"/> | Other: |
| <b>Physics</b>         | <input type="checkbox"/> | Year 11 | <input type="checkbox"/> | Year 12 | <input type="checkbox"/> | Year 13 | <input type="checkbox"/> | Other: |
| <b>English</b>         | <input type="checkbox"/> | Year 11 | <input type="checkbox"/> | Year 12 | <input type="checkbox"/> | Year 13 | <input type="checkbox"/> | Other: |

**C LANGUAGE BACKGROUND**

What do you consider to be your first language?

\_\_\_\_\_

**1. Indicate which of the following can be called animals:**

*(You may select more than one response)*

- |                                    |                                   |   |
|------------------------------------|-----------------------------------|---|
| <input type="checkbox"/> earthworm | <input type="checkbox"/> spider   | <input type="checkbox"/> person         |
| <input type="checkbox"/> rabbit    | <input type="checkbox"/> bacteria | <input type="checkbox"/> Venus fly trap |
| <input type="checkbox"/> starfish  | <input type="checkbox"/> octopus  | <input type="checkbox"/> butterfly      |

**2. Why do animals need energy?**

*(You may select more than one response)*

- to reproduce
- to grow
- to control internal functions
- to move
- to get rid of wastes, eg.: \_\_\_\_\_
- to respond to the environment, eg.: \_\_\_\_\_
- to repair the body
- don't know / not sure
- other *(please specify)* : \_\_\_\_\_

**3. Where do animals get their energy?**

*(You may select more than one response)*

- from the air that they breathe
- from water
- from sleeping
- from food
- don't know / not sure
- other *(please specify)* : \_\_\_\_\_

**4. Why do plants need energy?**

*(You may select more than one response)*

- to reproduce
- to grow
- to control internal functions
- to get rid of wastes, eg: \_\_\_\_\_
- to respond to the environment, eg: \_\_\_\_\_
- to repair themselves
- don't know / not sure
- other *(please specify)* : \_\_\_\_\_

**5. Where do plants get their energy?**

*(You may select more than one response)*

- from the gases in the air, eg: \_\_\_\_\_
- from 'food' in the soil
- from the sun
- from the wind
- from water
- from 'food' that they make
- don't know / not sure
- other *(please specify)* : \_\_\_\_\_

**6. Do bacteria need energy?**

*(Select one)*

- yes
- no
- don't know / not sure

**7. Which of the following parts of a person's body need oxygen to function?**

*(You may select more than one response)*

- skin
- heart
- lungs
- hair
- eyes
- muscles
- stomach
- bones
- brain
- don't know / not sure

**8. Why do you think oxygen is needed by the body part (or parts) you chose in question 7 above?**

*Please be as specific as possible.*

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**9. Please indicate what you know about the substances that ANIMALS like cows need to stay alive.**

*Indicate whether you think each of the following substances is needed by animals like cows. Where appropriate (i.e., if you answered yes), complete the last two columns if you can.*

Substance:	Is this substance needed by animals like cows?	How do animals like cows get this substance?	What do animals like cows use this substance for?
oxygen	<input type="checkbox"/> yes <input type="checkbox"/> no <input type="checkbox"/> don't know / not sure		
carbon dioxide	<input type="checkbox"/> yes <input type="checkbox"/> no <input type="checkbox"/> don't know / not sure		
Food	<input type="checkbox"/> yes <input type="checkbox"/> no <input type="checkbox"/> don't know / not sure		
water	<input type="checkbox"/> yes <input type="checkbox"/> no <input type="checkbox"/> don't know / not sure		
other <i>(please specify) :</i>			

10. **Please indicate what you know about the substances PLANTS need to stay alive.**  
*Indicate whether you think each of the following substances is needed by plants. Where appropriate (i.e., if you answered yes), complete the last two columns if you can.*

Substance:	Is this substance needed by plants?	Where do plants get this substance from?	What do plants use this substance for?
carbon dioxide	<input type="checkbox"/> yes <input type="checkbox"/> no <input type="checkbox"/> don't know / not sure		
oxygen	<input type="checkbox"/> yes <input type="checkbox"/> no <input type="checkbox"/> don't know / not sure		
water	<input type="checkbox"/> yes <input type="checkbox"/> no <input type="checkbox"/> don't know / not sure		
'food'	<input type="checkbox"/> yes <input type="checkbox"/> no <input type="checkbox"/> don't know / not sure		
light	<input type="checkbox"/> yes <input type="checkbox"/> no <input type="checkbox"/> don't know / not sure		
minerals	<input type="checkbox"/> yes <input type="checkbox"/> no <input type="checkbox"/> don't know / not sure		
other (please specify) :			

11. **Plants need to transport some substances, like water and sugars. What tissues do they use to do this?**

*Please be as specific as possible.*

---



---

12. **What would happen if a live plant is placed in a dark cupboard for a week? Assume that it is still watered properly and that there is sufficient airflow.**

---



---

**Please explain your answer:**

---



---

13. **During photosynthesis, plants produce sugars. Please explain what you think these sugars are used for.**

*Please be as specific as possible.*

---



---

14. The following list represents the categories (in order) that can be used to classify animals:  
phylum class order family genus species

Circle the one which you think contains the greatest number of different varieties of organisms.

15. The following terms are given in alphabetical order. List them below in order of physical size, from largest to smallest.

- |               |             |
|---------------|-------------|
| a) atom       | e) molecule |
| b) cell       | f) organ    |
| c) chromosome | g) organism |
| d) gene       | h) tissue   |

- 
- 
16. Please indicate your response to each of the biological terms that are given.

**CELLS:**

- I have never heard of cells  
 I have heard of cells, but don't really know what they are  
 I have heard of cells, and think that I could say something about them

*If you have heard of cells, please try to answer the following:*

**Describe a cell.**

*Please be as specific as possible.*

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---

**Where are cells found in your body?**

*Please be as specific as possible.*

---

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**DNA:**

- I have never heard of DNA  
 I have heard of DNA, but don't really know what it is  
 I have heard of DNA, and think that I could say something about it

*If you have heard of DNA, please try to answer the following:*

**Where is DNA found in your body?**

*Please be as specific as possible.*

---

---

**What is DNA used for in your body?**

*Please be as specific as possible.*

---

---

**CHROMOSOMES:**

- I have never heard of chromosomes
- I have heard of chromosomes, but don't really know what they are
- I have heard of chromosomes, and think that I could say something about them

*If you have heard of chromosomes, please try to answer the following:*

**Where are chromosomes found in your body?**

*Please be as specific as possible.*

---

---

**What are chromosomes used for in your body?**

*Please be as specific as possible.*

---

---

**GENES:**

- I have never heard of genes
- I have heard of genes, but don't really know what they are
- I have heard of genes, and think that I could say something about them

*If you have heard of genes, please try to answer the following questions:*

**Where are genes found in your body?**

*Please be as specific as possible.*

---

---

**What are genes used for in your body?**

*Please be as specific as possible.*

---

---

**What are genes made of?**

*Please be as specific as possible.*

---

---

**ENZYMES:**

- I have never heard of enzymes
- I have heard of enzymes, but don't really know what they are
- I have heard of enzymes, and think that I could say something about them

If you have heard of enzymes, please try to answer the following questions:

**What is an enzyme?**

Please be as specific as possible.

---

---

**Where are enzymes found in your body?**

Please be as specific as possible.

---

---

**What are enzymes made of?**

Please be as specific as possible.

---

---

**17. Do you think that the following organisms contain DNA?**

algae	<input type="checkbox"/> yes	<input type="checkbox"/> no	<input type="checkbox"/> don't know / not sure
mammals	<input type="checkbox"/> yes	<input type="checkbox"/> no	<input type="checkbox"/> don't know / not sure
ferns	<input type="checkbox"/> yes	<input type="checkbox"/> no	<input type="checkbox"/> don't know / not sure
fungi	<input type="checkbox"/> yes	<input type="checkbox"/> no	<input type="checkbox"/> don't know / not sure
bacteria	<input type="checkbox"/> yes	<input type="checkbox"/> no	<input type="checkbox"/> don't know / not sure
insects	<input type="checkbox"/> yes	<input type="checkbox"/> no	<input type="checkbox"/> don't know / not sure
tomatoes	<input type="checkbox"/> yes	<input type="checkbox"/> no	<input type="checkbox"/> don't know / not sure
genetically modified tomatoes	<input type="checkbox"/> yes	<input type="checkbox"/> no	<input type="checkbox"/> don't know / not sure

**18. Below is a problem that relates to the inheritance of particular characteristics. This type of problem may not be familiar to you, in which case you should tick the first box.**

**In horses, black coat colour (B) is dominant to chestnut (b). Suppose that a black stallion is mated with a chestnut mare and two black foals are born. Then suppose that these two black foals are mated.**

**What is the chance that the foal produced by this mating will be black?**

- I have never seen this kind of problem before
- I have seen this kind of problem before but don't know how to answer it
- I have seen this kind of problem before and think I can answer it

**If you think you can answer this problem, please try to do so. Show all your working.**



19. Does a human sperm cell contain:

- all the genetic information needed for a baby
- half the genetic information needed for a baby
- no genetic information needed for a baby
- don't know / not sure

20. Describe why a daughter can be said to look like her mother in some ways and like her father in other ways. For example, people might say a girl has her mother's eyes and her father's nose.

*Please be as specific as possible.*

---

---

---

---

21. Below is a list of cell sizes in metres. Tick the one that you think is the BIGGEST.

- $5 \times 10^{-5}$  m
- $5 \times 10^{-7}$  m
- $3 \times 10^{-5}$  m
- $8 \times 10^{-6}$  m
- Don't know / not sure

22. Below is a list of cell sizes in millimetres. Tick the one that you think is the SMALLEST.

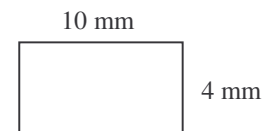
- 0.0507 mm
- 0.12 mm
- 0.012 mm
- 0.2 mm
- don't know / not sure

23. Below is a list of cell sizes. Rewrite them in order of physical size, from largest to smallest.

- a) 0.10 mm
- b) 150  $\mu\text{m}$
- c) 1.05 mm
- d) 10  $\mu\text{m}$

24. Suppose you have a rectangle with a length of 10 mm and width of 4 mm as in the diagram. What is the area of the rectangle in  $\text{cm}^2$ ?

*Please show all your working.*



25. A glucose solution can be made more concentrated by:

- adding more water
- adding more glucose
- don't know / not sure

Please give a reason for your answer:

---

---

In this question, glucose is the:

- solvent
- solute
- don't know / not sure

26. A drop of dye contains many dye particles. Suppose you add a drop of blue dye to a container of clear water and all the water eventually turns light blue even though it is not stirred. Describe the dye particles at this point:

- they have stopped moving
- they are still moving around randomly
- don't know / not sure

Please tick the best explanation for your answer:

- if the dye particles were still moving, the water would be different shades of blue
- if the dye particles stopped moving, they would settle at the bottom of the container
- particles are always moving
- other (*please be specific*): \_\_\_\_\_
- don't know / not sure

27. Suppose you have two containers with equal amounts of clear water in each. Container A is at 25°C and Container B is at 40°C. Now suppose that a drop of blue dye is added to each container and that all the water in each container eventually turns light blue even though there is no stirring.

Which container will this happen in first?

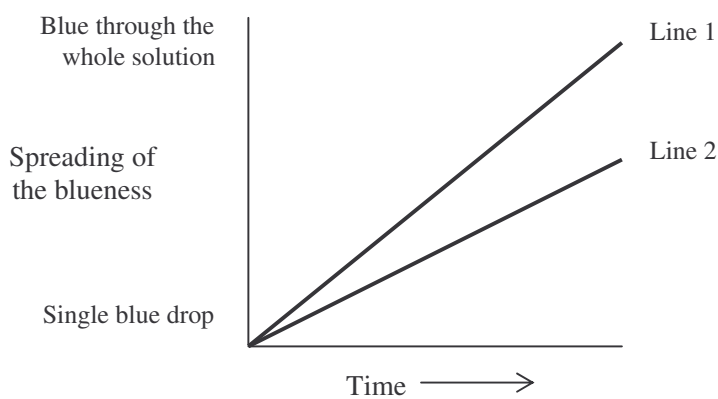
- container A (25°C)
- container B (40°C)
- don't know / not sure

Please tick the best explanation for your answer:

- the lower temperature breaks down the dye
- the dye particles move faster at higher temperatures
- cold temperatures make the dye particles move faster
- the temperature helps the dye particles to expand
- other (*please be specific*): \_\_\_\_\_
- don't know / not sure

The graph below represents the results from the experiment. Does line 2 represent:

- container A (25°C)
- container B (40°C)
- don't know / not sure



Please give a reason for your answer:

---

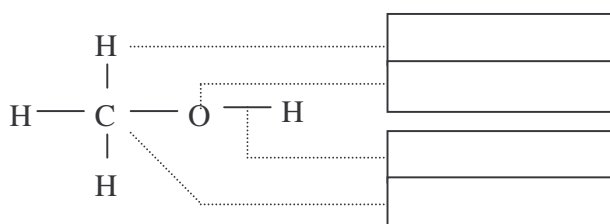


---

Please write a title for the graph:

---

28. Label the components of the following drawing by filling in the boxes:



Write one or more sentences about the above drawing using the following terms:

atom molecule bond

---

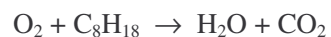


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---

29. Please write all that you can about the following:



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**THANK YOU FOR TAKING THE TIME TO COMPLETE THIS QUESTIONNAIRE.**

**At the end of the semester a list of grades against ID codes is published.**

**Can the researcher check to see what grade you received?**

The purpose of this is to see if there are any broad trends that are related to this questionnaire. The researcher will not be able to refer to your name at any stage.

- yes  
 no

**Would you be prepared to participate in a follow-up interview about this questionnaire?  
Please note that this is not compulsory.**

- yes      FIRST NAME: \_\_\_\_\_ Phone number: \_\_\_\_\_  
 no

## APPENDIX E

### INFORMED CONSENT FORM FOR INTERVIEWS WITH STUDENTS

---



Cathy Bunting  
Centre of Science and Technology Education Research  
The University of Waikato  
Private Bag 3105, Hamilton  
Phone: 838 4466 ext 8453  
Email: bunting@waikato.ac.nz

April 2003

Dear student,

As you know, I am currently investigating the teaching and learning in introductory biology courses as part of my PhD research. In particular, I am interested in student prior knowledge and how this may affect learning.

As part of this research, you have already completed a prior knowledge questionnaire. You indicated at the end of the questionnaire that you would be willing to participate in a follow-up interview, and I am keen to take you up on this offer. The purpose of the interview is to get a better understanding of why students gave particular responses.

With your permission, the interview will be tape-recorded. You will be provided with a transcript of the interview and have the opportunity to clarify anything that was said, or to request that all or part of the interview not be included in the study. Findings from the interviews will be reported in a way that prevents identification of individuals. Confidential information about participants will also not be made available to other researchers without the participant's permission. The research has been approved by the School of Science and Technology Human Research Ethics Committee at the University of Waikato.

Please contact me or my supervisor [name and contact details provided] if you have any questions about this research.

If you are happy for me to interview you about your questionnaire responses, I would appreciate it if you could please sign the form below.

Sincerely,  
Cathy Bunting

**CONSENT FORM:**

I am happy to be interviewed by Cathy.

I understand that:

- 1 I will be involved in a study on teaching and learning in first-year Biology courses
- 2 Data gathered for this project will not be made available to any third party and will be subject to the provisions of the New Zealand Privacy Act (1993)
- 3 I will not be identified in any way other than a code number or pseudonym in data records or reports of the research findings
- 4 My participation in this project will not in any way affect my academic progress
- 5 I may withdraw from parts of this study at any stage, and if I wish I may withdraw from the project completely
- 6 If I have any concerns about my participation in this research project I may approach [name and contact details of supervisor provided]

Signature: \_\_\_\_\_

Name: \_\_\_\_\_

Date: \_\_\_\_\_

**APPENDIX F**  
**MODIFIED PRIOR KNOWLEDGE QUESTIONNAIRE, MARCH 2004**

---

Student ID: \_\_\_\_\_

**THIS IS NOT A TEST.**

**What you write will not affect the way your performance in the course is assessed.**

**The reason for asking you these questions is to determine your background understanding so that we can see how we might teach difficult topics better.**

**Please answer all questions to the best of your ability.**

**A BIOLOGY BACKGROUND**

Please indicate only the *highest* level of biology that you have studied.

- |                                |                                  |   |                                |                                |                                |
|--------------------------------|----------------------------------|---|--------------------------------|--------------------------------|--------------------------------|
| <input type="checkbox"/>       | Year 11 science                  | <table border="1"><tr><td>Year 11 = 5<sup>th</sup> form</td></tr><tr><td>Year 12 = 6<sup>th</sup> form</td></tr><tr><td>Year 13 = 7<sup>th</sup> form</td></tr></table> | Year 11 = 5 <sup>th</sup> form | Year 12 = 6 <sup>th</sup> form | Year 13 = 7 <sup>th</sup> form |
| Year 11 = 5 <sup>th</sup> form |                                  |   |                                |                                |                                |
| Year 12 = 6 <sup>th</sup> form |                                  |   |                                |                                |                                |
| Year 13 = 7 <sup>th</sup> form |                                  |   |                                |                                |                                |
| <input type="checkbox"/>       | Year 11 human biology            |   |                                |                                |                                |
| <input type="checkbox"/>       | Year 12 science                  |   |                                |                                |                                |
| <input type="checkbox"/>       | Year 12 biology                  |   |                                |                                |                                |
| <input type="checkbox"/>       | Year 12 human biology            |   |                                |                                |                                |
| <input type="checkbox"/>       | Year 13 science                  |   |                                |                                |                                |
| <input type="checkbox"/>       | Year 13 biology                  |   |                                |                                |                                |
| <input type="checkbox"/>       | Year 13 human biology            |   |                                |                                |                                |
| <input type="checkbox"/>       | Bridging course: _____           |   |                                |                                |                                |
| <input type="checkbox"/>       | University biology course: _____ |   |                                |                                |                                |
| <input type="checkbox"/>       | Polytech biology course: _____   |   |                                |                                |                                |
| <input type="checkbox"/>       | Other: _____                     |   |                                |                                |                                |

**Please indicate when you completed the course selected in (A) above.**

Year: \_\_\_\_\_

**B OTHER BACKGROUND**

Please indicate only the *highest* level of the subjects listed below that you have passed.

- |                        |                          |         |                          |         |                          |         |                          |        |
|------------------------|--------------------------|---------|--------------------------|---------|--------------------------|---------|--------------------------|--------|
| <b>Any maths</b>       | <input type="checkbox"/> | Year 11 | <input type="checkbox"/> | Year 12 | <input type="checkbox"/> | Year 13 | <input type="checkbox"/> | Other: |
| <b>General Science</b> | <input type="checkbox"/> | Year 11 | <input type="checkbox"/> | Year 12 | <input type="checkbox"/> | Year 13 | <input type="checkbox"/> | Other: |
| <b>Chemistry</b>       | <input type="checkbox"/> | Year 11 | <input type="checkbox"/> | Year 12 | <input type="checkbox"/> | Year 13 | <input type="checkbox"/> | Other: |
| <b>Physics</b>         | <input type="checkbox"/> | Year 11 | <input type="checkbox"/> | Year 12 | <input type="checkbox"/> | Year 13 | <input type="checkbox"/> | Other: |
| <b>English</b>         | <input type="checkbox"/> | Year 11 | <input type="checkbox"/> | Year 12 | <input type="checkbox"/> | Year 13 | <input type="checkbox"/> | Other: |

**C LANGUAGE BACKGROUND**

What do you consider to be your first language?

\_\_\_\_\_

**1. Indicate which of the following could be called animals:**

*(You may select more than one response)*

- |                                    |                                   |   |
|------------------------------------|-----------------------------------|---|
| <input type="checkbox"/> earthworm | <input type="checkbox"/> spider   | <input type="checkbox"/> person         |
| <input type="checkbox"/> rabbit    | <input type="checkbox"/> bacteria | <input type="checkbox"/> Venus fly trap |
| <input type="checkbox"/> starfish  | <input type="checkbox"/> octopus  | <input type="checkbox"/> butterfly      |

**2. Why do animals need energy?**

*(You may select more than one response)*

- to reproduce
- to grow
- to control internal functions
- to move
- to respond to the environment, eg.: \_\_\_\_\_
- to repair the body
- don't know / not sure
- other (*please specify*) : \_\_\_\_\_

**3. Why do plants need energy?**

*(You may select more than one response)*

- to reproduce
- to grow
- to control internal functions
- to respond to the environment, eg: \_\_\_\_\_
- to repair themselves
- don't know / not sure
- other (*please specify*) : \_\_\_\_\_

**4. Do bacteria need energy?**

*(Select one)*

- yes
- no
- don't know / not sure

**5. Animals eat food. Some of the food is broken down to provide energy. What else is the food used for?**

*Please be specific.*

---

---

**6. Which of the following parts of a person's body are made up of cells?**

*(You may select more than one response)*

- |                                |  |
|--------------------------------|--|
| <input type="checkbox"/> skin  | <input type="checkbox"/> muscles               |
| <input type="checkbox"/> heart | <input type="checkbox"/> stomach               |
| <input type="checkbox"/> lungs | <input type="checkbox"/> brain                 |
| <input type="checkbox"/> eyes  | <input type="checkbox"/> don't know / not sure |



7. **Which of the following parts of a person's body need energy?**  
(You may select more than one response)

- |                                |  |
|--------------------------------|--|
| <input type="checkbox"/> skin  | <input type="checkbox"/> muscles               |
| <input type="checkbox"/> heart | <input type="checkbox"/> stomach               |
| <input type="checkbox"/> lungs | <input type="checkbox"/> brain                 |
| <input type="checkbox"/> eyes  | <input type="checkbox"/> don't know / not sure |

8. **Which of the following parts of a person's body need oxygen?**  
(You may select more than one response)

- |                                |  |
|--------------------------------|--|
| <input type="checkbox"/> skin  | <input type="checkbox"/> muscles               |
| <input type="checkbox"/> heart | <input type="checkbox"/> stomach               |
| <input type="checkbox"/> lungs | <input type="checkbox"/> brain                 |
| <input type="checkbox"/> eyes  | <input type="checkbox"/> don't know / not sure |

9. **Why do you think oxygen is needed by the body part (or parts) you chose in question 7 above?**

*Please be specific.*

---

---

10. **Plants carry out photosynthesis. What is needed in order for plants to carry out this process?**  
*Please list as many requirements for photosynthesis as you can.*

---

---

11. **During photosynthesis, plants produce sugars. What you think these sugars are used for?**  
*Please be specific.*

---

---

12. **Plants need to transport some substances, like water and sugars. What do they use to do this?**

*Please be specific.*

---

---

13. **Where do plants get the materials that they need as building blocks to make new cells?**  
(Select one)

- From the soil
- From the substances they make in photosynthesis
- Mainly from the soil but they can use substances they make in photosynthesis
- Mainly from the substances they make in photosynthesis but low concentrations of minerals are needed from the soil
- Other: \_\_\_\_\_
- Don't know / not sure

**14. Do plants need oxygen?**

*(Select one)*

- no
- yes, but only during the night time
- yes, during the day and at night
- don't know / not sure

**15. The following list represents the categories that can be used to classify animals. The categories are given in alphabetical order.**

- a) class
- b) family
- c) genus
- d) order
- e) phylum
- f) species

**List these categories in order from most specific to most general. Only use the terms that you are familiar with.**

---

**Which category do you think contains the greatest number of different types of organisms?**

---

**16. The following terms are given in alphabetical order. List them below in order of physical size, from largest to smallest. Only use the terms that you are familiar with.**

- a) cell
  - b) chromosome
  - c) gene
  - d) organ
  - e) organism
  - f) tissue
- 

**17. The following terms are given in alphabetical order. List them below in order of physical size, from largest to smallest. Only use the terms that you are familiar with.**

- a) atom
  - b) cell
  - c) ion
  - d) molecule
- 

**18. Please indicate your response to each of the biological terms that are given.**

**DNA:**

- I have never heard of DNA
- I have heard of DNA, but don't really know what it is
- I have heard of DNA, and think that I could say something about it

*If you have heard of DNA, please try to answer the following:*

**Where is DNA found in your body?**

- In all cells involved in reproduction but no other cells
- In the sex cells (eggs and sperm) only
- In all cells, including cells involved in reproduction
- In cells involved in reproduction and in a few other cells
- Other: \_\_\_\_\_
- Don't know / not sure

**CHROMOSOMES:**

- I have never heard of chromosomes
- I have heard of chromosomes, but don't really know what they are
- I have heard of chromosomes, and think that I could say something about them

*If you have heard of chromosomes, please try to answer the following:*

**Where are chromosomes found in your body?**

- In all cells involved in reproduction but no other cells
- In the sex cells (eggs and sperm) only
- In all cells, including cells involved in reproduction
- In cells involved in reproduction and in a few other cells
- Other: \_\_\_\_\_
- Don't know / not sure

**What is the relationship (if any) between DNA and chromosomes?**

*Please be specific.*

---

---

**GENES:**

- I have never heard of genes
- I have heard of genes, but don't really know what they are
- I have heard of genes, and think that I could say something about them

*If you have heard of genes, please try to answer the following:*

**Where are genes found in your body?**

- In all cells involved in reproduction but no other cells
- In the sex cells (eggs and sperm) only
- In all cells, including cells involved in reproduction
- In cells involved in reproduction and in a few other cells
- Don't know / not sure
- Other: \_\_\_\_\_

**What are genes used for in your body?**

*Please be specific.*

---

---

**What is the relationship (if any) between chromosomes and genes?**

*Please be specific.*

---

---

**ENZYMES:**

- I have never heard of enzymes
- I have heard of enzymes, but don't really know what they are
- I have heard of enzymes, and think that I could say something about them

*If you have heard of enzymes, please try to answer the following:*

**What is the function of enzymes?**

*Please be specific.*

---

---

**What are enzymes made of?**

*Please be specific.*

---

---

**Where are enzymes found in your body?**

*(You may select more than one answer)*

- Digestive system
  - Blood
  - Certain cells only, eg: \_\_\_\_\_
  - All cells
  - Other: \_\_\_\_\_
  - Don't know / not sure
- 

**19. Do you think that the following organisms contain DNA?**

- |                               |                              |                             |  |
|-------------------------------|------------------------------|-----------------------------|--|
| algae                         | <input type="checkbox"/> yes | <input type="checkbox"/> no | <input type="checkbox"/> don't know / not sure |
| mammals                       | <input type="checkbox"/> yes | <input type="checkbox"/> no | <input type="checkbox"/> don't know / not sure |
| ferns                         | <input type="checkbox"/> yes | <input type="checkbox"/> no | <input type="checkbox"/> don't know / not sure |
| fungi                         | <input type="checkbox"/> yes | <input type="checkbox"/> no | <input type="checkbox"/> don't know / not sure |
| bacteria                      | <input type="checkbox"/> yes | <input type="checkbox"/> no | <input type="checkbox"/> don't know / not sure |
| insects                       | <input type="checkbox"/> yes | <input type="checkbox"/> no | <input type="checkbox"/> don't know / not sure |
| tomatoes                      | <input type="checkbox"/> yes | <input type="checkbox"/> no | <input type="checkbox"/> don't know / not sure |
| genetically modified tomatoes | <input type="checkbox"/> yes | <input type="checkbox"/> no | <input type="checkbox"/> don't know / not sure |

20. Below is a problem that relates to the inheritance of particular characteristics. This type of problem may not be familiar to you, in which case you should tick the first box.

In horses, black coat colour (B) is dominant to chestnut (b). Suppose that a black stallion is mated with a chestnut mare and two black foals are born. Then suppose that these two black foals are mated.

What is the chance that the foal produced by this mating will be black?

- I have never seen this kind of problem before
- I have seen this kind of problem before but don't know how to answer it
- I have seen this kind of problem before and think I can answer it

If you think you can answer this problem, please try to do so. Show all your working.

21. A daughter can be said to look like her mother in some ways and like her father in other ways. For example, people might say a girl has her mother's eyes and her father's nose. Why is this?

*(You may select more than one answer)*

- The daughter inherited her nose gene from her father and her eye gene from her father
- The daughter inherited genes for eye colour from both her mother and her father, but the one from her mother was dominant
- It is just lucky that it worked out this way
- Other: \_\_\_\_\_
- Don't know / not sure

23. Suppose you could examine the DNA from a muscle cell and a cheek cell from the same person. Will the DNA be:

- Completely the same
- Mostly the same except for mutations
- Not the same because the two cells have different functions
- Other: \_\_\_\_\_
- Don't know / not sure

24. Suppose you could examine the DNA from a muscle cell from a father and a muscle cell from his daughter. Will the DNA be:

- Completely the same
- Mostly the same except for mutations
- Not the same because the two cells have different functions
- Other: \_\_\_\_\_
- Don't know / not sure

25. Below is a list of cell sizes in metres. Tick the one that you think is the BIGGEST.

- $5 \times 10^{-5}$  m
- $5 \times 10^{-7}$  m
- $3 \times 10^{-5}$  m
- $8 \times 10^{-6}$  m
- Don't know / not sure

26. Below is a list of cell sizes in millimetres. Tick the one that you think is the SMALLEST.

- 0.0507 mm
- 0.12 mm
- 0.012 mm
- 0.2 mm
- don't know / not sure

27. Convert the following measurements as indicated:

- a)  $150 \mu\text{m} =$  \_\_\_\_\_ mm
- b)  $0.10 \mu\text{m} =$  \_\_\_\_\_ mm
- c)  $1000 \text{ cm} =$  \_\_\_\_\_ mm
- d)  $1000 \text{ cm}^2 =$  \_\_\_\_\_  $\text{mm}^2$

28. Chemicals can be represented by chemical formulae. Please complete as much of the following table as you can. The first one has been done for you.

Symbol	Chemical
H <sub>2</sub> O	water
H	
O	
CO <sub>2</sub>	
C	
Cl <sup>-</sup>	
Na <sup>+</sup>	
K <sup>+</sup>	

29. Suppose you have two containers with equal amounts of clear water in each. Container A is at 25°C and Container B is at 40°C. Now suppose that a drop of blue dye is added to each container and that all the water in each container eventually turns light blue even though there is no stirring.

*Which container will this happen in first?*

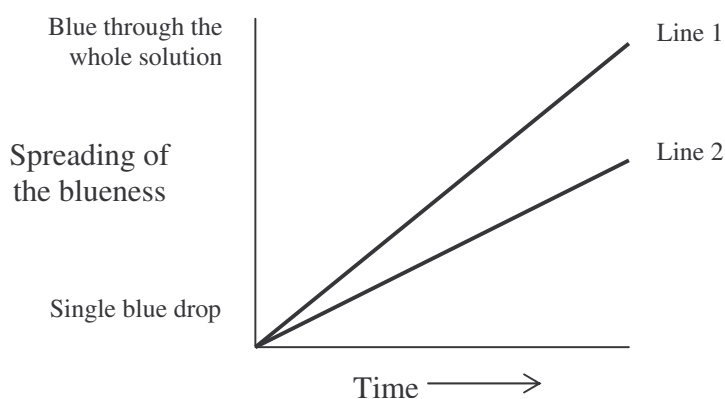
- container A (25°C)
- container B (40°C)
- don't know / not sure

Please tick the best explanation for your answer above:

- the lower temperature breaks down the dye
- the dye particles move faster at higher temperatures
- cold temperatures make the dye particles move faster
- the temperature helps the dye particles to expand
- other (*please be specific*): \_\_\_\_\_
- don't know / not sure

30. The graph below represents the results from the experiment.  
Does line 1 represent:

- container A (25°C)
- container B (40°C)
- don't know / not sure



Please give a reason for your answer:

---

---

31. The following is part of a redox reaction:  
 $\text{NAD} \rightleftharpoons \text{NADH}$

Which is the reduced form of the molecule?

- NAD
- NADH
- neither NAD nor NADH
- don't know / not sure

Which is the oxidised form of the molecule?

- NAD
- NADH
- neither NAD nor NADH
- don't know / not sure

What do you think it means if something is oxidised?

---

---

**THANK YOU SO MUCH FOR TAKING THE TIME TO COMPLETE THIS QUESTIONNAIRE.**

**Would you be prepared to participate in a follow-up interview about this questionnaire?  
Please note that this is not compulsory.**

- yes      FIRST NAME: \_\_\_\_\_ Phone number: \_\_\_\_\_  
 no





**APPENDIX H**  
**TUTORIAL EXPERIENCE QUESTIONNAIRE (COURSE 2)<sup>43</sup>**

---

1. Do you normally attend this tutorial session? (i.e., if you are going to attend a tutorial, will it normally be the one at this time slot?)
  - yes
  - no
  
2. If you answered YES to the above question, WHY do you normally attend this tutorial session?
  - It is most convenient according to my timetable.
  - It suits my timetable AND I specifically like the way that the tutorial is run.
  - I have attended other sessions but I specifically come to this one because I like the way that the tutorial is run.
  - Other: \_\_\_\_\_
  
3. The tutor has used a lot of concept maps in the tutorials. She has drawn them up on the board, using your input. She has also given you time to make up your own concept maps.  
 Please indicate how strongly you agree with each of the following statements about the tutorials:

	Strongly agree	Agree	Disagree	Strongly disagree
a Concept mapping seems to be a good way to study biology	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b Concept mapping helped me to understand the material	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c Concept mapping helped me to see links between concepts	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d It is easy to learn how to do concept mapping	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
e I found it useful to be able to work on making a concept map with other students	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
f I felt that there was enough time for me to ask questions during the tutorials	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
g I found that I had to think during the tutorials	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
h I felt relaxed in the classroom environment	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
i I would have preferred it if [the tutor] had answered questions <i>without</i> using concept mapping	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
j Concept mapping is helpful because it shows me what I know and what I need to learn more about	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

---

<sup>43</sup> Administered in June 2005 to students attending concept mapping tutorials (see Sections 3.4.3 and 6.4).

- k I have sometimes used concept mapping for studying biology outside of the tutorials
- l I have sometimes used concept mapping for studying in my other courses
- 

4. Do you have any other comments about concept mapping, or about the tutorial in general?
5. If you also attend other tutorials, which 'style' do you prefer?

---

Are you willing to participate in a short follow-up interview about this questionnaire?  
Please note that this is not compulsory.

Yes      First name: \_\_\_\_\_

Contact details: \_\_\_\_\_

No

This part of the questionnaire will be separated from the rest of the questionnaire to protect your anonymity.

**APPENDIX I**  
**MODIFIED TUTORIAL EXPERIENCE QUESTIONNAIRE (COURSE 2)<sup>44</sup>**

---

1. Do you normally attend this tutorial session? (i.e., if you are going to attend a tutorial, will it normally be the one at this time slot?)
- yes  
 no

2. WHY do you normally attend this tutorial session?
- It is the only tutorial that suits my timetable.  
 I could attend other tutorial sessions, but this one is most convenient.  
 I have attended other sessions but I specifically come to this one because I like the way that the tutorial is run.  
 Other: \_\_\_\_\_

3. Please indicate how strongly you agree with each of the following statements about the tutorials:

	Strongly agree	Agree	Disagree	Strongly disagree
a The tutorials helped me to understand the material	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b The tutorials helped me to see links between concepts	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c I felt that there was enough time for me to ask questions during the tutorials	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d I found that I had to think during the tutorials	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
e I felt relaxed in the classroom environment	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
f The tutorials are helpful because they show me what I know and what I need to learn more about	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

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4. What did you specifically like about the tutorials?
5. What would you change about the tutorials?
6. If you also attend other tutorials, which 'style' do you prefer?

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<sup>44</sup> Administered in June 2005 to students attending conventional tutorials (see Sections 3.4.3 and 6.4).