Chapter 1

Introduction

1.1 The agricultural, medical and industrial impact of biotechnology

In his report on biotechnology in U.S. schools, Zeller (1994) used the phrase "The future is here" (p. 460). This phrase sums up the present position of biotechnology in the world. Techniques like the cloning of animals and the designing of new species, which were previously popular only in science fiction, have become possible. New products have been developed that are already altering medicine, agriculture and industry.

In the period to 1996, the USA had allowed nearly five hundred clinical trials in which a gene was inserted into an adult cell, mostly as a therapy for cancer (Ross, Erikson, Knorr, Motulsky, Parkman, Samulski, Strauss & Smith, 1996). While the procedures used are still experimental, these trials indicate that the use of gene therapy in human subjects is feasible. The possible uses for gene therapy are only just being explored (Friedmann, 1997). This is a rapidly expanding area of medicine.

In the field of agriculture, Persley and Peacock (1995) reported that 20 crops were already being improved by genetic engineering and listed many other limitations to crop yields that could be solved by genetic techniques. One example is the release of cotton that is engineered to be resistant to the boll weevil, thereby significantly reducing the amount of insecticide that needs to be sprayed onto the land (Morris, 1995).

Industry related to biotechnology raised $2.2 billion dollars on the US stockmarket in 1995 and pharmaceutical companies invested a further $3 billion (Lehrman, 1996). This represents considerable employment for scientists. The Canadian Biotechnology industry is reported to consist of 300 companies, employing 8000 people and generating revenue of at least $1.3 billion (Canadian Biotechnology Industry Human Resources Study, 1998). Biotechnology is no longer only on the researcher's drawing board, it is a significant economic force.

1.2 Ethical and social issues

Along with the exciting benefits of this new type of technology come a range of problems. Ethical and social issues arise. For instance, the process of inserting a gene into an adult cell is no different from inserting a gene into an embryonic cell, which means that if gene therapy is being done then genetic manipulation of an embryo is also
practical (Boyce, 1997). Altering embryonic cells would allow scientists to permanently alter the genetic make-up of a human, and the succeeding generations. As McInerny (1990 p.3) notes "our ability to tinker with life has already generated considerable debate about the degree to which humans should intervene in the evolution of other organisms". In what circumstances, if ever, should scientists be allowed to change the human gene pool? On the one hand, diseases like cystic fibrosis might be eradicated. On the other hand, genes which have only a cosmetic effect could be altered so that humans approach some ideal of beauty. The long term consequences of such changes are impossible to predict.

Products such as crops which reduce the use of insecticide may provide substantial benefits to the human race but all products of biotechnology may not be so valuable. Each new product developed has to be evaluated. The multinational company Monsanto has gone to field trials with a cotton crop that is resistant the weedkiller glyphosate (Kleiner, 1997). By planting this cotton the farmer can spray more glyphosate on the ground without harming the crops (Schmidt, 1995). This is useful to Monsanto because they sell the herbicide. Is this a legitimate use of biotechnology to improve economic output or is this a misuse of the technology? Whose role is it to make decisions on such questions?

At present, all gene altering experiments in the USA have to be evaluated by the National Institute of Health Recombinant DNA Advisory Committee (RAC) and so far no experiments in germ cell alteration have been allowed (Ross, 1996). In 1997 President Clinton also put a five year ban on human cloning experiments in the USA. In Australia, the decision about whether to do such experiments is still made by individual hospital ethics committees (Chalmers & Nicol, 1997). Should these committees allow gene therapy on embryos if it will eradicate a genetic disease? How do these committees draw the line on what disease can be treated this way? There are many questions that can and should be raised, before setting the guidelines that will control and monitor the behaviour of institutions in possession of the technology.

So far we have not taken any irreversible steps towards changing the genetic constitution of human beings. The time for making choices about how much the human genetic state can be altered is going to be in the very near future. People may need to make decisions as individuals, about what their children will look like, behave like, think like. They will also need to make decisions as members of the democratic community, about how far agriculture and industry should be allowed to go in the use of genetic engineering. Will we as a community choose to limit ourselves to natural selection, will we allow
limited genetic tinkering to eradicate genetic disease or will we allow the creation of taller, smarter and more beautiful people?

1.3 Biotechnology education
There is a central role for the education system in dealing with all the questions arising from the emergence of biotechnology. As Peacock (1991) has emphasised to the Australian Science Teachers Association, it is the present generation of students that will have to make the critical decisions on when and how to apply the biotechnologies that can so dramatically alter human life. White (1991, p.16) points out that this means that "demystification of these technologies is thus of paramount importance for Australian science education." The future is here and the present generation of students need to know what these biotechnologies mean in order to make informed decisions on when and how to use them.

As well as explaining how biotechnology works, science education needs to "provide future citizens with the knowledge necessary for them to arrive at rational judgements about the many controversial issues that face humankind" (Cross & Price, 1994, p.29). Others have also urged reform of science education so that the future citizen is better equipped to make informed decisions about the application of science (see for example, McInerny, 1996; Kyle 1991b). This argument is often expressed as a demand for increased "scientific literacy", where "the goal of scientific literacy dictates that students who have completed their general education requirements in science be able to think about, talk about and write about scientific ideas" (Micikas, 1996, p.433). Some of the most important issues that students must be able to think and talk about arise from the development of biotechnology. It follows that education in biotechnology is essential if scientific literacy is to be achieved.

The figures presented in section 1.1 show that biotechnology is also going to provide increasingly important career opportunities for today's students. One function of science education is to help educate students to become the scientists of the future (see section 2.2). The techniques of genetic manipulation are being incorporated into so many areas of economic importance that it is no longer possible to ignore biotechnology, when one aim of science education is to provide a base that will enable students to participate effectively in the future economy.

1.4 Summary
Biotechnology has the potential to alter the quality of life by its impact on health, agriculture and industry. The outcomes of the genetic technologies may lead to greater economic output and improved treatment for diseases but they bring with them a range
of ethical and social issues. It is important that people understand both the advantages and disadvantages of biotechnology and how it can affect their lives. Therefore biotechnology has an important place in the education of today’s students.

1.5 Overview of this research

Having argued the importance of biotechnology in education, it is now necessary to consider the teaching of biotechnology. As a first step, this research will explore the teaching of biotechnology in New South Wales as a sample of biotechnology education. An examination of the science syllabus in NSW shows that there are few places where biotechnology is included, and these only as an option. The data on the options attempted by candidates in the Higher School Certificate exam show that few students are studying biotechnology. Why is this the case when biotechnology is revolutionising so much of modern biology? Research is needed that will examine the state of biotechnology education in NSW and identify problems that might be encountered by teachers when they undertake to teach students biotechnology. That problems exist is well documented (see McInerney, 1990 and Zeller, 1994), and it is necessary to know the extent to which these problems exist in NSW. Only then can solutions be found and proposals be made so that students in NSW are provided with the best chance for education in this important subject. To find ways of improving education in biotechnology in NSW is the ultimate aim of the present research.

The research reported here, investigating the teaching of biotechnology, proceeds through three stages. These are:

- an examination of the literature on the teaching of biotechnology in other countries;
- an investigation of the teaching of biotechnology in NSW, using a survey, interviews and case studies;
- the development of proposals for changes to the teaching of biotechnology in NSW

Each stage is presented sequentially in this report.

Research findings on the teaching of biotechnology in other countries are presented in chapter 2. These research findings are used as the basis for designing a study that asks teachers about the particular difficulties encountered in teaching biotechnology in NSW. The design of this study is described in chapter 3. Chapter 4 describes in detail the design, conduct and results of a survey that investigates the teaching of biotechnology in NSW. In chapter 5, the reasons why many teachers in NSW have chosen not to teach biotechnology are reported and analysed. Three cases of the teaching of a unit of biotechnology are described and interpreted in chapter 6. Chapter 7 outlines the implications of the findings of this study.
Chapter 2

The place of biotechnology in the curriculum

In chapter 1, it was argued that biotechnology now has a vital role in health, agriculture, and industry, and potentially holds a critical role in human evolution. Therefore, education in biotechnology was said to be important. In this chapter, the case for the inclusion of biotechnology in the school curriculum is argued in more detail (section 2.2). The current position of biotechnology in the secondary school curriculum in the USA, the UK and Australia is described in section 2.3. Its inclusion in the curriculum has, according to researchers (eg McInerney, 1990; Zeller, 1994), proved difficult. Some obstacles to the teaching of biotechnology that have been identified are explored in section 2.4.

2.1 What is "biotechnology"

The term biotechnology has already been used many times in this report. At this point it is necessary to define the term "biotechnology" as it will be used in this study. There are many definitions of this term, a number of them generated by the need for international legislation on new technologies. The International Union of Applied Chemistry (IUPAC) definition is; "the application of biochemistry, biology, microbiology, and chemical engineering to industrial processes and products and on the environment" (reported in McInerny, 1989, p.9). The European Federation of Biotechnology defines it as; "the integrated use of biochemistry, microbiology and engineering sciences in order to achieve technological application of the capabilities of micro-organisms, cultured tissues, cells and parts thereof" (reported in McInerny, 1989, p.10). Most of the current definitions emphasise that biotechnology is a multidisciplinary field of endeavour and imply a commercial outcome of the technology (Henderson, 1990).

These broad definitions say very little about what biotechnology actually entails and are of little use in explaining to teachers exactly what should be incorporated in a unit on biotechnology. An approach that eliminates confusion about which technologies are covered by the term biotechnology, is that of Jones (1995) who defines biotechnology as a gradient of technologies, from biological nitrogen fixation to genetic engineering. Those at the higher end of the gradient are the more scientifically complex. While the idea of listing technologies is a useful one, placing them on a gradient is controversial and unnecessary. For the purposes of this study biotechnology has been defined as a
set of technologies, similar to that proposed by Jones (1995). However, the range of new technologies listed by Jones was considered to be too narrow to include all of the emerging technologies about which students might learn. The specific technologies incorporated in the definition used in this study were taken from a review of new developments in biotechnology by Morris (1995). Specific technologies included in the definition are; monoclonal antibodies, in vitro fertilisation, DNA fingerprinting, genetic engineering, new biological technologies in food production and new biological technologies in waste management. Animal cloning might have been included, except that this procedure had not been reported when this study began. This illustrates how fast the field is changing and that there is a need to constantly revise even the definition of biotechnology.

The terms genetic manipulation and genetic technologies are also used in the following discussion about biotechnology. These terms relate to those areas of biotechnology where the fundamental technique used is the movement of genes from one organism to another, and hence are synonymous with genetic engineering. Genetic manipulation is a part of the many new biological technologies that have been introduced in food production, waste management and human health.

2.2 Why is it important to include biotechnology in the curriculum?

The aim of this research is to identify the problems that teachers face in educating students about biotechnology and to use this information to find ways in which education in biotechnology can be improved. Such a study is worthwhile only if biotechnology is an important element of science education. The reasons for biotechnology being a part of school education will be outlined in this section. As biotechnology is a part of science, the justification of biotechnology education is considered here in terms of the reasons that have been given for science education. Several arguments have been proposed to justify the teaching of science and therefore the inclusion of particular subject matter in the science curriculum. These will be discussed here and the relative merits of the justifications for science education, that have been identified from the literature, will be considered.

It is contended here that each of these arguments supports the view that biotechnology has a place in the science curriculum.

2.2.1 Reasons given as to why science education is important

Three competing views about the purpose of school science have been identified by Matthews (1994). He quotes writers from three different schools of thought, all of which were proposing different philosophies for science education in the US in the
1960's. One school stressed the importance of training enough competent scientists, the second emphasised the relation of science with human history and the problems of human society, and the third concentrated on the basic intellectual function of science knowledge. These three competing emphases of science education were summarised by Matthews (1994, p.15) as:

- a practical, technical, applied emphasis;
- a liberal, generalist, humanistic emphasis;
- a specialist, theoretical, disciplinary emphasis.

A similar division of the major themes of science education was given by Goodson (1987, p.25). He called his categories the academic tradition, the utilitarian tradition and the pedagogical tradition. The academic tradition corresponds with "a specialist, theoretical, disciplinary emphasis and the pedagogical with the generalist humanist emphasis. The utilitarian tradition corresponds to a practical, technical, applied emphasis. Current debate may use different terminology but similar themes remain. The 'science, technology and society' movement would correspond to the 'pedagogical tradition' and arguments for the economic importance of science education are consistent with a utilitarian tradition.

Roberts (1988) agrees that the traditions Goodson identifies are important themes in science education but he has proposed others. From an examination of curriculum materials in use in science classrooms, he has identified seven "curriculum emphases" that could be used to answer the student question "Why are we learning this stuff?" (p. 33). These emphases were described as follows:

- Every-day Coping, for example teaching to explain how household appliances work.
- Structure of Science, for example the value of atomic theory as a scientific tool.
- Science, Technology and Decisions, described as "an emphasis which brings out the interrelatedness of scientific explanation, technological planning and problem solving, and decision making about practical matters of importance to society." (p.35).
- Scientific Skill Development, that is, students should learn skills associated with scientific thinking eg. observation, deduction.
- Correct Explanations, where students are expected to "learn it because it’s correct".
- Self as Explainer, where the students learn about the how scientists developed new understandings of the world.
- Solid Foundation, an emphasis that the present course is preparation for a future course.

Roberts regards his seven curriculum emphases as subdivisions of the traditions identified by Goodson (1987) and puts Scientific Skill Development, Correct Explanations, Solid Foundations and Structure of Science into the academic tradition, Everyday Coping into the utilitarian tradition and Science Technology Decisions into the pedagogic tradition. Using a similar approach (that of examining existing course materials) Fensham (1995) confirmed the value of Roberts curriculum emphases but he added three others, science in applications, science for nurturing, science in making.

Another set of reasons for teaching science has been generated by Claxton (1991). The reasons he identified included "to transmit knowledge; to improve young people's personal theories about the world; to make young people better learners; to train routine scientists; to be frontier scientists; to think straight; to give students an understanding of the world of science proper; and to establish scientific literacy". These divisions do not correspond exactly to those of Roberts (1998) but they can be classified into the same groups of emphases described above as academic (includes 'to transmit knowledge'; 'to improve young people's theories'; 'to give students an understanding of science proper'), utilitarian (to train routine or frontier scientists) and pedagogic ('to establish scientific literacy'; 'to think straight').

The existence of so many slightly different explanations of why we teach science has generated a complex terminology which is potentially confusing. In order to avoid confusion among these terms for the purposes of science education, in the following discussion of reasons for the teaching of biotechnology, the terminology of Roberts' 'curriculum emphases' will be used. These curriculum emphases will be regarded as subsets of Goodson's academic, pedagogic and utilitarian traditions in science education.

2.2.2 Competition between the reasons given as to why science education is important

The curriculum emphases above have informed recent debate on the need for reform in science education as curriculum designers ask "which of these emphases are most important?". Some analysts (Cross, 1995; Jenkins, 1990 and Matthews, 1994) see the quest for an answer to this question as a struggle between the utilitarian argument and the pedagogical argument. The notion of 'scientific literacy' is at the centre of this debate. Yet, "different interpretations of scientific literacy reflect different value
positions" (Jenkins, 1990 p.256). Those who argue that a utilitarian emphasis should determine the curriculum for science education see greater scientific literacy as a way of developing a pool of skilled labour to boost national economies. This interpretation of scientific literacy was instrumental in the formation of the British National Curriculum (Fensham, 1995) and can be seen in a document to the Australian Minister for Science (National Board of Employment, Education and Training, 1994). However, the term 'scientific literacy' is also used by those who believe that science education should be justified by a pedagogical argument. When defined from this value position, scientific literacy is a complex entity that emphasises the interrelationship between science and society. An example is the definition of a scientifically literate individual, found in The National Standards for Science in the USA and paraphrased by Micikas (1996, p.432), as one who can

...ask, find or determine answers derived from curiosity about everyday experiences... describe, explain and predict natural phenomena... read with understanding articles about science in the popular press... engage in social conversations about the validity of the conclusions... identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed... evaluate the quality of the scientific information on the basis of its source and the methods used to generate it... pose and evaluate arguments based on evidence... and apply conclusions from such arguments.

As Kyle (1991a) has said, there is general agreement that science education needs to promote scientific literacy but little agreement on what this term really means.

Which concept of scientific literacy should be emphasised in a science curriculum? Debate over the answer to this question has been going on throughout the history of science education and different traditions have been strongest at different times. Roberts (1982) offers a plausible explanation for this. He argues that the debate about alternatives is too theoretical. In practice, the reason why science is taught to one group of students in any place and time is dependent on the needs and conditions pertaining to those students and those circumstances. It is not possible to define one overriding reason why we should teach science on the basis of a piece of research. He proposes that the question should always be, "What aspect of science (curriculum emphases) shall we stress, for these students now?" (p.235). Roberts also argues that a defensible teaching program is one that covers the greatest range of curriculum emphases. Fensham (1995, p.27) comments, "The fact that science in school might have different purposes, and hence different types of content, was beginning to be recognised by the late 1980's". An example of such a compromise can be seen in the US National Science
Education Standards (National Research Council, 1995, p.9) which lists the goals of school science as:

- experience the richness and excitement of knowing about and understanding the natural world;
- use scientific processes and principles in making personal decisions;
- engage intelligently in public discourse and debate about matters of scientific and technological concern;
- increase their economic productivity through the use of the knowledge, understanding and skills of the scientifically literate person in their careers.

Evidence of all three traditions in science education is discernible in this statement.

The quote from Fensham (1995), as cited above, reiterates that the purposes of school science are linked to the content of school science. If, as Roberts (1982) has argued, the aim of a course is to cover as many curriculum emphases as possible then the content should be chosen so that it can satisfy an academic, utilitarian and pedagogic rationale. Therefore, a defence of a biotechnology program should be argued in terms of the range and depth of curriculum emphases that can be incorporated.

The importance of biotechnology to each of the traditions of science education will be considered in the following sections, 2.2.3-2.2.5. It is then argued, that as biotechnology is important to each of these traditions, the inclusion of biotechnology in the curriculum is appropriate.

### 2.2.3 The pedagogic tradition and biotechnology

Two different emphases have been placed on the contribution of biotechnology to scientific literacy by proponents of the pedagogic goals of science education. That is:

1. Biotechnology will affect our lives. Knowing about science which affects our lives is an essential feature of scientific literacy (Peacock, 1991; White, 1991; McInerny, 1990).
2. Various topics within biotechnology (eg biological diversity, the human genome project) are exciting ways to teach science so that it can better address science subject matter, and thereby promote scientific literacy (Cross & Price, 1994; McInerny, 1996).

By including biotechnology in the curriculum proponents of both arguments can be satisfied. Not only does biotechnology provide a vehicle for creating innovative programs that teach students about issues and equip them for a decision making role in the community, it teaches them about the most vital issues that are going to confront them in the near future, those associated with alteration of the human genetic material.
In a report on biotechnology teaching for the OECD, McInerny (1990, p.4) summarised this view by stating:

The implications for sound education, therefore, are clear: each country must provide its students and teachers with sound content about the science of biotechnology and with the skills and information to analyse rationally the personal and social implications of biotechnology within the ethical, cultural and legal traditions of that country. A well educated citizenry in each of the world’s countries can help the dreams of biotechnology become reality in the improvement of the quality of life on Earth.

Thus, the teaching of biotechnology is justified for its contribution to scientific literacy.

2.2.4 The utilitarian tradition and biotechnology

The economic impact of biotechnology is yet to be determined, but it is reasonable to assume that it is going to be great. In 1995 the stockmarket investment in biotechnology industry was $2.2 billion and $3 billion were invested by large companies to develop biotechnology products (Lehrmann, 1996). Similar data for product sales is yet to be reported, because nearly all of the products are still at the experimental stage. However this level of investment already ensures considerable employment for skilled scientists and technicians. A search of recent articles in the journals *Nature* and *New Scientist* shows that new ideas for biotechnology products are being proposed regularly. As these products are developed, industries and research institutions associated with agriculture, health and environmental management will be requiring expertise in biotechnology. Therefore, if productivity is to be increased through creating scientific literacy, as supporters of a utilitarian interpretation of scientific literacy propose, it follows that students require skills and knowledge in biotechnology.

Thus the teaching of biotechnology can be justified in terms of its potential contribution to technology, and the resulting economic benefits.

2.2.5 The academic tradition and biotechnology

Goodson (1994) gives an account of the historical process by which biology was finally given status as a "hard core" academic subject in the British curriculum. In order to become an accepted subject, biology first had to be regarded by the major universities as a serious discipline. Using this criterion (of acceptance as an important theoretical discipline), biotechnology can be shown to have gained acceptance as an academic subject. Adamson (1996) reports that the key influences on university science curricula in the 1980's were molecular biology (courses that deal with the biochemistry of genetic
material and the techniques of genetic engineering) and the environment. Most Australian universities have devised courses in biotechnology related subjects over the past ten years. Therefore, biotechnology has been accepted as important component of biological knowledge and if secondary school biology is to have an academic curriculum emphasis then biotechnology has a place. In terms of Roberts (1988) curriculum emphases, biotechnology is important as a 'solid foundation' for university studies in biological sciences.

Roberts also listed "scientific skill development" as a curriculum emphasis in the academic tradition. Biotechnology incorporates an important set of skills that cross the boundaries between traditional areas of biology. Although each product of biotechnology is unique, and different ethical issues may arise in each case, there is a fundamental technique of genetic manipulation whether it is being used to examine evolution, produce insulin with bacteria or grow blue roses. Students need to be given an understanding of the method by which DNA can be sequenced and then manipulated, so that they can apply this understanding when making decisions on specific ethical issues.

Thus the study of biotechnology in the school forum is part of the academic foundation for future studies in biology.

2.2.6 Justification for the inclusion of biotechnology in the curriculum
It has been argued that a defensible curriculum is one that incorporates a number of curriculum emphases (section 2.2.2). A defensible biology curriculum must include subject matter that can be justified in terms of the academic, pedagogic and utilitarian traditions of science education. The emergence of biotechnology as a university discipline, as a source of issues of social significance, and as a contribution to economic advancement justifies the inclusion of biotechnology in the school science curriculum.

2.3 Biotechnology in the curriculum
Whether the aim of science education is seen as being the transmission of a worthwhile body of knowledge, the training of career scientists or the development of scientifically literate individuals, these aims can only be met if biotechnology is part of that education. To what extent has this been recognised by the makers of biology curricula around the world? The USA and Britain have been at the forefront of biotechnology curriculum development (McInerny, 1990) and the current state of the field in these two nations will be analysed in sections 2.3.1 and 2.3.2. McInerny (1990) has reviewed the teaching of
biotechnology worldwide and he has concluded that only the USA and the UK have made significant advances in the development of curricula in this area. The position of biotechnology education in the Australian and NSW curriculum is examined in section 2.3.3. The research reported (see section 2.3.1-2.3.5) suggests that biotechnology is not being incorporated into the classroom with the same ease with which it is being included in National curricula. Some problems with the implementation of teaching units in biotechnology are identified in section 2.4. The problems that have been identified in other education systems have been used as a starting point for the present study into the teaching of biotechnology in NSW (section 2.5).

2.3.1 The USA

Having defined the National Standards for Scientific Literacy (National Science Education Standards, 1995) the USA has been the leading innovator in developing courses that incorporate those standards in biology, including the particular field of biotechnology (White, 1991). One of the principal groups involved in developing the new curricula is the Biological Sciences Curriculum Study, BSCS. There are very close links between the 'Benchmarks for Scientific literacy' and the innovative programs designed by this group (Micikas, 1996). The BSCS makes references and classroom protocols available to teachers for a number of biology topics including biotechnology. Other resources are available to teachers in the US who have an interest in including biotechnology in their teaching program. For example, a search of the internet under "biotechnology" uncovers many resources designed for use by teachers in US high schools and colleges. The journal The American Biology Teacher advertises many training courses for teachers in the US and publishes many articles explaining how to do experiments associated with DNA manipulation. Recently some teachers who have experimented with teaching a unit in biotechnology have published their lesson outlines for use by other teachers (eg Hays, 1994; Ahmed, 1996; Paolella, 1991). Each of these outlines placed emphasis on introducing some hands-on work with DNA and on examining the issues and questions of bioethics.

The evidence above indicates a move in the USA, at least at the level of curriculum design and development, toward the teaching of biotechnology in the secondary school. The extent to which these initiatives are being taken up in the classroom is still in some doubt. Zeller (1994) surveyed 170 prize winning biology teachers about the biotechnology that they taught and the instructional methods they used. Only half of the respondents taught some biotechnology content on 10 or more days and most of the content areas that were listed were part of the traditional genetics curriculum. Given that the teachers in Zeller's (1994) study were experts in their field, it can be assumed that this sample overestimates the amount of biotechnology being implemented in the
classroom. Though these teachers were winners of the "Outstanding Biology Teacher Award", they reported that they used very few practical activities in their teaching of biotechnology. The reasons that they gave for not teaching the newer topics in biotechnology were lack of money for equipment, time constraints and lack of training. Zeller (1994) also found a positive correlation between the amount of training the teacher had had and the amount of practical work they did on this topic. This finding highlights the importance of teacher training in translating the desired curriculum into classroom practice.

2.3.2 The United Kingdom

In the years between 1985 and 1992 the UK has introduced a National Curriculum for all subjects, including science. The aim of the science curriculum has been to move away from subject divisions and to introduce what is described as "broad and balanced" science (Lock & Soares, 1992). The arguments for this broad and balanced science parallel those for scientific literacy. The National Curriculum is organised into a set of Attainment Targets. Teachers must follow, and assess according to, a series of Statements of Attainment (SoA’s) (Lock & Soares, 1992). The introduction of these new guidelines has meant that teachers have had to implement many new modules that cater for the SoA’s and cross traditional boundaries between biology, chemistry and physics. Biotechnology, and in particular genetic engineering has been given a prominent position in the National Curriculum, and specific reference is made to the social issues. That is, students should "understand the basic principles of genetic engineering, selective breeding and cloning, and how these give rise to social and ethical issues." (National Curriculum, cited in Lock, Miles and Hughes, 1995, p.276). Since this curriculum applies to all students in compulsory school years, all students in the UK are now required to have some education in biotechnology.

In order to meet the requirements of the curriculum, resources were developed and made available to teachers. The National Centre for School Biotechnology was established in the UK in 1985 and this centre has developed in-service courses for teachers, contacts between teachers and researchers in the field, and practical kits for use in the classroom (White, 1991). Textbooks dealing with biotechnology became available in the late 1980's (for a list see McInerny, 1990) and teaching units are available via the internet eg the European Initiative for Biotechnology Education (1997) which is a project of Reading University in the UK. In summary, the UK is well advanced in curriculum reform in biotechnology and in the provision of resources to support its teaching. As was the case with the USA, there is little information on how far these reforms have actually penetrated the classroom.
In one study, Lock, Miles and Hughes (1995) showed what can be achieved when the SoA's relating to biotechnology are applied. Teachers were given teaching materials on issues in biotechnology and encouraged to use them in a way that suited their particular classroom environment. A survey was given to the students before and after the teaching to determine their understanding of, and their attitude to, biotechnology. The resources provided incorporated enough material for only two or three lessons, therefore relatively small gains were to be expected. The researchers found that the students became more aware of what biotechnology means and were better able to give specific examples of these technologies (eg genetically engineered food, DNA fingerprinting) as a result of the teaching. More significantly, when some of the students who had been taught were interviewed a year later they were better able than their untaught counterparts to give sound reasons for their attitudes to various biotechnology issues. This study also found that the attitude of the students was influenced by the teaching style used, in that more rational arguments were used by the students when the teacher had employed a "scientific approach" to teaching the controversial issues.

2.3.3 Australia

In 1989, a group comprising the ministers of science of the states and territories of Australia agreed on national goals for schooling. These have since been translated into a national curriculum (Australian Education Council, 1994a). The core set of six agreed national goals do not mention scientific literacy specifically and the trend has been toward an emphasis on the economic and training aims of schooling (Fensham, 1995). An emphasis on the economic value of science education has also been evident in two recommendations to the minister for science released by the National Board of Employment, Education and Training (1994 and 1996). That is to say, the Australian National curriculum profiles have been developed to serve a utilitarian curriculum emphasis. Within this framework the importance of biotechnology as subject matter has been recognised. For example, a knowledge of the techniques of DNA technology and reproductive technologies is included in the prescribed outcomes for the category "Life and Living" (Australian Education Council, 1994b).

Although scientific literacy and the need to educate a generation to cope in the modern technological world does not receive prominence in the national goals, it is not ignored. Goal one includes "to provide an excellent education ... which develops their talents and capacities to full potential, and is relevant to the social, cultural and economic needs of the nation" and part ten of goal six includes the aim to develop in students "a capacity to exercise judgement in matters of morality, ethics and social justice." (Australian Education Council, 1994a, appendix 2). An examination of the National Curriculum Profiles, and the associated outcome areas, (Australian Education Council, 1994b) that
deal with biotechnology (Life and Living), show that considerable importance is given to the issues and social consequences of the biological sciences. For example one profile suggests students "prepare a case for or against the use of a biological control of a pest or disease (p.88). Another recommends "report on ways we have used microorganisms and the likely future uses of them" (p.112). A third suggests the activity "write a report evaluating the use of growth hormones in agriculture." (p.112).

This National Curriculum promotes the teaching of biotechnology and its teaching with an emphasis on the implications for society. However, as in the other countries examined above, it is difficult to determine how much influence the national curriculum has had on classroom teaching. There has scarcely been time for the individual Australian states to rewrite their own curricula in the wake of the national profiles and therefore it is likely that the national curriculum has not yet had a great influence on school science.

2.3.4 New South Wales
Junior secondary science in NSW is covered by a general syllabus that dates from 1984 (Secondary Schools Board, 1984) and which is to be used in conjunction with a set of outcomes, written more recently and stated to be to "maintain as much congruence as possible with the nationally developed profiles" (NSW Board of Studies, 1992). This syllabus states that its basic philosophy has not changed since the 1975 syllabus and that it is "to provide experiences that will contribute to the development of children", an aim so broad as to provide very little direction. The syllabus defines a number of content areas, including reproduction and food production, which could be interpreted to include biotechnology although this topic is not explicitly mentioned. Both the syllabus, and the outcomes added later, are sufficiently broad as to allow for biotechnology to be included in the school program if the school so desired, but there is no syllabus requirement to deal with this topic.

Senior science in NSW is organised according to the subjects available for the Higher School Certificate (HSC) exam in year 12. Each subject syllabus now includes a course of work that is preliminary to the work that will be examined, and a course of work to which the HSC exam questions are pertinent. The preliminary course is studied in the first three terms of year 11 and the examinable course is studied for the last term of year 11 and all of year 12. Two of the HSC subjects contain a significant section of work that would be classified as biotechnology as defined in section 2.1. These are: "Science for Life", in a module called Biotechnology, and "2 Unit Biology", in an elective called "Genes in Action". The content of these topics is described in detail in section 6.2.1. Both of these topics are optional components of the respective HSC subject. The
Science for Life module on biotechnology (NSW Board of Studies, 1989, p.34) deals with socially relevant aspects of biotechnology in some detail. This module places an emphasis on relating the theory to the everyday life of the students. The 3/4 Unit Science course also contains a small amount of biotechnology (genetic engineering) as part of an elective on Reproduction and Genetics (NSW Board of Studies, 1994a).

As was the case in other countries, the National and NSW curriculum allows for the teaching of biotechnology but the evidence is that these options are not being taken up in the classroom. In 1995, 4474 students completed the HSC exam in Science for Life and of these 108 answered the questions on the biotechnology module (Science Education News, 1996) This may underestimate the number of students who actually studied the module because students have a choice about which exam questions they answer. However, it indicates that a very small proportion of NSW students studied this biotechnology module as part of their curriculum in that year. In the more academic 2 Unit course, 1541 students out of 14,797 answered the exam questions on the “Genes in Action” elective. Adding these figures together, a total of 1649 students in NSW had a senior level education in biotechnology in 1995. The number of students who had some teaching about biotechnology in junior science is unknown.

The data indicate that few students in NSW are being educated about biotechnology even though syllabus options exist that would allow teachers to choose a biotechnology program. As has been found in the USA and the UK, providing a set of curriculum guidelines will not, of itself, result in the implementation of biotechnology in the classroom. Some reasons as to why biotechnology has failed to reach the classroom have been documented in the literature and these are discussed in the following section.

2.4 Difficulties with implementing courses in biotechnology
Six problems encountered in the teaching of biotechnology have been identified in the literature. Five of these have been reviewed by McInerny (1990) in the UNESCO report on the teaching of biotechnology around the world. Three have been confirmed by Zeller (1994). A sixth problem has been identified from the work of Venville and Treagust (1996).

One problem described was "teachers lack of awareness of biotechnology" (McInerny, 1990, p.244). The article points out that the average age of teachers (in the US) is about forty and therefore most teachers were trained before courses in molecular biology became standard at university. In most countries courses in molecular biology have only been routinely available within the last ten years. Of those science teachers trained in the last ten years in Australia only those majoring in biological sciences would have
encountered biotechnology, as there is no requirement to study this subject at university. Therefore only a small proportion of the total population of teachers are likely to have had a university training in biotechnology. This means that the comment made by Bayrhuber (cited in McInerny, 1990, p.244) remains relevant "Teachers throughout the world are not adequately prepared for the task of teaching biotechnology". Lack of training in biotechnology was also listed as a problem by the teachers interviewed by Zeller (1994).

Another obstacle highlighted by McInerny's report was the lack of resource materials for biotechnology. This problem was also reported by Zeller (1994). In the last three years a larger number of resources have been made available. The CSIRO has published a booklet of resources available in Australia, which includes videos, books and practical kits (Biotechnology in the Classroom, 1995). A search on the internet reveals many teaching resources, including practicals, work-sheets and articles. It may no longer be the case that resources are unavailable, however it may be that these resources are still not accessible to classroom teachers. As McInerny (1990) points out, many of the practical activities in biotechnology are expensive and require a lot of preparation. Related to the lack of resources is a lack of interaction between schools and industries that would enable more affordable laboratory work to be provided to the school.

A third problem listed by both Zeller (1994) and McInerny (1990) is the problem of overcrowded curricula. If the curriculum and the formal assessment procedures place pressure on teachers to teach a range of other subjects, because of the "discipline-bound academic nature of traditional science education" (McInerny, 1990 p.247), then teachers simply do not have time to do the preparation required to include another topic, no matter how interesting or important.

The controversial nature of some of the material in biotechnology was raised by McInerny (1990) as a possible fourth obstacle teachers might encounter. Parent groups might object to the inclusion of the topic in the curriculum, although no cases where this has happened have so far been reported.

A fifth problem in biotechnology teaching, mentioned by McInerny (1990), is that because it is multi-disciplinary and contains controversial material, biotechnology requires innovative teaching methods, and many teachers are not able to cope with this type of teaching. This problem may be related to the one discussed below, ie innovative teaching may be necessary to deal with the difficulties many students experience in understanding concepts important to biotechnology. A problem likely to be compounded if the teachers lack subject matter knowledge.
A sixth problem suggested by some work by Venville and Treagust (1996) is that the students find some of the concepts in biotechnology very difficult to understand. These researchers worked with several teachers who were teaching genetics to a junior science class. These teachers found that students readily understood that genes were responsible for inherited traits but the students were unable to understand that genes make proteins which in turn give rise to the visible phenotype. This emphasis on genes as a process rather than as isolated heritable particles was beyond the understanding of all but one of the students, even though one of the teachers had used many creative activities to demonstrate this idea. Venville and Treagust (1996, p.20) pose the question:

mutation, for example, or genetic engineering, are fascinating and sensational topics for discussion; but what opportunity do students have for understanding the concepts involved if they do not understand what genes do but only have an understanding of genes being particles?

In summary the problems that teachers encounter in implementing programs in biotechnology can be listed as:

1. lack of teacher expertise in the area (McInerny, 1990; Zeller, 1994);
2. lack of resource materials (McInerny, 1990; Zeller, 1994);
3. lack of time in the crowded curricula for another topic (McInerny, 1990; Zeller, 1994);
4. difficulties due to the controversial nature of the material (McInerny, 1990);
5. the need for innovative teaching methods (McInerny, 1990);
6. lack of student understanding of the underlying concepts (Venville & Treagust, 1996).

None of these studies dealt with the teachers' attitude to biotechnology. Where the teaching of biotechnology is optional, the extent to which teachers consider biotechnology to be important and/or interesting is also a potential obstacle to the teaching of this subject. The attitude of teachers toward biotechnology is investigated in the research reported in this work.

2.5 Implications of the problems in biotechnology teaching for the present study

For each of the problems in biotechnology teaching listed above, it is possible to ask to what extent these problems occur in the NSW school environment and to what extent they affect the teacher's decision to teach biotechnology. It is also necessary to ask whether there are any factors unique to NSW that result in teachers choosing not to teach
biotechnology. The reasons that teachers perceive to be important can then be compared to the actual problems encountered when teachers undertake a unit of biotechnology. By making an assessment of the problems that are important to NSW teachers when they are faced with implementing a program in biotechnology it may then be possible to identify ways in which these problems can be overcome.

2.6 Statement of aims of this research

This research uses the problems identified elsewhere as a basis for investigating the situation that exists in biotechnology teaching in NSW. In particular, it is postulated that teachers in NSW are not electing to teach biotechnology because they do not know enough about this topic. However, it is recognised that other problems may prevent the teaching of biotechnology and the study aims to identify these problems. Once the problems have been identified, ways in which these problems can be overcome are explored, in order that students in NSW be able to experience education in the topic of biotechnology.

The aims of this research are to:

- describe the state (map the terrain) of biotechnology teaching in NSW;
- determine whether teachers in NSW do not teach biotechnology because they do not have the knowledge and experience adequate to the task;
- identify other reasons why NSW teachers choose not to teach biotechnology;
- describe problems encountered in teaching biotechnology in NSW;
- suggest ways in which the problems encountered in the teaching of biotechnology can be overcome.

The design of the study is explained in chapter 3.
Chapter 3

Design of the study

Biotechnology has been shown to have a place in the secondary school curriculum. Six barriers to the teaching of biotechnology were identified in the literature, described in section 2.4. It was also postulated that unique problems may be encountered by teachers in NSW. The six problems, that had been identified from the literature, were used as a basis for an investigation of the teaching of biotechnology in NSW. The aims of this investigation were listed in section 2.6 as to:

• describe the state (map the terrain) of biotechnology teaching in NSW;

• determine whether teachers in NSW do not teach biotechnology because they do not have the knowledge and experience adequate to the task;

• identify other reasons why NSW teachers choose not to teach biotechnology;

• describe problems encountered in teaching biotechnology in NSW;

• suggest ways in which the problems encountered in the teaching of biotechnology can be overcome.

Both qualitative and quantitative research methods were used to investigate the extent to which the problems listed in section 2.4 affected the teaching of biotechnology in NSW. Section 3.1 describes the quantitative methods that were used. The qualitative methods are described in section 3.2.

3.1 Quantitative methods

A survey was considered to be the most appropriate method to accomplish the first two aims listed above. A questionnaire, see Appendix 1, was designed that would investigate these aims. To accomplish the first aim of this research, to map the terrain of biotechnology teaching in NSW, questions were designed that asked teachers how much biotechnology they were teaching and in what form (eg as “Genes in Action” or as a junior science topic).

The second aim of the survey was to determine whether the teachers did not teach biotechnology because they did not have the knowledge and experience adequate to the task. In order to obtain data relevant to this aim, survey questions were designed that asked the teachers about their background, so that this background could be related to the amount of biotechnology that they taught. The hypothesis proposed was “that teachers do not teach biotechnology because they do not have the knowledge and
experience adequate to the task. In order to test this hypothesis, five sub-hypotheses that related to the teachers background were formed. These were:

- that the number of years of teaching experience is related to the amount of biotechnology taught;
- that the number of years of experience as a biology teacher is related to the amount of biotechnology taught;
- that the major subject of the teacher’s degree is related to the amount of biotechnology taught;
- that the level of qualification (in science and education) is related to the amount of biotechnology taught;
- that extra training in biotechnology (either as work or extra study) is related to the amount of biotechnology taught.

Questions that related to each of these sub-hypotheses were formulated.

The hypothesis that the gender of the teacher affects the amount of biotechnology taught, was also tested.

As stated in section 2.6, the aims of this research also involved identifying reasons why teachers do or do not teach biotechnology, and defining problems that they encounter. Therefore, questions about these issues were included in the questionnaire. A series of statements were prepared that summarised the difficulties detailed in section 2.4 and teachers were asked to indicate whether they strongly disagreed or strongly agreed with these statements using a 5 point Likert scale. The survey data then provided preliminary evidence as to which of the problems that are suggested in the literature are of significance to the teachers of NSW. It also gave an indication of the experiences these teachers had when teaching biotechnology.

The teachers attitude to biotechnology was also considered to be important, due to the optional nature of this subject in NSW. Therefore, teachers were asked to rate a series statements that reflected their opinion of biotechnology on a 5 point Likert scale. From these ratings, scales that measured both the interest and importance that teachers gave to biotechnology were developed. These scales were then used to test the following hypotheses about the impact of the teachers attitude to biotechnology on the number of hours of biotechnology taught:

- that the teachers’ interest in biotechnology affects the amount of biotechnology taught;
- that the importance teachers give to biotechnology affects the amount of biotechnology taught.
The scales were also used to test whether the teachers' attitude to biotechnology was affected by the background factors measured in the survey. Given that more experienced teachers were less likely to have studied biotechnology, the hypotheses that were tested were:

1. more experienced teachers have less interest in biotechnology;
2. more experienced teachers consider biotechnology to be less important;
3. there is a relationship between extra training in biotechnology and the amount of interest the teacher has in this subject;
4. the gender of the teacher affects the amount of interest they have in biotechnology.

The questionnaire was mailed to 100 randomly selected NSW government schools and 35 randomly selected non-government schools. The principal of each school was asked to give the survey to one science teacher, selected at random.

The survey was able to provide quantifiable data on a large sample but the scope of the questions had to be restricted, to prevent the survey becoming so long that its length would operate as a disincentive to respond. For example, teachers were asked to strongly agree or strongly disagree with the statement "there are not enough practicals" but were not asked about why they felt that practicals were important. The survey could explore the extent to which teachers agreed with prepared statements about problems in biotechnology teaching. However, it was not possible to discover the nature of all of the obstacles encountered by teachers by using a series of short statements. Initially, therefore, an open-ended section was included in the survey and teachers were invited to add further comments. For a more in-depth investigation of the teaching of biotechnology qualitative methods were employed.

3.2 Qualitative methods

There has been debate in the literature on education research concerning the relative value of qualitative and quantitative approaches to research. Those who would use the methods of qualitative research were compelled to justify their choice (eg Lincoln and Guba, 1985; Peshkin, 1993). However as Roberts (1996, p.243) states, "in the past 15 years there has been a remarkable legitimation of the idea that qualitative research might have a place in science education". He points out that both approaches can be shown to be rigorous and that "their capacity to provide a 'take' on events in science education is complementary rather than competitive" (p.246). The strength of quantitative research is said (Roberts, 1996) to be more on the side of precision than scope, qualitative research is stronger on the side of scope than precision.
Both methods have been used in a complementary way in this research to identify the problems that inhibit the teaching of biotechnology. A survey was designed to provide data on problems teachers encounter. Qualitative data was then sought, to explain the nature of these problems in the context of the NSW education system.

One method of qualitative data collection used in this research took the form of discussion with teachers who attended a workshop about biotechnology. These informal interviews (the details of which are described in section 5.1) were used to obtain teachers' explanations of the reasons why they had not taught biotechnology. The data enriched the survey data, in addressing the third aim of this research, to identify other reasons why NSW teachers choose not to teach biotechnology.

To find out more about the problems encountered when a biotechnology topic is undertaken in the classroom (aim 4, section 2.6) a case study methodology, as defined by Merriam (1988), was used. The case study was considered appropriate, as the unit of biotechnology was a bounded phenomenon about which a holistic description was required. Merriam (1988, p.xiv) asserts that this is the nature of a case study. The methods associated with the case study include interviews, document analysis and observation (Tesch, 1990; Cohen and Manion, 1989). These methods were used in the three case studies of the teaching of a unit of biotechnology reported in this thesis. Detail of the method used is described in section 6.1.

Originally it was intended that these case studies would encompass both of the biotechnology units in the HSC syllabus and a unit in junior science, thus covering the range of possible situations in which biotechnology might be implemented in the classroom. However, as Lincoln and Guba (1985, p.208) have stated, in qualitative research it is often necessary to use an emergent design because meaning is determined by context to such a great extent; because the existence of multiple realities constrains the development of a design based only on one (the investigator's) construction; because what will be learned at a site is always dependent on the interaction between investigator and context and this interaction is not fully predictable; and because the nature of mutual shapings cannot be known until they are witnessed.

In this study it was found that the constraints of working within the teachers timetable, and the existence of unforeseen factors in the school environment, required the modification of the design of the research as the study progressed. It was also found that once the survey data was analysed, information became available that could be used to direct the remainder of the research.
Erickson (1986) has argued that it is important to present the natural history of the enquiry in a report of a study. Therefore, the emerging design of this research, as outlined below, has been reported in detail in sections 5.1, 6.1.1, 6.2.1.3 and 6.2.2.4.

As a result of unforeseen factors in the school environment, the original design of the study (where it was intended that case studies be conducted on the teaching of each of the biotechnology units in Science for Life, junior science and “Genes in Action”) was modified. It proved to be possible to locate teachers who were teaching the 2 Unit biology elective "Genes in Action" but not possible to locate teachers who were teaching either the Science for Life module on biotechnology, or a junior science unit on biotechnology. Although it was useful to document the problems associated with teaching "Genes in Action", it could not be assumed that the problems associated with this unit were the same as the problems that would be encountered under different circumstances. Therefore, different strategies had to be used. A case study of the biotechnology unit in Science for Life was replaced by an in depth interview with a teacher experienced in teaching the topic. To find out more about the obstacles to implementing biotechnology in junior science, an outline for a biotechnology unit was prepared, using the survey results as a guideline. This outline was given to a teacher of junior science, who then used it as the basis of a unit of biotechnology for a year ten class. The implementation of this biotechnology unit became the subject of a case study.

The data collection and analysis for this research occurred in five phases and these are reported sequentially in the following chapters. These phases are summarised in table 3.3.1. Erickson (1986, p.146) states that one basic task of the data collected in research is to establish assertions and generate an “evidentiary warrant” for these assertions. Assertions were made at the end of each phase of this enquiry and these assertions were modified as evidence was obtained. The final assertions, made at the end of chapter six, for which an evidentiary warrant has been established, are the findings of this enquiry into the teaching of biotechnology in NSW.

3.3 Summary
This research has used complementary quantitative and qualitative methods to investigate the teaching of biotechnology in NSW. The data obtained from a survey to 'map the terrain' of biotechnology teaching in this state was used to inform the design of the qualitative study. Using data from the survey, interviews and case studies it was then possible to make some assertions about the problems encountered in teaching biotechnology. Findings arising from the analysis of data from all sources and methods were used to address the final aim, to suggest ways to improve
the teaching of biotechnology in NSW. In table 3.3.1 the phases of the inquiry are summarised. Table 3.3.2 gives a brief overview of the research method.

The following chapters describe in detail the methods used in this study. Chapter 4 describes the survey design, data collection and analysis, and presents the findings from this analysis. This chapter concludes with a discussion of the data relevant to the first two aims of this study, ie to map the terrain of the teaching of biotechnology and to determine whether teachers do not teach biotechnology because they do not have the knowledge and experience adequate to the task. Chapter 5 describes the data from interviews and discusses results from the survey that are relevant to the aim "to identify reasons why NSW teachers do not teach biotechnology". The case studies of “Genes in Action” and the implementation of the unit of biotechnology for junior science are described in chapter 6. Final assertions (the research findings) about the problems that teachers encounter when teaching biotechnology in NSW are presented at the end of chapter 6. Chapter 7 deals with the implications of the findings of this research and suggests ways in which the teaching of biotechnology in NSW might be improved.
Table 3.3.1 Phases of the inquiry

<table>
<thead>
<tr>
<th>Research phase</th>
<th>Date carried out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey of 135 schools conducted and analysed</td>
<td>Jun 1996-May 1997</td>
</tr>
<tr>
<td>12 teachers interviewed about why they choose not to teach biotechnology</td>
<td>December 1996</td>
</tr>
<tr>
<td>Interview with teacher experienced in teaching Science for Life</td>
<td>April 1997</td>
</tr>
<tr>
<td>Case studies of Genes in Action</td>
<td>May 1997-July 1997</td>
</tr>
<tr>
<td>Preparation and implementation of unit of biotechnology for junior science</td>
<td>Aug 1997-May 1998</td>
</tr>
</tbody>
</table>

Table 3.3.2 Summary of research method

<table>
<thead>
<tr>
<th>Aim of research</th>
<th>Data collection</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>To describe the state of biotechnology teaching in NSW</td>
<td>Survey</td>
<td>135 NSW secondary schools</td>
</tr>
<tr>
<td>To determine whether teachers do not teach biotechnology because they do not have the knowledge and experience adequate to the task</td>
<td>Survey</td>
<td>As above</td>
</tr>
<tr>
<td>To identify reasons why teachers choose not to teach biotechnology</td>
<td>Survey, Interviews</td>
<td>As above</td>
</tr>
</tbody>
</table>
| To describe the problems encountered in teaching biotechnology in NSW          | Case studies (Genes in Action) | Rob, Rivervale High School.  
                                                                                                                                 Michael, Cleland High School  
                                                                                                                                 Alan  
|                                                                                | Interview (Science for Life) |                                    |
|                                                                                | Case study (junior science) | Verity, Drayton High School                |
Chapter 4

Design, conduct and analysis of the survey
investigating the teaching of biotechnology in NSW

Biotechnology has been shown to have a place in the secondary school curriculum (chapters 1 and 2). NSW students, as part of the global population, require an education in biotechnology. Some problems encountered by others in the teaching of biotechnology have been reported (chapter 2) and the need for an investigation of the teaching of biotechnology in NSW has been established. The aims of this investigation were listed in section 2.6. They were to:

1. describe the state (map the terrain) of biotechnology teaching in NSW;
2. determine whether teachers in NSW do not teach biotechnology because they do not have the knowledge and experience adequate to the task;
3. identify other reasons why NSW teachers choose not to teach biotechnology;
4. describe problems encountered in teaching biotechnology in NSW;
5. suggest ways in which the problems encountered in the teaching of biotechnology can be overcome.

Science teachers were surveyed about those aspects of the teaching of biotechnology that related to aims 1–4 above, as summarised in chapter 3.

Chapter 4 reports the design of the survey questions (section 4.1), the method of data collection and analysis (section 4.2) and the findings of the survey (section 4.3). In section 4.4 the findings of the survey are summarised. A discussion of the findings of the survey that relate to aims 1 and 2, mapping the terrain of biotechnology in NSW and determining whether teachers do not teach biotechnology because they do not have the knowledge and experience adequate to the task, is presented in section 4.5. A summary of the main findings from the survey concludes chapter 4.

A copy of the survey is presented in Appendix 1.

4.1 Design of the survey questions

4.1.1 The amount of biotechnology taught
The first stated aim in section 2.6 was to describe the state of biotechnology teaching in NSW. To do this, an estimate of how many hours of biotechnology
were taught was obtained. The content of these teaching hours in biotechnology was also sought.

As stated in section 2.3.4, there are three sections of the science curriculum where biotechnology may be taught. These are:
1. Science for Life, in the elective module "Biotechnology";
2. 2Unit Biology, in the elective "Genes in Action";
3. as part of the junior science syllabus.

To determine the amount of biotechnology taught in senior science, respondents were asked to state whether they had taught either of the biotechnology electives in 1995/96 (question 9 of the survey). To estimate the hours of biotechnology taught in junior science a more complex question had to be designed. In order to avoid confusion caused by possible different interpretations of the word "biotechnology" the definition given in section 2.1 was used as the basis for question 10 in the survey. Each component of biotechnology was listed separately and respondents were asked to state the number of periods taught and the length of the period. Data obtained was then converted into the number of hours of biotechnology taught.

4.1.2 The teachers background
McInerny (1990) found that teachers lack of experience in biotechnology was a major impediment to their willingness to implement programs in biotechnology. The hypothesis was proposed, that teachers in NSW do not teach biotechnology because they do not have the knowledge and experience adequate to the task. To test this hypothesis, information about the teachers academic background was obtained, as an indication of their knowledge about biotechnology. A range of factors were included as being possible indicators of the teachers' knowledge and experience in the field. These were:

- how many years had they taught science;
- how many years had they taught biology;
- what subject had been the major of their degree;
- what level of qualification they had in both science and in education;
- whether they had any extra training in biotechnology, for example as an in-service or as work experience.

A separate hypothesis was framed for each of these factors. These hypotheses were used to formulate the questions used in the survey. The hypotheses were:
• that the gender of the teacher affects the amount of biotechnology taught (question 1);

• that the number of years of teaching experience is related to the amount of biotechnology taught (question 3);

• that the number of years of experience as a biology teacher is related to the amount of biotechnology taught (question 4);

• that the major subject of the teacher's degree is related to the amount of biotechnology taught (question 5);

• that the level of qualification (in science and education) is related to the amount of biotechnology taught (questions 2 and 6);

• that extra training in biotechnology (either as work or extra study) is related to the amount of biotechnology taught (questions 7 and 8).

Testing these hypotheses would enable conclusions to be drawn about whether teachers do not teach biotechnology because they lack the knowledge and experience to adequately carry out the task. It should be noted that the survey also asked teachers directly for their opinion on whether they did not teach biotechnology because they did not know enough about it (as part of questions 12, 13, 14).

4.1.3 Reasons for not teaching biotechnology

Section 2.4 lists the problems that have been identified by others as reasons why teachers do not teach biotechnology. This list was used as the basis for survey questions 11, 12, and 13 which ask teachers why they have chosen not to teach biotechnology. Using the list, a series of statements were formulated and teachers were asked to use a Likert scale (as described in Burns, 1994) to rate whether they strongly agreed or strongly disagreed with these statements. For example, Venville and Treagust (1996) suggested that one of the concepts in biotechnology was too difficult for students to learn. The statement formulated was "the students find it too difficult" and respondents were directed to circle 1 if they strongly disagree with this statement and 5 if they strongly agree. A Likert scale was chosen because it allows the measure of agreement to be numerically analysed, the scale being treated as an ordinal variable.

Other examples of statements derived from the list in section 2.4 were:

• "I do not know it well enough to teach it" and "the school does not have a program for it" which apply to the lack of teacher expertise;

• "there are not enough references" and "not enough practical work can be done" which apply to the problem of lack of resource materials;
• "I do not have time to fit in another topic", which relates to the problem of crowded curricula;
• "It is too controversial", which is consistent with the suggestion of McInerney (1990) that biotechnology raises controversial issues which may inhibit its teaching.

While most items in the list of suggestions offered in questions 11, 12 and 13 were based on the list in section 2.4, items were added to deal with the particular circumstances of NSW. Respondents to this survey were in the position of having to decide which elective their students would study for their final school exam. The students themselves sometimes choose which elective to study. Therefore teachers were asked for their opinion of how the students would respond to the electives on biotechnology using the statements, "the students find it boring" and "it is not important to my students". Due to the importance placed on the HSC exam, the possibility that teachers do not teach an elective because the students will not achieve a high mark led to the inclusion of the statement, "the exam questions are too hard".

The possibility that the teacher had a reason for not teaching biotechnology that had not been described by any of the above statements was taken into account by leaving a space for "other reasons" at the end of each question.

The same list of suggestions was used in each of the questions asking teachers about why they did not teach biotechnology. Question 11 related to "Genes in Action", question 12 to "Biotechnology" in Science for Life and question 13 to junior science. In framing a question about reasons for not teaching biotechnology in junior science, a problem arose because biotechnology had been defined as a series of subtopics. Respondents could well ask "which topic of biotechnology?". One solution would have been to ask teachers separately about each subtopic, but this would have required five additional long questions. Rather than risk reducing the response with a longer survey, genetic engineering was selected as the most fundamental subtopic to any unit on biotechnology and teachers were asked why they did not teach genetic engineering.

A different subset of respondents answered each question and it was possible for one respondent to answer more than one question about why they chose not to teach biotechnology and to give different reasons for different situations. For example, a teacher could agree with the statement, "The exam questions are too hard" when giving reasons why she did not teach "Genes in Action" but disagree with this statement when explaining why she did not teach biotechnology as part of Science for Life.
4.1.4 Experiences in the teaching of biotechnology

Despite the barriers to the teaching of biotechnology (as listed in section 2.4), HSC exam data on the electives students attempt showed that some teachers had persevered to teach the biotechnology related electives. Question 14 asked teachers who had taught biotechnology about their experience. The same list of possible difficulties given in section 2.4 was used to generate a series of statements that might sum up the teachers experience about teaching biotechnology. In some cases the wording of the statement was changed to take into account the different context, for example "I do not know it well enough to teach it" was changed to "I need to learn more about the topic". As before, respondents were asked to rate the statements using a Likert scale from 1 to 5 where 1 indicates strongly disagree and 5 indicates strongly agree. Opportunity was also given for the participant to list other comments about their experience of biotechnology teaching.

4.1.5 Teacher attitude to biotechnology

McInerney (1990) claimed that teachers were unaware of the importance of biotechnology because they lacked experience in the area. In NSW, where all biotechnology teaching is optional, the teachers' attitude to the importance of biotechnology is of consequence. It was considered possible that teachers were aware of current trends in biotechnology, eg through reports in the media, even though they had not studied this subject during their training. How important they found the subject to be, and how interested they were in the new discoveries in biotechnology, might have had an impact on their willingness to choose to teach biotechnology. Therefore question 15 was designed to measure to what extent teachers were interested in biotechnology and to what extent they considered it to be an important area of science.

Interest was measured by ranking the statements:

- "I enjoy learning about biotechnology"
- "I would like to teach more biotechnology"
- "I like to read about biotechnology"
- "The issues in biotechnology are interesting"
- "I like to watch TV shows about biotechnology"

Importance was measured by ranking the statements:

- "It is important that we all know more about it"
- "Biotechnology can improve our quality of life"
- "Biotechnology is a destructive social element"
The statements were used in a similar way to those of previous questions, ie respondents were asked to rate whether they strongly agreed or strongly disagreed with the statement on a scale of 1 to 5.

4.2 Conducting the survey

4.2.1 Content validity
The questionnaire was given to an academic expert in statistics and quantitative research methods who gave valuable advice on how the questions could be written to facilitate the later analysis. Once the questions had been designed, the questionnaire was sent to five practising teachers for review. All of the teachers had experience in research. The teachers completed the survey and confirmed the validity of the instrument. Suggested minor modifications were made.

4.2.2 Ethical considerations
No information that could identify the school or the teacher was sought in the questionnaire. Letters were sent to inform the school principal, the head teacher and the participant of the nature of the survey. Respondents were advised that participation was voluntary.

Approval for the research was obtained from the NSW Department of School Education and from the Ethics Committee of the University of Western Sydney. Permission was given for the questionnaire to be sent to a specified list of one hundred government secondary schools that had been chosen at random. The list included city and country schools, selective and comprehensive schools.

4.2.3 The sample
The questionnaire was mailed to the principal of the approved government schools and to the principal of 35 NSW non government schools. One randomly selected science teacher from each school was requested to return the questionnaire. A stamped and addressed envelope was included to facilitate a high return rate.

In total, fifty nine surveys were returned, a return rate of 44%. This was a disappointingly low figure but it may be accounted for by the many steps the questionnaire had to go through in order to reach the teacher (at least one was returned by the school principal, unanswered) and by the fact that most teachers are very busy.
4.2.4 Analysis of Survey

Statistical analysis of the survey was carried out using SPSS for Windows. Details of this analysis are described in section 4.3.

4.3. Results of the Survey

4.3.1 What is taught

In describing the state of biotechnology teaching in NSW (aim 1 of the research), the first question asked was "how much biotechnology is taught?" Data was obtained for each of the possible units of biotechnology. With regard to the 2 Unit biology elective "Genes in Action", 48 of the respondents taught 2 Unit biology and of these 6 (12.5%) taught the elective. HSC exam figures from 1995 (Science Education News, 1996) showed that 10.1% of 2 Unit biology students answered the questions on "Genes in Action". The survey data and the HSC exam figures both indicate a similar proportion (10-12%) of students of 2U Biology undertaking "Genes in Action".

Of the 59 science teachers who replied to this survey, 14 had taught Science for Life and of these 3 (21%) taught biotechnology. The figures from HSC exam results (Science Education News, 1996) indicate that in 1995, 108 out of 4474 (2.4%) students answered the exam questions on biotechnology. The percentage of students being taught biotechnology as part of "Science for Life" was measured to be 21%, nearly 10 times higher than might be expected from the number of students answering the exam questions. There are two factors that would explain this discrepancy. First, students who are taught biotechnology can choose not to answer the exam questions on this elective. Therefore, more students will be taught biotechnology than will eventually answer the relevant exam questions. Second, teachers with an interest in biotechnology may have been more likely to respond to this survey. Because the sample is small, a slight bias towards those Science for Life teachers with a particular interest in biotechnology would make a very large difference to the measured percentage.

To estimate the amount of biotechnology taught in years 7 to 10, biotechnology was defined as a series of specific subtopics, as described in section 2.1. Teachers were asked to list how many periods of each subtopic were taught to each year. The purpose of this strategy was to avoid confusion over the meaning of the word biotechnology. For the analysis of the survey responses, the total number of hours of biotechnology taught was estimated by adding the periods taught across all subtopics and all years.

Figure 4.1 shows the distribution of hours of biotechnology taught in junior science by the sample of teachers in this survey.
The mean number of hours taught was 3.7, with more than half of the sample teaching less than three hours of biotechnology. Of the subtopics taught, the greatest percentage of the total hours was given to genetic engineering (39.4%) and in vitro fertilisation (20.8%). DNA fingerprinting (13.1%) and biotechnologies in food production (16.0%) were the other most commonly taught subtopics. Almost all (90.4%) of the biotechnology taught in junior science was taught in years 9 and 10.

In order to determine the total number of hours of biotechnology taught by each teacher, so that this figure could be compared with that individuals background, the number of hours taught in junior science was combined with the number of hours taught in senior electives. As the survey did not ask for an estimate of the number of hours spent on any particular elective, a figure of 13 hours was used for each elective taught. For example, if a respondent taught 4 hours of biotechnology in junior science and taught "Genes in Action" but not Science for Life, the total hours taught would be 17. The estimate of thirteen hours was chosen because it represents four weeks of five, forty minute periods a week. This corresponds to the minimum number of hours prescribed for any HSC elective.
4.3.2 Background and biotechnology teaching

As was explained in section 4.1.2, several hypotheses were proposed about factors in a teachers background and whether these would predispose them to choose to teach biotechnology. Factors that were included were the teachers years of experience both as a teacher and a biology teacher, the area of their major in science and the level of qualification obtained both in science and education. The survey results that deal with each hypothesis are analysed separately in the following section.

4.3.2.1 That the number of years of teaching experience is related to the amount of biotechnology taught

In the sample of 59 teachers who responded to the survey, the mean number of years of teaching experience was 18.6 (sd= 9.2). Only one teacher had less than five years of teaching experience. The hypothesis that had been proposed was "that the number of years of teaching experience is related to the amount of biotechnology taught". To test this hypothesis a Pearson's correlation was carried out, comparing years of experience with the number of hours of biotechnology taught. This analysis showed that there was no significant correlation (r=-0.14, p = 0.298) between years of experience as a teacher and the amount of biotechnology taught for the sample of teachers surveyed.

4.3.2.2 That the number of years of experience in biology teaching is related to the amount of biotechnology taught

An identical analysis to that of section 4.3.2.1 was done using years of experience in teaching senior biology as one variable and hours of biotechnology taught as the second variable in Pearson's correlation. Again there was no significant correlation (p=0.633, r= -0.06). The average number of years of senior biology taught was 12.5 (sd= 8.96) and there were 7 teachers who had less than 5 years of experience teaching senior biology.

4.3.2.3 That the level of qualification in education was related to the amount of biotechnology taught

In question 2 on the survey, respondents were asked to indicate whether their highest teaching qualification was a diploma, bachelor, master or doctoral degree. The frequencies of the responses are shown below
Table 4.1 Teacher qualification; frequency

<table>
<thead>
<tr>
<th>Degree</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diploma</td>
<td>33</td>
<td>56</td>
</tr>
<tr>
<td>Bachelor</td>
<td>17</td>
<td>29</td>
</tr>
<tr>
<td>Master</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>Doctor</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

The hypothesis tested was that the level of the teaching qualification was related to the amount of biotechnology taught. When the three groups of diploma, bachelor and master were compared for mean number of hours of biotechnology taught, using a one way analysis of variance, $F(2, 58) = 39$. Using the Student-Newman-Keuls test no two groups were found to be significantly different at the $<0.05$ level ($p=0.68$). Therefore, for this sample of teachers, the level of teaching qualification was not related to the amount of biotechnology taught.

4.3.2.4 That the major subject of the teachers degree was related to the amount of biotechnology taught

Question 5 on the survey asked teachers to tick which area of science, physics chemistry, biology or geology had been the subject of their major during undergraduate study. The hypothesis to be tested was that the major subject of the teacher's degree was related to the amount of biotechnology taught. The frequencies of responses are listed below

Table 4.2 Major subject of science qualification; frequency

<table>
<thead>
<tr>
<th>Major subject</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physics</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Chemistry</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>Biology</td>
<td>45</td>
<td>79</td>
</tr>
<tr>
<td>Geology</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>

As such a large proportion of the sample had done biology as a major it was not possible to treat the other subjects as large enough groups for statistical analysis. Therefore the number of respondents who had done physics, chemistry and geology or who had filled in the "other" category were placed into a "not biology" group. The mean number of
hours of biotechnology taught by each of the biology and “not biology” groups were then compared using an independent t-test. The analysis shows that there is no significant difference between the amount of biotechnology taught by those respondents with a degree in biology compared with those with a degree in another area of science (df= 55, t=-0.32, p=0.75).

4.3.2.5 That the level of qualification in science was related to the hours of biotechnology taught
Teachers were asked to indicate whether the level of their science qualification was that of diploma, bachelor, masters or doctoral degree. The frequencies of responses are shown in table 4.3

<table>
<thead>
<tr>
<th>Qualification</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>diploma</td>
<td>5</td>
<td>8.8</td>
</tr>
<tr>
<td>bachelor</td>
<td>48</td>
<td>80.0</td>
</tr>
<tr>
<td>master</td>
<td>4</td>
<td>7.0</td>
</tr>
<tr>
<td>doctor</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

As there were very few who had a diploma, masters or doctoral degree, the data was not used for further statistical analysis. The results of this survey could not be used to determine whether the level of science qualification was related to the amount of biotechnology taught.

4.3.2.6. That extra training in biotechnology, either as work or study, was related to the amount of biotechnology taught
The survey asked teachers to report on whether they had any special expertise in biotechnology (question 7) or had done any extra study in the topic (question 8). The distribution of answers for these questions is shown below.
Table 4.4 Experience in biotechnology

<table>
<thead>
<tr>
<th>Experience in biotechnology</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra study</td>
<td>7</td>
<td>11.8</td>
</tr>
<tr>
<td>Work experience</td>
<td>8</td>
<td>13.5</td>
</tr>
<tr>
<td>Total sample</td>
<td>59</td>
<td></td>
</tr>
</tbody>
</table>

This question was aimed at testing the hypothesis "that extra training in biotechnology is related to the amount of biotechnology taught". An independent t-test was used to compare the mean hours of biotechnology taught by those who had done either extra work or extra study in biotechnology versus those without. The analysis showed that there is a significant difference between the amount of biotechnology taught by those teachers who have worked in a biotechnology field compared to those who have not (t=2.11, df=57, p=0.04). Teachers who had worked in biotechnology taught a mean of 11.0 hours of biotechnology, compared to a mean of 5.3 hours taught by teachers who had not worked in biotechnology. A significance difference was also found (t=2.33, df=57, p=0.023) between the amount of biotechnology taught by those who have done extra study in biotechnology eg as an in-service and those who had not done extra study.

The sample size of the groups used in the above analysis (of teacher experience in biotechnology) were small. In an attempt to overcome this problem the groups comprising “study” and “work” experience were combined into a larger sample of 15 teachers who had “extra training” either as work or as study, in the field of biotechnology. This larger group was then compared with teachers who had no extra training for the mean number of hours of biotechnology taught. A significant difference between the amount of biotechnology taught by the two groups was obtained (t=3.52, df=57, p=0.001). Teachers with extra training in biotechnology taught a mean number of 11.3 hours of biotechnology, compared to a mean of 4.7 hours for those teachers with no extra experience.

All of these results show that extra training, whether in work or as extra study, has a large impact on the number of hours of biotechnology taught.

The analysis above considers the total number of hours of biotechnology taught. When a t-test was used to compare teachers with “extra training” with teachers who had no
extra training, for the number of hours of biotechnology taught in junior science the t value obtained was 0.75, which is not significant at <0.05 (p=0.456). Therefore the influence of extra training was at the level of senior science. Those teachers with extra training were more likely to teach an HSC elective involving biotechnology. Given that only 3 respondents taught the Science for Life elective, it can be concluded that extra training in biotechnology had the greatest influence on whether a teacher was willing to undertake the "Genes in Action" elective as part of 2 Unit biology.

4.3.2.7 That the gender of the teacher is related to the amount of biotechnology that is taught

Of the 59 respondents to the survey, 38 were male and 19 were female. These two groups were compared using a t-test, for the number of hours of biotechnology taught. There were no significant gender differences in the amount of biotechnology taught (df=55, t=0.59, p=0.55).

4.3.3 Reasons for not teaching biotechnology

As has been stated elsewhere (section 2.3.4), many teachers elect not to teach biotechnology related topics. The survey was designed to identify the reasons teachers gave for this choice. Teachers were presented with reasons suggested in the literature as to why biotechnology might not be taught and asked to rate these reasons on a scale of one to five. The reasons why a teacher may elect not to teach biotechnology to junior science students may be different from the reasons why a teacher does not elect biotechnology for senior science. In each case the syllabus is different, the aims of the students may be different and the environment in which the material must be taught is different. Therefore separate questions were asked about why teachers choose not to teach "Genes in Action", "Biotechnology" in Science for Life and biotechnology in junior science.

4.3.3.1 Genes in Action

Of the 48 teachers who indicated that they taught 2 Unit biology, 37 indicated that they did not teach the elective "Genes in Action". These teachers were asked to rate the reasons why they did not teach "Genes in Action" in question 11 of the survey. The mean scores given by this group are summarised in table 4.5.
Table 4.5 Reasons teachers choose not to teach "Genes in Action"

<table>
<thead>
<tr>
<th>Suggested reason</th>
<th>Mean score</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>There are not enough references</td>
<td>2.78</td>
<td>1.05</td>
</tr>
<tr>
<td>The students find it boring</td>
<td>2.50</td>
<td>0.88</td>
</tr>
<tr>
<td>I do not know it well enough to teach it</td>
<td>2.81</td>
<td>1.35</td>
</tr>
<tr>
<td>It is not important to my students</td>
<td>2.39</td>
<td>1.07</td>
</tr>
<tr>
<td>Not enough practical work can be done</td>
<td>3.44</td>
<td>0.92</td>
</tr>
<tr>
<td>I do not have time to fit in another topic</td>
<td>3.08</td>
<td>1.14</td>
</tr>
<tr>
<td>It is too controversial</td>
<td>1.83</td>
<td>0.74</td>
</tr>
<tr>
<td>The exam questions are too hard</td>
<td>2.93</td>
<td>1.21</td>
</tr>
<tr>
<td>The school has no program for it</td>
<td>3.05</td>
<td>1.16</td>
</tr>
<tr>
<td>The students find it too difficult</td>
<td>3.61</td>
<td>1.09</td>
</tr>
<tr>
<td>n=37</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The highest mean score (greatest agreement) is given for, "The students find it too difficult". Considerable agreement was also given to, "Not enough practical work can be done". The greatest disagreement was recorded for the reason, "It is too controversial". There is also very little agreement with the statements, "The students find it boring" and, "It is not important to my students".

4.3.3.2 "Biotechnology" in Science for Life

As only 3 teachers responded to this question, the data was not considered suitable for statistical analysis.

4.3.3.3 Biotechnology in Junior Science

As explained in section 4.1.3, the junior science topic of genetic engineering was chosen because this was seen as a central feature to an understanding of biotechnology. To ask separately about each biotechnology topic listed in section 2.1 would have been too cumbersome. Analysis of the data from question 10 confirms that genetic engineering was included wherever a unit of biotechnology was taught. Data on the reasons given for not teaching genetic engineering is shown as a mean of the score out of five for a sample of 21 teachers, in table 4.6 below.
Table 4.6 Reasons teachers choose not to teach genetic engineering in junior science

<table>
<thead>
<tr>
<th>Suggested Reasons</th>
<th>Mean score</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>There are not enough references</td>
<td>2.92</td>
<td>1.12</td>
</tr>
<tr>
<td>The students find it boring</td>
<td>2.38</td>
<td>1.01</td>
</tr>
<tr>
<td>I do not know it well enough to teach it</td>
<td>2.60</td>
<td>1.00</td>
</tr>
<tr>
<td>It is not important to my students</td>
<td>2.20</td>
<td>0.91</td>
</tr>
<tr>
<td>Not enough practical work can be done</td>
<td>3.56</td>
<td>1.16</td>
</tr>
<tr>
<td>I do not have time to fit in another topic</td>
<td>2.88</td>
<td>1.24</td>
</tr>
<tr>
<td>It is too controversial</td>
<td>1.67</td>
<td>0.76</td>
</tr>
<tr>
<td>The exam questions are too hard</td>
<td>2.46</td>
<td>0.93</td>
</tr>
<tr>
<td>The school does not have a program for it</td>
<td>3.61</td>
<td>1.03</td>
</tr>
<tr>
<td>The students find it too difficult</td>
<td>3.25</td>
<td>1.03</td>
</tr>
<tr>
<td>n=21</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A high score was again given to, "Not enough practical work can be done" and there was considerable agreement with the statement, "The students find it too difficult". As occurred when asked about "Genes in Action" the greatest disagreement is with the statement, "It is too controversial". The main area in which the figures for junior science differ from those for senior science are in the ratings for the reason, "The school has no program for it", which was much more highly scored as a reason for not teaching genetic engineering in junior science.

4.3.4 Experiences of biotechnology teaching

Those teachers who had taught a unit in biotechnology were asked about their experiences. This question (14) did not distinguish between those who had taught biotechnology in junior science from those who had taught biotechnology in senior science. An analysis of data from previous questions showed that the teachers who answered this question came from both groups.

Mean scores given by teachers about whether they agreed or disagreed with the suggested experiences are given in table 4.7 below.
### Table 4.7 Experiences of biotechnology teaching

<table>
<thead>
<tr>
<th>Suggested experience</th>
<th>Mean score</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>This is an important area of biology</td>
<td>4.32</td>
<td>0.85</td>
</tr>
<tr>
<td>Finding information was difficult</td>
<td>2.76</td>
<td>1.01</td>
</tr>
<tr>
<td>The students found it boring</td>
<td>2.16</td>
<td>0.9</td>
</tr>
<tr>
<td>I need to learn more about the topic</td>
<td>3.44</td>
<td>1.00</td>
</tr>
<tr>
<td>It is not relevant to the students lives</td>
<td>1.72</td>
<td>0.84</td>
</tr>
<tr>
<td>Not enough practical work can be done</td>
<td>3.44</td>
<td>0.87</td>
</tr>
<tr>
<td>Discussing controversial issues was hard</td>
<td>2.44</td>
<td>1.04</td>
</tr>
<tr>
<td>There were too many controversial issues</td>
<td>2.16</td>
<td>0.91</td>
</tr>
<tr>
<td>The exam questions are too hard</td>
<td>2.46</td>
<td>0.93</td>
</tr>
<tr>
<td>The school did not support this new area</td>
<td>2.24</td>
<td>0.83</td>
</tr>
<tr>
<td>The students found it very difficult</td>
<td>3.46</td>
<td>0.90</td>
</tr>
<tr>
<td>It was exciting the class loved it</td>
<td>3.72</td>
<td>0.68</td>
</tr>
<tr>
<td>n=21</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The teachers who had taught biotechnology recorded considerable agreement with the statements, "Not enough practical work can be done" and, "The students found it very difficult." They also agreed with the statement, "I need to learn more about the topic". The highest mean score recorded was with the statement, "This is an important area of biology". This result is consistent with the answers obtained from question 15, reported in the next section. A high level agreement was also recorded with the statement, "It was exciting the class loved it" and a corresponding low level of agreement with the suggestion that the students find it boring.

In order to directly compare the experiences of those teachers who had taught biotechnology with the expectations of the teachers who had not, scores for those statements that were repeated exactly in both questions 11, 12, 13 and 14 were compared. Two groups were compared, those respondents who had never taught biotechnology in either senior or junior science versus those who had experience in teaching a biotechnology unit. An independent samples t-test was carried out on the scores obtained from each group for the statement, "The students find it boring". There was no significant difference between the responses of these groups (t = -0.35, df=19, p= 0.72).
A similar comparison was carried out for the statement, "The students find it too difficult" and, "Not enough practical work can be done". The t values obtained were -0.32 and -1.01, which were not significant at 0.05. Therefore, in the sample of teachers surveyed, there was no significant difference between the experiences of those that did teach biotechnology and the expectations of those that chose not to teach biotechnology. This suggests that perceived, predicted difficulties related to teaching biotechnology are confirmed by its actual teaching.

4.3.5 Teacher interest in biotechnology

Respondents were asked to rate how much they agreed with a series of statements that were designed to reflect their interest in biotechnology and to what extent they considered biotechnology to be important. Question 15 on the survey contained the statements shown below in table 4.8, which lists the mean scores that teachers gave each statement. Where the statement was phrased in a negative fashion (rows 7 and 9 in table 4.8) the scores have been reversed so that a high score means a high level of interest in biotechnology.

Table 4.8 Teacher attitude to biotechnology

<table>
<thead>
<tr>
<th>Statement given</th>
<th>Mean score</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>I enjoy learning about biotechnology*</td>
<td>4.42</td>
<td>0.56</td>
</tr>
<tr>
<td>I would like to teach more biotechnology</td>
<td>4.26</td>
<td>0.61</td>
</tr>
<tr>
<td>I like to read about biotechnology*</td>
<td>4.09</td>
<td>0.77</td>
</tr>
<tr>
<td>The issues in biotechnology are interesting*</td>
<td>4.39</td>
<td>0.49</td>
</tr>
<tr>
<td>It is important we all know more about it</td>
<td>4.29</td>
<td>0.62</td>
</tr>
<tr>
<td>Biotechnology can improve our quality of life</td>
<td>4.14</td>
<td>0.78</td>
</tr>
<tr>
<td>Biotechnology is a destructive social element</td>
<td>3.88</td>
<td>0.75</td>
</tr>
<tr>
<td>I like to watch TV shows about biotechnology*</td>
<td>4.14</td>
<td>0.74</td>
</tr>
<tr>
<td>I am not interested in biotechnology at all*</td>
<td>4.62</td>
<td>0.52</td>
</tr>
</tbody>
</table>

These results show that among the sample of teachers who answered this survey there is very little disagreement with the idea that biotechnology is both important and interesting. The data from the statements marked with an asterisk were combined to make a scale of 'interest' and the data from the unmarked statements were combined to
give a scale of 'importance'. The internal reliability of these items for use in such a scale was assessed using Kronbach's alpha. For the items in the interest scale, alpha = 0.838 (n=55), and for items in the importance scale, alpha = 0.664 (n=57). Both of these alpha values were considered sufficient for the items to be aggregated into sub-scales.

Having obtained a scale of 'interest' and a scale of 'importance', questions could then be asked about how these variables related to other variables in the survey.

4.3.5.1 'Interest and 'importance' related to amount of biotechnology taught

The hypothesis was proposed that the teachers interest in biotechnology affects the amount of biotechnology that they teach (section 3.1). A Pearson's correlation between the interest scale and the total number of hours of biotechnology taught yielded a correlation coefficient of 0.255 (n=59) which corresponds to a significance of 0.05. This is on the borderline of what is conventionally regarded as statistically significant. It can be stated that there is a correlation between the teacher's interest in biotechnology and the amount of biotechnology taught. However, this finding needs to be supported by data from a larger sample of teachers.

When the interest scale was compared with the number of hours of biotechnology taught in junior science the correlation coefficient obtained was 0.227 (p=0.083). While no significant correlation was found, probabilities of 0.05-0.08 suggest further study of relationships between a teacher's interest in biotechnology and the hours of biotechnology taught might be worthwhile. However, the results of the present survey do not support the hypothesis that the amount of biotechnology taught in junior science is related to the interest that the teacher has in the subject.

Similar analyses were carried out for the importance scale versus the total hours of biotechnology (r=0.18, p=0.18), and the importance scale versus the hours of junior biotechnology taught (r=0.11, p= 0.39). In both cases there was no significant correlation between the amount of biotechnology taught and the degree of importance teachers gave to biotechnology.

4.3.5.2 'Interest' and 'importance' versus teacher experience

Another hypothesis proposed in section 3.1, "that more experienced teachers will have less interest in biotechnology", was tested using the data in this survey. This hypothesis is based on the expectation that more experienced teachers will be older and therefore less likely to have studied biotechnology as part of their university studies. A Pearson's correlation between the interest scale and years of experience as a teacher did not support
the hypothesis that these two variables are related \( r = -0.145, \ n = 59, \ p = 0.273 \). Similarly, no significant correlation is obtained when interest is compared to the number of years of experience in teaching biology \( r = 0.087 \). Comparing years of teaching experience to the importance teachers give to biotechnology also fails to show any significant correlation \( r = 0.083 \). Therefore the data obtained in this survey do not support the hypothesis that there is a correlation between the teacher’s experience and their level of interest in biotechnology.

The hypothesis “that there is a relationship between extra training in biotechnology and the amount of interest the teacher has in this subject” (see section 3.1) was tested using the data from the survey. In an independent t-test between the groups of those with extra training (in work or study) versus those without, the t value obtained at 57 degrees of freedom was 0.58, \( p = 0.56 \). Therefore, the data in this study do not support the hypothesis that extra training in biotechnology means that the teacher will show greater interest in the topic. Similar results were obtained when the importance scale was used in place of the interest scale.

4.3.5.3 Interest and importance versus gender
The hypothesis that the gender of the respondent affects the amount of interest that they have in biotechnology was tested \( t = -0.05, \ df = 55, \ p = 0.96 \). This hypothesis was not to be supported by the data in this survey. Both male and female teachers indicate the same high level of interest in biotechnology.

4.4 Summary of survey results
The results of the survey show that:

- 12.5% of students of 2U Biology study “Genes in Action” and the average number of hours of biotechnology taught per year as part of junior science is 3.7;
- the number of hours of biotechnology taught is not related to the teachers years of experience in teaching or to the major subject of their university degree;
- many teachers do not teach “Genes in Action” because they do not have the knowledge and experience adequate to the task;
- teachers of junior and senior science rate the statements, “The students find it too difficult” and “Not enough practical work can be done” most highly as the reasons they choose not to teach biotechnology;
- teachers of junior science show a high level of agreement with the reason, “The school has no program for it”;

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• teachers do not agree with the statement, "The students find it boring" and "It is too controversial";
• teachers who have taught biotechnology agree with the statements "the students find it difficult" and "not enough practical work can be done";
• teachers consider biotechnology to be interesting and important;
• teachers who consider biotechnology to be interesting and important do not teach a greater number of hours of biotechnology.

4.5 Discussion of research aims 1 and 2; mapping the terrain and determining whether teachers do not teach biotechnology because they do not have the knowledge and experience adequate to the task

4.5.1 Aspects of the terrain
This survey confirms that only a small proportion of teachers who take senior biology choose to teach the biotechnology electives. Most teachers who responded to the survey included several lessons on a biotechnology related topic in their junior science program, but only a very small number of teachers covered a range of biotechnology subtopics and could therefore be said to have taught a unit of biotechnology. The average number of hours spent on biotechnology in junior science in a school year was 3.7. If a school allocates a junior topic six weeks of a term for five periods a week the number of hours spent on the topic would be twenty (assuming a period length of forty minutes). Using these figures as a comparison, it can be estimated that the time spent on biotechnology is very low compared to the time spent on many other topics in junior science. Comments made on question 8 in the survey suggest that teachers often added one or two lessons on either genetic engineering or IVF technology to the topic of reproduction, and that this accounted for most of the biotechnology taught in junior science.

The low number of hours taught by this sample are not due to a lack of interest in biotechnology as a topic, or to a feeling that it is not an important part of the curriculum. Although teachers are interested in biotechnology, the obstacles to teaching it are sufficiently great that most teachers do not teach the topic. The implication of this finding is that providing more awareness of the importance of biotechnology will not be a way of stimulating teachers to teach more of this subject unless other barriers are also overcome.

One such barrier, the lack of teacher knowledge, is discussed below. Other problems that were identified in the survey will be dealt with in more detail in chapters 5 and 6.

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4.5.2 That teachers do not teach biotechnology because they do not have the knowledge and experience to adequately carry out the task

Results from the present sample show that a background in biology did not predispose teachers to teach more biotechnology. Although this survey was originally intended for all science teachers, the sample that replied to the survey was dominated by biology teachers. This may have been because the survey was preferentially given to biology teachers by the school principal or head science teacher. It may also have been because biology teachers were more interested in the subject matter and therefore more willing to take the trouble to return the survey. The effect of teacher background may have been different if a larger number of non-biology teachers had replied to the survey. That is, teachers with a major in physics or chemistry may have been found to teach even less biotechnology. What can be said is that this sample preferentially contained those teachers who are most qualified to teach biotechnology and yet very few hours of biotechnology were taught by these respondents.

The sample of respondents to this survey also contained a greater number of experienced teachers and relatively few inexperienced teachers. The statistical analysis showed that there was no relationship between years of teaching experience and amount of biotechnology taught for this sample of teachers. However, inexperienced teachers may be a special case in two respects. Firstly, they might have less confidence as teachers and therefore be less likely to teach a topic which is regarded as difficult by their peers. Secondly, they are more likely to have studied biotechnology at university, as this subject is a recent addition to university courses. In this survey, no valid data was obtained as to whether an inexperienced teacher would be less or more likely to teach biotechnology. Had the sample contained more teachers with between five and ten years of teaching experience, data on the effect of recent university study on the teaching of biotechnology could have been gathered.

One reason for the speculation that recent university study may affect the amount of biotechnology taught, is that those respondents who had greater experience in biotechnology, either as work or as study, taught a larger number of hours of biotechnology. The data shows that the greatest increase in biotechnology taught was at the senior level. That is, teachers with experience in biotechnology were more likely to choose to teach a HSC elective in this area. However, greater experience in biotechnology did not affect the number of hours of junior science taught. As those teachers who were experienced in biotechnology were willing to undertake a unit of senior biology, but did not teach a unit of biotechnology at junior school level, it can be
deduced that factors other than the level of teacher education was determining how much biotechnology was taught in junior science.

Beetlestone and Teasdale (1984) (cited in McInerney, 1990, p.244) reported that many teachers were aware of the economic importance of biotechnology but few had the training to pass this awareness on to their pupils. This would appear to be as evident now in NSW as it was then in the UK, for the teaching of biotechnology at senior secondary school level. The present survey found that all teachers were aware of the importance of biotechnology, but those with extra experience were more likely to teach a unit of biotechnology. As more biotechnology is offered in university science courses the number of teachers with education in biotechnology should slowly increase, but it may be many years before this “extra experience” influences the teaching of biotechnology to a majority of NSW students. One way to increase the amount of senior level biotechnology taught in schools may be to offer in-service programs and special training courses in biotechnology to teachers already in the education system. This approach has been taken in the US and the UK where institutions like The National Centre for Biotechnology and The Biological Sciences Curriculum Study have devised programs to help teachers keep their knowledge up to date with research in biotechnology (White, 1991).

Main findings from the survey
The main findings of the survey are:
1. Few students study biotechnology in senior science.
2. In junior science little time is spent on the teaching of biotechnology.
3. Teachers do not teach biotechnology because:
   - they lack the knowledge and experience of the subject matter to do so;
   - it is perceived to be difficult for the students;
   - they consider that there is insufficient practical work in biotechnology;
   - programs are not available in junior science.
4. Teachers consider biotechnology to be interesting and important.

The reasons teachers choose not to teach biotechnology were the subject of further investigation. Interviews with 12 teachers that relate to the findings of the survey in this area are described in chapter 5. At the end of chapter 5, seven assertions based on the findings of the interviews and the survey are made. An evidentiary warrant for four of these assertions is presented in chapter 6.
Chapter 5

Investigation of the reasons teachers choose not to teach biotechnology

The findings of the survey indicated that teachers chose not to teach biotechnology because it was too difficult for the students and because not enough practical work could be done (for summary see section 4.4). As stated in section 3.1, the scope of the survey questions had to be limited and therefore these findings warranted further investigation. At the same time as the survey was conducted, a number of interviews, taking the form of in-situ discussions with teachers, were carried out. These provided a source of data about why teachers chose not to teach biotechnology. The method of conducting these interviews and the sample of teachers involved are described in section 5.1. A discussion of these interviews and of associated sections of the survey (presented in section 4.3.3) is included in section 5.2. The chapter concludes with a statement of empirical assertions that are derived from the research reported in chapters 4 and 5, and these inform the design of the case study research reported in chapter 6.

5.1 Method
In December 1996, the CSIRO Education Centre hosted a series of workshops entitled “Gene Technology in Action”. Each school attended a half day session, and fifteen sessions were taken up. The researcher attended nine of these workshops, with the intention of locating teachers who were teaching biotechnology, and who would be willing to participate in further research on this topic. (This was to supplement attempts to locate relevant teachers through the survey, and by advertisement in an academic journal). The workshops were also used as an opportunity to identify aspects of the teaching of biotechnology that were of importance to teachers in NSW. During those parts of the workshop where students were occupied with activities, the teachers were engaged in discussion about the teaching of biotechnology. The course of these discussions (interviews) was determined by the individual experience of the teachers. Those teachers who were teaching biotechnology spoke about their experiences of this topic. Teachers who were not teaching biotechnology discussed their reasons for attending the workshop and their thoughts on the teaching of biotechnology. These discussions took place very early in the research, and were deliberately made wide ranging, in order to identify themes important to the teachers. The teachers were not selected in any way other than by their presence at the workshop. Field notes were taken from these discussions.
The eleven teachers who participated in these discussions included Connie and John who were from a private school in the central west of Sydney; Julie from a country school; Anne and Don from a selective school; Malcolm, Katrina and Graham from comprehensive government schools; and Sue, who taught at a Sydney TAFE college. The reasons for attending the workshop varied and included "to stimulate interest" (Anne and Don) "to broaden their horizons" (Julie) and to "give them a taste of year 12 work" (Connie and John).

Nine of the teachers had already decided not to teach biotechnology at the time of the workshop. Two of the teachers, Katrina and Sue, intended to teach biotechnology during 1997 and agreed to participate in a case study. The reasons why these teachers subsequently decided not to teach biotechnology were reported in field notes made during follow-up phone conversations.

At the beginning of the workshops all teachers were given a letter explaining the nature of the research. All participation in the research was voluntary and it was explained that the participants could withdraw from the study at any time. The names of all the teachers and schools have been changed in this report.

Another teacher, Paul, was interviewed at Drayton High School. He had been approached as a possible participant in a trial of a unit of biotechnology for year 10 students. Field notes were taken from a discussion where this teacher was asked why he decided not to teach biotechnology.

5.2 Reasons for not teaching biotechnology
Three of the reasons for not teaching biotechnology that were highlighted in the survey were also identified as important by the teachers interviewed. The first of these was the assessment made by the teachers that the subject matter was too difficult for the students to understand. The second was their concern over the lack of resources available for the teaching of biotechnology. The third was the lack of a program for biotechnology. The data from the survey and the interviews that pertains to each of these themes is discussed in section 5.2.

5.2.1 Student understanding of the subject matter of biotechnology

5.2.1.1 Student understanding of the subject matter – senior science
Analysis of the survey (section 4.3.3) showed that teachers with greater experience in biotechnology taught a larger number of hours of biotechnology, as HSC subjects. However, the teachers surveyed did not rate lack of knowledge highly as a reason for
not teaching senior biotechnology. If a lack of training was a problem preventing teachers from choosing biotechnology electives, many teachers either did not recognise this problem or they did not regard it as a problem in their particular circumstances. The teachers surveyed gave the highest rating to the problem, "The students find it too difficult". The prominence of this reason for not choosing the biotechnology electives was supported by the comments added to question 11, many of which stated the view that the "Genes in Action" elective is too difficult for the students. This view that “Genes in Action" is too difficult for the students was subsequently endorsed by the teachers interviewed. At least two of the teachers (Julie and Connie) had majors in a subject related to genetics and they felt very confident that they could teach the “Genes in Action" elective. They had never taught the elective because they considered it too hard for the students. They pointed out that other electives are easier for students, and, as teachers, they had a responsibility to their students to help them get the highest possible mark in the HSC exam.

A comment which encapsulates the views of these teachers about "Genes in Action " was:

Most classes have students with a mix of abilities. About the top third of the higher classes would enjoy and do this topic well, however the lower 2/3 would find it difficult and would be better advantaged by taking a simpler elective. I strongly feel that middle to lower ability students would comprehend and enjoy other electives more and consequently achieve better results. These are usually the students that have some difficulty with the genetics core. (Comment appended to a survey)

This comment raises a number of issues regarding teachers’ views:

1. All 2 unit biology teachers have already taught a genetics 'core' topic by the time they choose the electives. Therefore, they have had some feedback on what their students do and do not understand.
2. The teachers choose the subjects that they think will allow as many of their students as possible the best chance of a high mark in the exam. Not only is ‘Genes in Action’ difficult, but other electives are easier and teachers think their students will score higher marks in the HSC exam if they choose these other electives.
3. Difficulty is linked to enjoyment. If the students find the elective difficult they will not enjoy it.

These issues are considered further (see below) with reference to the interview data.

Difficulty with the subject matter in biotechnology was also a problem for the two teachers who had decided to teach an elective in biotechnology but had then changed their minds. Katrina was from a Western Sydney comprehensive school and the year 12
Science for Life class that she had brought to the workshop had already done the module on biotechnology. She stated that the class had found it difficult but they had enjoyed it. At that time she intended to do the module again the following year with a new class. However, by the time the new school year began she had decided that that module was too hard for the students and she would not teach it. Her comments were similar to others heard during the course of this research, in reference to the Science for Life module on biotechnology. That is, the students enjoy this topic but they do not answer the questions in the exam (students are required to answer questions on just 3 out of the 13 modules). Those teachers who answered the survey question about Science for Life also agreed that the exam question on biotechnology was too hard for the students.

Sue was teaching a unit on biotechnology that had recently been introduced by the NSW TAFE. She had more resources than the school teachers and her mature age students were all very motivated to work hard and gain a place at university. The class she brought to the workshop asked very probing questions and worked very diligently at the experiment. Sue was enthusiastic about the course, which she was teaching for the first time that year. The content in the TAFE course covered a similar broad range of biotechnology to that encompassed in the Science for Life syllabus, but involved a greater depth of treatment. Unlike the HSC students, the TAFE students were assessed on a portfolio of written work that involved research on aspects of biotechnology. One problem the students had encountered was that they had to spend a lot of time finding information for these reports and the information available was very difficult to read. Sue had found that the biotechnology students had to put in a lot of work for relatively low marks compared to the marks for their other science topics. Other options were available and Sue recommended to students starting in 1997 that they choose these options instead of the biotechnology course.

The experience of Sue and Katrina indicated that for some students the biotechnology they were studying was both difficult and enjoyable. This experience was different to that reported by many teachers who responded to the survey, these teachers reporting that the difficulty of the topic reduced the students enjoyment. Thus, some teachers see the difficulty of biotechnology causing a lack of interest and enjoyment. Others see these as separate issues, opining that biotechnology is both difficult and enjoyable.

Three different biotechnology units, Science for Life, Genes in Action and TAFE Biotechnology, were considered by the teachers interviewed for this study, and each unit was rejected as too difficult. One common feature between these units is that they were all being undertaken by students vying for university entrance and in all cases a prime motivation for the teacher was to maximise the number of marks the students
achieved. The teachers concluded that the best way to do this was to avoid biotechnology. The problem with biotechnology may not be that it is too hard, it is just harder than other electives offered in biology.

The results of this study are consistent with a conclusion that many teachers chose not to teach biotechnology because they considered:

1. the subject matter too difficult for students to comprehend;
2. the exam questions in biotechnology more difficult to secure high marks in than other options.

However, individual teachers expressed other reasons for choosing not to teach biotechnology. Two teachers from a selective school (Anne and Don) stated at the workshop interview that they would not hesitate to teach "Genes in Action" but the head teacher had decreed that another elective would be taught. Malcolm, an older male teacher from a western suburbs comprehensive school, gave the response that he did not think gene technology rated more than a couple of lessons and that he had always preferred the elective "Control and Co-ordination".

5.2.1.2 Student understanding of the subject matter—junior science

Teachers who participated in the survey indicated that genetic engineering is too difficult for students in junior science (section 4.3.4). Three of the teachers interviewed in the workshop (Connie, Julie and John) supported the survey data, agreeing that biotechnology is too difficult for junior science students. John mentioned that “the younger students are afraid of it; they just think it will be hard without knowing anything about it”. Only one teacher thought that biotechnology could be taught to year ten, a teacher from a selective school. This rejection of biotechnology as a topic for year ten, based on student capabilities, was also observed in the school where a case study of a unit of biotechnology for year ten was eventually conducted. The teacher in the case study (see chapter 6) re-organised her allocation of classes so that she would have one of the ‘top’ year ten classes. A teacher at the same school, Paul, showed interest in trying the unit but he was adamant that his lower ability class would never be able to handle the topic.

Unlike the senior science subjects, where the syllabus was specified for the teacher and the difficulty of the exam questions determined the degree of difficulty of the subject, the teachers of junior science were able to influence the degree of difficulty of a biotechnology unit. Teachers could design their own (easier) unit of biotechnology. Yet, none of the teachers interviewed (even those who had done a unit in senior science) were teaching a significant amount of biotechnology to junior students. Why were
teachers of the opinion that biotechnology is too difficult for the students? One reason may be that they considered biotechnology to be intrinsically more difficult than other junior science topics. It has been reported that teachers consider genetics to be one of the most difficult subjects in biology (Venville, 1996). A difficulty with biotechnology may be that it requires a knowledge of genetics. However, if a difficulty with genetics explains why teachers do not teach biotechnology, one might wonder about the prevalence of genetics in the junior science curriculum.

Is it the case that teachers themselves have not carefully analysed why they think that biotechnology is difficult? The respondents to the survey may have used “difficulty” as a convenient explanation when the real reasons are more complex. This is easy to do, as the survey offers a series of prepared statements including, “It is too difficult for the students”. The tendency to select this convenient explanation may have been more pronounced because the question was directed to the sub-topic of genetic engineering, which requires more understanding of genetics than other areas of biotechnology. A comment included in one survey may represent the position of many teachers of junior science. The respondent stated, “It quite honestly has not occurred to me to teach it, although I have a strong interest in genetics and a substantial part of my undergraduate degree involved genetics.”

The impression that, “it had not occurred to (them) to teach it” was also gained during the interviews with teachers. When asked about the possibility of teaching biotechnology to year 10, three teachers expressed the opinion that it was too difficult, but they seemed surprised to have to consider the question. It is possible that difficulty was the first explanation to come to mind, especially as this reason had already been discussed in the context of senior science.

For the researcher trying to find ways to improve biotechnology teaching, the question of whether biotechnology is intrinsically too difficult for secondary school students is an important one. Further investigation of this question was conducted, through the case study reported in chapter 6.

5.2.2 The lack of resource materials
McInerny (1990) reported that both lack of practicals and lack of written resources was a problem in biotechnology teaching and that the extent of the problem varied between countries. The problem with reference material was not highlighted by respondents to the NSW survey although one comment was made that "readability level of reference material is often difficult for some students". Most teachers found the lack of references
much less of a hindrance to the teaching of biotechnology than the lack of practical work.

Both respondents who had taught biotechnology and those who had not, agreed with the survey statement that not enough practical work is available. However this problem was not mentioned in the interviews at the CSIRO workshop. Neither Sue nor Katrina mentioned the lack of practicals as a reason for not continuing to teach biotechnology. For Sue, lack of written resources was more of a hindrance in that the students were having to spend a lot of time finding the information they needed to write the essay assignments for the portfolio on which they were assessed.

One explanation for the difference between the survey and the interviews, is that in the survey the respondent was put into a position of having to make a judgement about practical work because the statement was offered. The interviews did not include a specific question about practical work. Therefore this explanation would only have been discussed if the teacher chose to mention it. In this way the survey can distort the importance of the reasons offered to the respondents as to why they do not teach biotechnology.

As the syllabus for “Genes in Action” does not specify any practical experiences, unlike other programs in the biology syllabus, there has been little incentive for the development of appropriate practicals for this elective. If it is not required by the syllabus, why do the teachers say that not enough practical work is available? There are a number of possible answers to this question. The desire for practical work may arise from a wish to demonstrate abstract concepts using practical examples, or it may arise from the need to provide interesting activities. Or it may be that teachers of science are trained to believe that all topics should include appropriate practical activities so that scientific skills and method will be reinforced. While the survey records the fact that teachers agree that there is not enough practical work to be done, more research is needed to find out why teachers feel this way and what they see as the reason for this practical work. Further investigation of the teachers view of the role of practical work in biotechnology is reported in chapter 6.

5.2.3 The school program
The reasons teachers chose not to teach biotechnology to senior students (that is, it is too difficult and there is not enough practical work) were also given as reasons biotechnology is not taught to junior students. However, another reason emerged from the survey as to why teachers do not teach biotechnology as a junior science unit. This was the lack of a program in the school. There are a number of reasons why the lack of
a school program for biotechnology may prevent teachers from undertaking this subject. For some teachers, the lack of a program might mean that biotechnology does not have to be taught and therefore they will not teach it. To write a program would require time, and possibly knowledge, that they do not have and therefore biotechnology is not included among the school's junior science programs. The type of problems teachers might face in setting up a program for biotechnology were summed up by one respondent as a series of points:

- "no real prac work can be done and funded by the department;
- genetic engineering competes with a growing list of relevant issues;
- plus a compulsory 40% science process skills;
- plus existing science content;
- plus reduction in the number of science hours taught;
- general lack of interest in the rigorous work of science".

Beneath the agreement with the statement "The school has no program for it" lies a complex set of factors which inhibit the teaching of biotechnology. These factors are investigated in chapter 6.

5.2.4 Teaching methods and controversial issues
McInerny (1990) suggests that one problem with teaching biotechnology for those teachers who are used to traditional teaching methods, is the difficulty of knowing how to deal with the controversial issues. In this survey, the suggestion that teaching the controversial issues was difficult was consistently disagreed with by teachers. They neither considered the controversial issues to be a reason for choosing not to teach biotechnology nor did they find them a problem during the teaching of this topic. However, only a small proportion of respondents had taught a significant amount of biotechnology and most of these had taught "Genes in Action", the syllabus of which contains only a short section on ethical issues. The question could be asked "Are these teachers able to know that teaching about ethical issues would not be a problem?". Given the importance of ethical issues as a justification for teaching biotechnology (section 2.2) it was considered important to investigate further the teaching of controversial issues. This investigation is described in chapter 6.

5.3 Assertions based on the findings from the survey and the interviews
Erickson (1986, p.146) states that one basic task of the data collected in research is to generate assertions and to establish an "evidentiary warrant" for these assertions.
From the findings of the survey and interviews conducted so far, some assertions can be made about the teaching of biotechnology in NSW. These are that:

1. many teachers do not have the knowledge and experience to adequately teach the subject;
2. teachers consider biotechnology to be interesting and important;
3. the problem associated with the teaching of controversial issues, that had been postulated by McInerney (1990), is not an obstacle to the teaching of biotechnology;
4. the subject matter of biotechnology is more difficult than that of other elective subjects;
5. the subject matter of biotechnology is too difficult for the students;
6. not enough practical work is available;
7. the lack of a program for biotechnology prevents teachers from teaching this subject as part of junior science.

The assertions that were considered to require more investigation in order to obtain this “evidentiary warrant”, and which could be addressed by case studies of the teaching of unit of biotechnology, were that:

1. teaching about controversial issues was not an obstacle to the teaching of biotechnology;
2. the subject matter of biotechnology is too difficult for the students;
3. not enough practical work is available;
4. the lack of a program prevents teachers from teaching biotechnology as part of junior science.

The design, method and results of three case studies that were conducted to investigate these assertions are described in chapter 6.
Chapter 6

The experiences of teachers who taught biotechnology

One way to find out more about the problems faced by teachers when they undertake a unit of biotechnology, and ultimately to suggest ways to overcome these barriers, is to observe the teachers who are teaching the topic. This reveals what these teachers find to be the problems, and their strategies for dealing with these obstacles. These strategies and insights can then be used to formulate recommendations about ways to approach a unit of biotechnology. Such an approach was used in this research.

The survey and interviews provided evidence about the teachers experiences with biotechnology. However a limitation of this approach was that it was restricted to the perceptions of the teacher. To get richer data about the teaching of biotechnology, three case studies were conducted in the natural setting of the school. The assertions listed at the end of chapter 5, that:
1. teaching about controversial issues was not an obstacle to the teaching of biotechnology;
2. the subject matter of biotechnology is too difficult for the students;
3. not enough practical work is available;
4. the lack of a program prevents teachers from teaching biotechnology as part of junior science;
were the foci of these case studies.

These case studies allowed a broader range of experience to be documented. For example, by making observations in the classroom it was possible to find out whether the subject matter of biotechnology was too difficult when evaluated by the teacher, by the students and by a class test. Chapter 6 details the case study research that was done in three schools and discusses the findings of this research. Material from an interview with a teacher who had recently completed a unit of biotechnology is also included. Findings from the survey about teachers experiences of biotechnology (see section 4.3.3) are also discussed in chapter 6. Section 6.1 describes the design and method of the case study research in schools, section 6.2 gives the background to the case studies and section 6.3 reports the evidence from the case studies that is relevant to the assertions made in section 5.3.
6.1 Case study design and method

Merriam (1988, p.xiv) defines a qualitative case study as "an intensive holistic description and analysis of a bounded phenomenon such as a program, an institution, a person, a process or a social unit." The case studies conducted in this research provide an intensive holistic description of the teaching of a unit of biotechnology as it was conducted in a natural setting (the school classroom). One feature of a qualitative case study is that it relies heavily on the "human as instrument" (Tesch, 1990, p.44). This means that the researcher needs to be trained to systematically collect data in the field (Cornett, 1995) and that novice researchers need to reflect on the pitfalls that they may encounter in their attempts to observe the complex interactions that commonly occur in a natural setting (Roberts and McGinty, 1995). This researcher cannot claim to have been systematically trained in the methods of data collection. To counter this problem, every attempt has been made to support observations of the researcher with the words of the teacher, or the students or with material from documents collected during the study.

In order to continue to present the "natural history of the research", as recommended by Erickson (1986), the events leading up to the case studies and the trial of the biotechnology unit designed for this research, are described in detail in section 6.1.

6.1.1 Selection of participants

Three case studies of the teaching of a biotechnology unit were conducted. Rob from Rivervale was teaching the "Genes in Action" elective to a year 12 class. Rob and his class attended the CSIRO workshop on "Gene Technology in Action". An initial interview was conducted at this workshop and Rob agreed to participate in a case study. Michael from Cleland High School, a comprehensive school in a middle class area of Sydney, agreed to participate in a case study after a phone conversation about biotechnology where he mentioned that he was about to start teaching "Genes in Action" to his year 12 class. Both of these teachers were intending to teach the unit of biotechnology regardless of the involvement of a researcher.

The selection of cases illustrated some of the problems that can be encountered when doing research in the natural setting. At the end of the first year of investigation, Rob, Sue, Alan and Katrina had agreed to participate in case studies as they taught units encompassing "Genes in Action", the "Biotechnology" module of Science for Life and a TAFE Tertiary Preparation Course in Biotechnology. As reported in section 5.2.1, Sue and Katrina decided not to teach biotechnology because it was too difficult for the students. Alan was unable to teach the "Biotechnology" module because he was subsequently assigned to a different class. These changes in the teachers' plans meant that a lot of time was wasted and other case studies could not be organised to fill the
gaps, as it was difficult to find schools that were teaching biotechnology. Consequently it was not possible to conduct a case study illustrating a Science for Life module on biotechnology within the time frame of this study and data about the teaching of biotechnology in Science for Life had to be obtained by other means.

Data on the teaching of biotechnology in Science for Life were obtained from Alan by a detailed interview that was recorded on audio tape and transcribed. Alan spoke about his experience in teaching biotechnology to a class of year 11 students at a comprehensive high school in the western suburbs of Sydney.

The third case study was different from the others in that the implementation of the unit came about as a direct result of a request by the researcher. The teacher, Verity, was offered a unit of work prepared by the researcher and asked to decide whether she thought it would be suitable for a year ten class. Verity showed great interest in conducting the work on biotechnology and she convinced her department to allow her to teach this topic. However, the department decided that this subject had to be squeezed in between the other topics that the school had set down for year ten. This meant that Verity could only spare two weeks for the biotechnology course. As the unit first offered required at least four weeks of sequential study, the final unit of biotechnology undertaken was significantly adapted by Verity. The teaching of this adapted unit became the final case study.

6.1.2 Informing participants
Teachers who had agreed to participate in the study were given a letter explaining the research. A similar letter was given to the school principal and the permission of the principal was obtained before any work commenced. The teacher and principal were also given a copy of the permission from the Department of School Education to conduct the research. These letters stated that the names of all schools and participants in the study would remain confidential and that participants were free to withdraw at any time. Each letter also included a paragraph inserted by the Ethics Committee of the University of Western Sydney, giving a contact number should any problem arise.

6.1.3 Data collection
The methods traditionally used to collect data during a case study include interviews, the collection of documents and artefacts, and observation (Merriam, 1989). Each of these methods were used in the 3 case studies of the teaching of biotechnology that are reported here. Before each unit of biotechnology commenced the teacher was interviewed. Teachers were asked about their background in biotechnology, about their opinion of biotechnology as a subject and about their expectations of the unit they were
about to undertake. These interviews were recorded as field notes in the case of Rob and Michael. The interview with Verity was recorded on audio tape.

At the commencement of the unit the teacher introduced the researcher to the class and explained that she would be sitting in on the lessons. The class was also given a letter to take home that explained the nature of the research. This letter also included a permission note so that parents could agree to the researcher interviewing their children about what they thought about biotechnology.

All of the handouts that the teachers gave to the class were collected and kept with the relevant field notes. In the case of the year 10 study some of the students work, eg concept maps, was also collected.

6.1.3.1 Method of observation
The lessons in the biotechnology unit were observed by the researcher. In qualitative research an observer can be participant, "where the observer engages in the activity he sets out to observe" or non-participant where he "stands aloof from the group activities" (Cohen and Manion, 1989, p.125). At the beginning of this study a role as non-participant had been planned but again the realities of the natural setting shaped the design. The teachers who participated in the study had formed an opinion of the researcher as an informed person on the subject of biotechnology. In all three cases, they referred questions to the researcher that they found difficult and asked for reassurance about some facts in dispute. This altered the perception of the class in turn. For example, in one study period, a student called out to the "very smart genetics lady" to answer a question. In the case of the year ten class where the unit had been partly the design of the researcher, this position of participant in the class as independent expert became even more apparent. During this unit the researcher was requested to explain an entire practical on DNA extraction. As refusing to answer these questions seemed rude and unhelpful, the position of the observer gradually changed, becoming more involved in the class as the units progressed.

6.1.3.2 Record keeping
Observations were recorded as field notes. An attempt was made to record events in each lesson without imposing any categories. The teachers words and actions were noted, student questions were recorded and notes were made of student conversations that were relevant to the topic at hand. The mood and behaviour of the class were noted. When reflections on the material being recorded were made these were noted in the margins for future analysis. When an idea for a synthesis of the data occurred, it was discussed with the teacher at the end of the lesson and the teacher's views were
recorded. Teachers were given the option of reading these notes but they declined to do so. Where time permitted, each lesson was discussed with the teacher at the end of the period.

6.1.3.3 Student opinion
The method of data collection from the students was different in each case. This was due to the different circumstances prevailing in each school. Each teacher had control over the way in which researcher and students could interact. Rob had time to take students out of class for a separate interview. Michael did not have time to spare from the lessons as his students were very busy. Michael suggested the use of a short survey to be completed during study time as the best method for obtaining the opinion of the students in his class. Classroom organisation also had considerable impact on the method used to obtain student feedback. Both of the senior classes were seated in rows and there was only limited communication between rows. At Drayton the students were seated in groups and most of the work was carried out in groups. Therefore, at Drayton student opinion could be obtained during group discussion.

At Rivervale, three students from the class were interviewed as a group. These students were selected by the teacher as representing a “high”, “middle” and “low” ability group. The students were interviewed in a quiet room in the school library. The interview was taped and transcribed. The group interview format enabled discussion among the students, which opened up topics for discussion that had not been instigated by the researcher. However, the presence of the high ability student may have inhibited the responses of the low ability student, who remained quiet throughout most of the discussion.

A short survey was completed by the students at Cleland during the last lesson of the elective. The questions and the results of this survey are shown in table 6.1. Two students at this school (Tanya and Debbie) were interested in genetics at university and these students often discussed their impressions of biotechnology with the observer either during or at the end of the lesson. Notes were taken from these informal discussions.

During the lessons at Drayton, the content of group discussion between students was recorded as field notes, and in some cases as audio tape. Care was taken to sit with different groups at each lesson. Students had been warned that recordings would be made of the group activities and were always asked for permission to use their words. Because the group work had been recorded and the result of the group work was often available in written form, students at Drayton were not interviewed in a separate session.
One limitation of this method of data collection was that the dynamics of group interaction may have been altered by the presence of the observer.

6.1.4 The researcher
In his report of a study of a fundamentalist christian school in the USA, Peshkin (1986, p.17) writes "as I increasingly come under conviction (an expression I owe to this study) about the relationship between who I am, what I see, and what I conclude about what I see, I feel increasingly inclined to reveal enough about myself so that readers can make their own judgements about what I saw, what I missed and what I misconstrued." This need to describe the personal agenda behind a study was dramatically illustrated by Wolcott (1990) from his own personal experiences. As the present study progressed it became clear that the background of this researcher influenced the emphasis placed on some events in the classroom. These classrooms were being observed by a person with many years of experience in scientific research and only a few years of experience in teaching. This may have led to a different emphasis being placed on the data from that which would have been given by a researcher whose greater experience was in teaching. Therefore the reader of this study should be aware that the assumptions derived from many years commitment to a scientific career may still be influencing the recording and analysis of the data presented.

6.1.5 Validity
In qualitative research the term validity is out of fashion and yet those who undertake such research must have ways of justifying the value of what they do. Wolcott (1990) lists ways of "getting it right", Lincoln and Guba (1985) list ways of establishing "trustworthiness". Both of these authors stress the importance of using the words of the participants in the study and allowing the reader to come to their own conclusions. This report has used this approach. The words of the participants were used throughout. In order to facilitate this approach, each case study was written up as a separate report then the three reports were compared. These complete case studies are not reproduced in full but may be provided if requested.

Trustworthiness is also established through the process of member checking (Merriam, 1988). In this study the case report was given to the teacher involved so that they could express any doubts about the interpretation. The teachers were surprised to read about themselves from a different perspective and in some instances they pointed out that too much had been made of one incident in the effort to illustrate a point. For example, Rob had used an example about insulin where his ethical stance differed from that of the prepared answer given by the examiners of the HSC. This example was highlighted in the report as an instance where the free discussion of ethical issues was overshadowed
by the presence of the exam. Rob felt that the selection of this example gave the wrong impression of his approach to ethical issues. Where such comments were made the report was altered to take into account the teacher's opinion.

Another method of ensuring that a case study is trustworthy is to use data triangulation, described by Hitchcock and Hughes (1995) as the collection of data over a period of time from more than one location and from more than one person. In this study, data about the teaching of three different biotechnology units was collected and this data was obtained from a variety of sources; from the teacher, from the students, from direct observation and from supporting documentation. Data obtained in the case study can also be compared to the survey results that deal with the same area.

A limitation of this study may be that it relies on the data collected by one investigator (an exception to this was the case study of Verity, where discussions were held between a supervisor and the teacher). Resources were not available to use other observers. Peer review was available, however, in the form of a continuous briefing of the supervisor of this study about the progress of the work.

6.1.6 Data analysis
Individual case reports were compared for themes common to each study. Data that dealt with similar themes were collected together and further analysed for a central theme. This analysis was carried out using the assertions listed in section 5.3 as a guideline. The final report encompassed the main elements recommended by Erickson, p.145) which are:

1. Empirical assertions.
2. Analytic narrative vignettes.
3. Quotes from field-notes.
4. Quotes from interviews.
5. Synoptic data reports.
6. Interpretive commentary framing particular description.
7. Interpretive commentary framing general description.
8. Theoretical discussion.

6.2 The case studies
Section 6.2 describes the case studies of the teaching of the biotechnology units. A brief discussion of the syllabus for each of the biotechnology units is followed by a description of the way in which the teacher approached the unit. This background is
provided so that the subsequent themes can be discussed in the context of the whole case study. The themes discussed in detail are derived from the assertions made in section 5.3. These are:
1. the lack of practical work (section 6.3.1);
2. the difficulty of the biotechnology subject matter for the students (section 6.3.2);
3. the discussion of ethical issues (section 6.3.3);
4. the lack of a program for biotechnology in junior science (section 6.3.4).

6.2.1 A description of the biotechnology units
Two of the studies (Cleland and Rivervale) involved the elective from 2 unit Biology "Genes in Action". An interview with Alan dealt with his experiences in teaching the Biotechnology module in Science for Life. The third case study involved a biotechnology unit taught to a year 10 class. Each of these units will be outlined below.

6.2.1.1 Genes in Action
This elective covers a wide range of topics from traditional genetics and modern genetics. Its stated aim is "to explore further the mechanisms of inheritance at cell, organism and population level" (NSW Board of Studies, 1994). The topics to be learned include:

- the types and causes of mutations;
- multiple alleles;
- polygenic inheritance;
- transcription and translation;
- genetic manipulation.

In the last section ethical questions and genetic counselling are specified topic areas. Some activities are suggested, none of which are laboratory practicals. They consist of examining karyotypes, using models, discussion of possible theories, (eg operon theory) and case studies of genetic diseases. The student is expected to know the steps of the operon, the steps of protein synthesis and the characteristics of a number of genetic disorders. These three topics involve a large amount of new terminology that the student is expected to be able to use effectively when answering the exam questions. In any lesson at Cleland and Rivervale, it was usual for a student to ask “Do we need to know this for the exam?” and for the teacher to produce examples of questions from past papers that illustrated the depth of information required. In previous years, only a small proportion of the exam questions had been about the ethical issues. Therefore this
section of the course was allocated only a small proportion of the time available for the teaching of the elective.

6.2.1.2 Science for Life- the "Biotechnology" module
The syllabus for biotechnology as part of Science for Life (NSW Board of Studies, 1989) specifies three focus areas which are:

- Biotechnologies exist which can control, alter and repair biological systems
- Some biotechnologies can be applied to humans and their environment
- Some biotechnologies can be applied to other animals and plants

Some science skills are specified and suggestions are provided as to the type of learning areas that could be used to illustrate the focus areas. These include; visit a local farm that uses biotechnologies, bring in newspaper articles, and visit the CSIRO. In practice the teacher has a great deal of latitude in the aspects of biotechnology on which they choose to concentrate. There is a requirement to do at least some practical work so that the specified skills can be taught but this practical work need not require specialised equipment and expertise. Making yoghurt or observing cells under a microscope are examples of the type of practical work that would be appropriate.

The new terminology to be learned would be the minimum needed to explain the examples of biotechnology used in the unit. Protein synthesis, multiple alleles and operon theory would not be included. However, even this minimum amount of new terminology may have been enough to make some students avoid the exam questions. Alan commented that some of his students are not good at expressing themselves in writing, and the biotechnology exam required at least some skill at written explanation of the work they had done.

6.2.1.3 A biotechnology unit for year 10
At the conclusion of the survey and the case studies it had proved difficult to locate a teacher who was teaching biotechnology as part of junior science. Teachers who responded to the survey had said that biotechnology was too difficult, there were not enough practicals and that they did not have a program for it. It was proposed that an outline of a unit of work for biotechnology, which included a significant amount of practical work, be developed and then offered to teachers as a solution to the problems already identified. With this aim in mind, resources were collected and collated. These resources were used as the basis of a unit that involved a sequence of eight activities, from introducing micro-organisms and DNA structure to a debate on an ethical issue. This unit has been called the Biotech-R unit. A copy of the outline of the unit that was given to the teachers at Drayton High School is included as appendix 3. The unit provided instructions and work-sheets for practicals, copies of magazine articles, work-
sheets on aspects of theory and information on where other resources (videos, texts) could be obtained. It did not provide a lesson by lesson program for the teaching of biotechnology.

The unit of biotechnology that was taught at Drayton consisted of seven lessons of eighty minutes duration. A brief summary of each lesson is given here to describe the unit. All lessons involved group work. The class was seated in groups organised by the teacher. At the beginning of a lesson each group member drew lots to see who would record and who would report the group results.

**Lesson 1. Biotechnology concept map**
Students were asked to make a concept map, taking as their starting point the word biotechnology.

Once the concept maps were completed the students were shown a documentary about DNA, genetics and cloning. The class were issued with work-sheets on which to record a summary of the main ideas in the video.

**Lesson 2. Yeast cells**
After watching the remainder of the video and completing the work-sheet the class were given a copy of an article from a text book that defined biotechnology and described examples such as the making of bread and wine. At the end of the sheet there were directions to look at the microscope slides of yeast and draw the cells.

The class were directed to answer questions from a textbook article that explained how yeast cells work in the making of bread.

**Lesson 3. Making bread**
Students were given a work-sheet (modified from one provided in the Biotech-R unit) on how to make bread dough. The activity appeared simple but the students all had great difficulty getting a dough of the right consistency. A great deal of mess was created.

After the practical the students returned to the textbook exercise from the previous period. At the end of the lesson groups were asked to report on the practical work they had carried out.

**Lesson 4. Protein synthesis**
The teacher explained how yeast acts to make bread rise and then showed a video about the process of protein synthesis.

The class were given the task of making a second concept map using the word biotechnology as the starting point. This map was used by the teacher to evaluate how well the class understood the biotechnology they had been learning. An example is shown in figure 6.2.

Lesson 5. DNA extraction
The class were given a work-sheet with a step by step method of extracting DNA from peas. Only two steps of this procedure could be carried out in the classroom and these were duly completed.

The groups then discussed the questions on the work-sheet and a class report was given.

Lesson 6. Defining biotechnology
The class read an article describing examples of biotechnology, including vaccines, gene therapy and new breeds of plants. The students were directed to make a concept map in their books, showing how these examples of biotechnology could be classified into groups. They were then asked to make up some exam like questions about biotechnology.

Lesson 7. Ethical issues
The strategy for the lesson involved showing a segment of a video that dealt with an ethical question. Then the groups were asked to write down their opinions on the question raised and give reasons for their views. A reporter from each group then explained the group’s response to the whole class.

6.2.2 A description of the teaching of the biotechnology units
In the four cases (Verity, Alan, Michael and Rob) of the teaching of biotechnology units studied, the approach used by each teacher was different. This was true even where the material to be taught came from the same syllabus, as in the two studies of "Genes in Action". The form and style of the unit taught was influenced by a number of factors, including the teachers background, the composition of the class and the requirements of the syllabus. In the following section each teachers individual approach to biotechnology will be illustrated, by describing examples of classroom events. These descriptions provide the background for the discussion of the themes raised in these case studies, which are reported in section 6.3.
6.2.2.1 Teaching Genes in Action at Rivervale-Rob

Rob used a style of teaching that involved presenting an overhead transparency of a topic, explaining the material briefly while the students wrote notes, and then answering questions from the class. When the questions ceased the class did some written work on the topic and then moved on to the next overhead. The overhead transparencies he used were part of a prepared set from Tutor Courseware. The information on these sheets was very detailed, as shown in the example in figure 6.1. Students were given a booklet consisting of copies of these overhead transparencies, to use as reference.

The following is an example of a typical lesson in Rob's class. This lesson was on protein synthesis. Rob began by revising work he had introduced during the core topic.

He asked "What is the basic subunit of a protein?" This question got a rather desultory response so Rob put up an overhead showing the structure of amino acids. At this point the students had their heads down reading the booklet. Rob gave the class time to read the notes then explained nature of the amino and carboxyl terminal of an amino acid.

As there were no comments, Rob presented the next overhead which showed a polypeptide with 123 amino acids. He asked how many DNA bases would be needed to code for this protein. Most of the students misunderstood and said 3 or 4. Rob then revised the meaning of codon and anti-codon. After some more discussion most of the class were beginning understand the nature of a codon and recall their previous work on the genetic code.

Cheryl, who had been reading ahead on her notes asked why there were up to six codons for some amino acids. Rob explained about redundancy in the code. She asked, "What are terminator codons?"

After the explanation, Kim asked about one of the other overhead replicas shown in her booklet, which had a run of six codons bordered by a stop codon. "Does this represent a gene?" she inquired.

Rob said, "Yes". Then he explained that proteins could be any length but always began with the code for methionine.

Tiffany said, "It doesn't matter how many come in between, it is just where the start and stop codon occur!".

She sounded pleased to have sorted this out for herself.
Figure 6.1 Example of an overhead transparency used in the teaching of “Genes in Action at Rivervale

**Beef Ribonuclease**

- Enzyme catalysing the breakdown of RNA in cattle
- The tertiary structure of the protein is maintained by 4 di-sulphide bridges between the cysteine bases
- Comprised of a total of 123 amino acids

**The Genetic Code**

- DNA codes for assembly of amino acids
- The code is read in a sequence of three bases called: triplets on DNA
  - Codons on mRNA
  - Anticodons on tRNA
- Each triplet codes for one amino acid, but a single amino acid may have up to six different triplets coding for it (due to redundancy of the code)
- There are a few triplets that make up the START and STOP sequences for polypeptide chain formation (shown here in the mRNA form):
  - START: AUG
  - STOP: UAA, UAG, UGA

**Example:**
A mRNA strand coding for 6 amino acids with a start and stop sequence:

```
AUG ACG GUA UUA CCC GAA GGC UAA
```

**Decoding The Genetic Code**

- Two-base codons would not give enough combinations with the 4-base alphabet to code for the 20 amino acids (it would provide for only 16 amino acids)
- Many of the codons for a single amino acid vary in the last base only — reducing the effect of point mutations

<table>
<thead>
<tr>
<th>Amino Acid</th>
<th>Codons</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alanine</td>
<td>GCC</td>
<td>4</td>
</tr>
<tr>
<td>Arginine</td>
<td>CCG, CGG, AGC, AGG</td>
<td>6</td>
</tr>
<tr>
<td>Asparagine</td>
<td>AAI, AAC</td>
<td>2</td>
</tr>
<tr>
<td>Aspartic Acid</td>
<td>GAI, GAC</td>
<td>2</td>
</tr>
<tr>
<td>Cysteine</td>
<td>UGG, UGC</td>
<td>2</td>
</tr>
<tr>
<td>Glucose</td>
<td>GCA, GAG</td>
<td>2</td>
</tr>
<tr>
<td>Glutamine</td>
<td>GAA, GAG</td>
<td>4</td>
</tr>
<tr>
<td>Histidine</td>
<td>CAU, CAC</td>
<td>2</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>AUU, AUA, AUI</td>
<td>3</td>
</tr>
<tr>
<td>Leucine</td>
<td>UUA, UGU, CUC, CUA, CUG</td>
<td>6</td>
</tr>
<tr>
<td>Lysine</td>
<td>AUA</td>
<td>2</td>
</tr>
<tr>
<td>Methionine</td>
<td>AUA, UAG</td>
<td>1</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>UUU, UUC</td>
<td>2</td>
</tr>
<tr>
<td>Proline</td>
<td>CCU, CCC, CCA, CGG</td>
<td>4</td>
</tr>
<tr>
<td>Serine</td>
<td>UCU, UCC, UCA, UCG</td>
<td>6</td>
</tr>
<tr>
<td>Threonine</td>
<td>ACT, ACC, ACA, ACG</td>
<td>4</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>UGG</td>
<td>1</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>UUA, UAC, UAU, UGU, AGG</td>
<td>2</td>
</tr>
<tr>
<td>Valine</td>
<td>GGU, GUC, GUA, GUG</td>
<td>4</td>
</tr>
</tbody>
</table>
These sorts of exchanges continued throughout the lesson. The students garnered information from the overheads and then asked questions as they felt the need. In this way the students ideas about the mechanism of protein synthesis were clarified. During the break between periods, two of the students who had not spoken up in class, went to Rob and asked him whether the ribosomes were re-used once a protein had been made. After the break Rob showed a short video that consisted of the standard BBC commentary and basic classroom diagram used to explain the detail of protein synthesis. A student commented at the end, "It's a dumb video, but I get everything in it, know what I mean?" Nobody argued.

Rob was happy with this lesson. He named a few students who were still confused but he felt there was time for extra revision with these people. The rest of the class could be left to get on with exam questions while he gave help to the few who did not understand. Independent learning by the students was a feature not just of Rob's class but of the whole school. Students were trusted, eg to go to the library without supervision and even to study music in biology if that was what they needed to do. Observation of the class and discussion with the students revealed that this trust was honoured and appreciated. The students offered the opinion that Rob knew a lot about this subject and that he was a good teacher. Rob was in touch with the capabilities of each of the students (there were 15 in the class) and ready to spend whatever time was needed to help them.

Rob could be confident that his selective school class were going to behave well and listen throughout the lesson. His students were aiming for a high score in the HSC exam, which was only months away. The class frequently asked questions about the trial exams and the HSC exam. At the end of each lesson, sample HSC questions were handed out to be completed for homework. In the interview with the students they explained that all they were expected to do was memorise facts for the forthcoming exam. Kim's analysis was, "Well, for the HSC, you're not trying to actually learn anything though, you are just trying to memorise facts that you can regurgitate for the test."

This class were not given activities designed to stimulate interest. The students interviewed were asked about this. They stated that the course would be more interesting if they could spend more time discussing the issues and doing some practicals. They blamed the HSC exam system. Kim summed up their opinions as,
"Probably it would be more interesting (if they did lab work) but it is just the whole high school thing, there's not enough time or need for it."

This class was willing to memorise the subject matter and answer the exam question even when they did not understand what they were writing. The driving force in the lessons was to set out all the material to be memorised and learn to apply it to previous HSC exam questions. These students were always well behaved; they copied notes assiduously; did their homework; and could be relied upon to ask questions when they needed information. They did not want to waste time that could be better spent on learning what they needed to know for the exam and, they claimed, their best way of learning was to read the text book and to practise exam questions. Rob felt that his responsibility was to help the students do what they most wanted, get the highest possible exam mark.

6.2.2.2 Teaching Genes in Action at Cleland-Michael
For the core topics in 2 Unit biology, Michael taught a class of 26 students of mixed ability. This class was offered the chance to choose their own elective. One group, which consisted of 12 students had voted to do the "Genes in Action" elective. The rest of the class had been equally adamant that they would not do this elective and had voted for "Control and Co-ordination". Michael had agreed to accommodate both groups by splitting the class into two halves and teaching both electives at once. For half of the periods he gave lessons on one elective, then that group did private study while the rest had lessons on the other elective. Michael was not convinced that this arrangement was ideal but he thought it more effective than forcing half the class to do something to which they were opposed. Michael admitted that he had had a lot of trouble with discipline in this class and several students had been removed from the class in the previous term. Michael had made it clear that because half of the lessons were private study, how well the students went would depend to a large extent on them. During the time of the observation, attendance and motivation among the "Genes in Action" group was high. However the same was not true of the other group, a considerable number having decided not to attend school on a regular basis. When asked about the low attendance Debbie said, "There is a lot on at the shops at this time of day". Allowing the students to choose the electives this way, had resulted in the self-selection of a group which was very motivated to get high marks in the HSC exam in "Genes in Action". As was the case at Rivervale, the teacher considered he had a responsibility to ensure that the students did as well as possible in the exam.

Michael had twenty eight years of experience in teaching. He had once studied zoology but he felt that that was a long time ago and he was not confident about his knowledge
of genetic technologies. At the time of the initial interview he was still seeking resources that could be used and collecting library texts for the private study sessions. His main aim for the course was to go over all the material in the short time he had available and explain it as well as he could. He did not have time for revision and he had little time to help students individually. At most stages of this course he was stressed and harassed because there were so many things he had to do. In spite of this, he put considerable effort into finding interesting and effective ways of explaining the subject matter in "Genes in Action". This lesson on protein synthesis illustrates Michael's approach to teaching this elective.

Michael wrote on the board, "The flow of information from DNA to protein". He said "You have blue eyes because of your proteins, but why?". When there was no response he prompted, "What is making your eyes blue?" Michelle mumbled "Protein". Michael explained that most of the structural parts of our body are made of protein. He then wrote on the board that proteins are made of amino acids. Alicia, asked why phenylalanine is in Coke and why do they put a warning on the label. Tony pulled a bottle of Diet Coke out of his bag and Michael read the label. He explained that people with phenylketonuria could not consume phenylalanine but he did not know why Coke contained phenylalanine.

Returning to his previous point, Michael asked, "What does protein do for us?" "Building blocks of all cells", was called out from the front row.

Michael used a description of the starvation in concentration camps to illustrate how protein is part of the structure of the body and when people are starving the body eats its own protein. Alicia added that this also happens when people have anorexia.

The next question was about how this protein was broken down. Michael asked the students about what the digestive system does. A few said, "Breaks it down to amino acids".

Michael continued, "The cell has to get amino acids and then re-build them. It is like moving a building to Western Australia. First you would have to take it apart. Then what would you have to do?"

The class did not have a suggestion so Michael supplied, "Number all the bricks, This led up to Michael writing on the board, "Our cells absorb amino acids and recombine them to make proteins".

He then asked, "If I am going to make a lego house, I am coordinating the process. If your body wants to make a certain protein what is coordinating the process?"

Alicia answered, "DNA"
Michael explained that DNA is the template and the template is like the builders plan.

Having completed the house analogy, Michael put up an overhead summarising transcription and translation and asked the class some questions about the functions of various organelles. After some hesitant answers about what ribosomes do, Michael explained that ribosomes were like the landing site for tRNA spaceships that are coming into earth. The spaceships cannot land until they find the right sequence.

Michael then asked the class to come to the front desk where he had set out a model of protein synthesis that he had made himself. The tRNA were made of painted wooden blocks with 3 prongs. Many smaller blocks representing the amino acids were spread around on the desk. Michael directed the students to move the blocks around to simulate the making of a protein. The students matched their amino acid with the correct tRNA. They then put these amino acids into the sequence directed by the mRNA until a row of blocks were lined up to represent a protein.

This example shows how much effort Michael put into explaining the subject matter in ways to which he thought the class could relate. He had an enthusiastic style of speaking and often made his stories interesting with anecdotes or jokes. It was never clear to what extent students in the class appreciated this effort. They seldom asked questions, although they would answer those that Michael put to them. There was very little classroom conversation that could be used to reveal the students' responses to the material they were learning. Michael explained that this subdued attitude may have been due to his previous attempts to impose discipline on the class, which had led to them being wary of treating him with too much informality. Debbie and Tanya were interested in the subject matter and both were speculating about doing a course at university that would involve gene technology.

When asked whether they understood the subject matter Debbie shrugged and said, “It’s not too bad.”

The impression these two students conveyed was that they were indifferent to the method by which the subject matter was taught to them.

6.2.2.3 Teaching biotechnology as part of Science for Life—Alan

Alan taught Science for Life at a comprehensive school in the west of Sydney. The situation that he dealt with was different in some ways from the situation observed in the case studies on the “Genes in Action” elective. Alan's students were openly
uninterested in their exam marks and he could not rely on them to do the work unless they were really interested in the subject matter. He did not see his primary aim as being to help the students get the highest marks in the HSC. He was primarily motivated by a desire to get his students to be aware of the implications of biotechnology and to help them realise that it was a part of their life. He explained,

"I think the real key ones (ideas) I want to get across in this topic are that biotechnology may sound a little strange but if you break up the word it is not hard to understand, like at first mention of biotech nobody understands what it is but it's just bio and technology. Then from there, biotechnology can have an enormous influence on your lives, the things that we will be doing might happen to you in your lifetime or in your kids' lifetime for sure."

These students studying Science for Life class had little background knowledge of cells, micro-organisms or DNA so all of this material had to be introduced before genetic engineering could be explained. Alan had a commitment to doing as much of this as possible using practicals because, as he said, "The main thing is you try to do something really practical otherwise the kids get really bored."

He began with examples of traditional biotechnology, like making yoghurt, because all of the class had had some experience with yoghurt. He then introduced cells and micro-organisms using an experiment such as collecting bacteria on plates. Later in the course he included an experiment showing the action of an enzyme that is present in potatoes. All of these experiments can be found in the textbooks used for junior science but they are not presented in a biotechnology context. Alan puts "a biotechnology spin" on them. Alan teaches at a school with very few resources and he has no hope of doing electrophoresis or of taking his students to workshops about the extraction of DNA. His advantage is that he has worked in the field of biotechnology and he feels confident in adapting experiments to suit his own purposes.

Alan finds that his students are interested in the practical work and they enjoy talking about diseases and mutations, which they relate to their own family. However, they have less interest in aspects of the subject which they do not see as relevant to their own lives. He would not even begin to teach protein synthesis or operon theory, but he has to give some explanation of what a gene is before he can explain genetic manipulation. He uses current media articles to help him with these explanations. One example he had used was that of a pig that had been genetically altered to make a human protein. Alan commented, that after a discussion of this example with the class,
"The bit that I find difficult, probably needs more resources explaining, is just what is a gene. Trying to link it's a gene, it's a chromosome, what actually is it. That is the bit that the kids find hard."

Alan has taught this topic five times and has used the topic as a research project on using the media in a Science-Technology-Society approach to biotechnology teaching. Overall he has been satisfied with the outcomes although he reports that few of the students go on and answer the questions on this topic when they do the HSC exam.

6.2.2.4 Teaching biotechnology in junior science-Drayton

The teaching approach that was used for the biotechnology unit that was taught at Drayton was influenced both by the researcher and by the teacher. This is because the unit taught (described in section 6.2.1) was a hybrid of the Biotech-R unit and those lessons that were developed by the teacher in response to the needs of her students. As a consequence different lessons reflected different teaching styles. A description of the course of events leading up to the implementation of the biotechnology unit is included here because it helps to explain why the approach used for the teaching of biotechnology was not the approach Verity would have used if the Biotech-R unit had never been suggested. Yet neither was it the approach recommended in the unit provided. This juxtaposition of these two different approaches affected the way biotechnology was taught.

The outline of the Biotech-R unit was presented to Verity and Paul in the last term of 1997. They were asked to examine the unit and decide whether they would be able to conduct a trial. Paul elected not to teach the unit. Verity was interested in conducting the trial and to this end she made plans to change her class allocation so that she would have one of the higher ability year 10 classes. The science department at Drayton were willing to allow Verity to go ahead with the biotechnology unit provided that she continued to teach all of the other year ten topics.

At the beginning of the 1998 school year Verity was interviewed about her plans for the teaching of the Biotech-R unit. She reported, "I have half a term to do cells, some genetics and biotechnology." The cells and genetics were part of a school program for year ten, "Cells", that included learning about DNA structure, meiosis and mitosis, monohybrid crosses and the structure of cells. After the completion of the work specified in the "Cells" program, there were three weeks left in the term and one of these weeks had been allocated to examinations. The Biotech-R unit had to be modified to suit a two week time frame. Soon after the work on biotechnology commenced, Verity
reported that the sections of the Biotech-R unit that included the nature of the genetic code and the use of the code to make proteins were too detailed for her purposes. These sections were to be left out so that a discussion on ethical issues could be included. Verity stated her aim for the teaching of biotechnology as being to encourage the students to start developing some opinions about the ethical issues associated with biotechnology.

For the first two lessons Verity had the Biotech-R outline open on the desk and used it as a reference. These lessons involved introducing the use of micro-organisms in traditional biotechnology using yeast and bread as an example. The aim of this section of the Biotech-R program was to introduce biotechnology as being a part of the students immediate environment prior to discussion of the more sophisticated gene manipulation technologies. The assumption of the Biotech R unit was that the students would not previously have studied DNA, genetics, or gene technology. However this was not the case for the class at Drayton, as they had just completed a topic involving cells and genetics. Therefore Verity used the activities outlined for a different purpose than that originally intended.

In the first lesson Verity explained to the class that they were beginning a new topic about biotechnology. She asked them to make a concept map using the word “biotechnology” as their starting point. The teacher asked the class to contribute suggestions, but they did not do so until she had suggested some ideas. Only then did they record ideas on their paper. The result was a series of very similar maps, an example of which is shown in figure 6.2a. All of the maps emphasised the importance of using genes to manipulate living things to make them more perfect. Verity considered that the concept of biotechnology that had been revealed by these maps was too narrow. As a result, in lesson 2, she gave the class a photocopied article that defined biotechnology in a similar way to the Biotech-R unit. The definition given in the article was, “Biotechnology involves the use of living cells or materials from cells to provide useful products and services.” Verity then used the activity suggested in the Biotech-R unit, the observation of yeast cells, in combination with a textbook article on yeast respiration, as a way of illustrating the use of living cells in traditional biotechnology. In the Biotech-R unit, observation of yeast cells was suggested as a way of introducing cells to students who were starting biotechnology without any knowledge of cells or micro-organisms.

In Lesson 3, the class were given a work-sheet on making bread dough using yeast. A similar work-sheet was provided with the Biotech-R unit but Verity had written out new instructions and added directions to the students to answer some questions from a class
textbook. The aim of this practical was to give students the experience of using a micro-
organism to provide a product. Verity thought that it would also be useful as a way of
teaching some process skills. In addition, she expected the students to learn the method
by which yeast makes bread rise, as the textbook article completed in lesson 2 had dealt
with yeast respiration. At the completion of the practical the class reported on their
experiences. It was clear from these reports that many students thought that yeast makes
bread rise because the yeast doubles in size and takes up more volume. From
Figure 6.2 Concept maps made by students at Drayton

(a) Lesson 1

Biotechnology: It is the technology of living things.
- It is done by genetically engineering living organisms in a lab with needles and test tubes.
- It is used to clone things, to change the genetic construction of things, etc. (Test tubes)

(b) Lesson 4

Biotechnology: breeding animals and plants for their best features
- Eg mouse with ear on his/her back
- Eg mouse with the ear on his/her back

Changing things
- Manipulating living things
- Breeding animals and plants for their best features

Use genes to "mix" characteristics from one organism to another
- Changing things
discussion with individual groups it was also clear to Verity that many students did not see how making bread was related to biotechnology.

In the next lesson the students were asked to complete the textbook questions on yeast respiration and construct another concept map using the word biotechnology as a starting point (an example is shown in figure 6.2b). Verity included this second concept map as a way of testing her suspicion that the students did not have an accurate understanding of the definition of biotechnology. By the end of this lesson, Verity had determined that the class was still thinking about biotechnology in terms of gene manipulation to make things perfect, as they indicated in the concept maps in lesson 1. They did not include yeast or micro-organisms in their outline of biotechnology. Verity said that she thought that the approach was not working and she discussed possibilities for changing the lessons to deal with this misconception that she had identified, ie that biotechnology means manipulation of genes to make things perfect. The idea of allowing the class to research a specific example of biotechnology, eg production of insulin, was discussed and dismissed on the ground that the students would not find enough information. Verity said that she needed to think about the best way to proceed.

In the meantime she went ahead with the practical on the extraction of DNA from peas that had been prepared. This practical had been suggested in the Biotech-R unit. The aim of the practical was to help students to understand that DNA is a real substance by allowing them to see it. The Biotech-R had included this practical as part of a section on DNA structure and accompanied it with the construction of a model of a double helix. The class at Drayton had already made a model of DNA and they had been taught about DNA structure. The reasons for doing the practical at Drayton were that there was a commitment to the testing of new practical work for biotechnology, and this practical had already been planned. As the practical was not directly related to the subject matter that the students were learning, it was difficult to explain to the class why they were extracting DNA. Each group was able to produce a sample of a stringy white substance and they were interested to know more about this material. Some students went to the trouble of setting up a microscope so they could look at the substance. Having observed that the students showed interest in the practical Verity decided that it could be done as part of a junior science biotechnology unit in subsequent years, but it should be presented as being just for fun. She felt that the practical was out of place at that time because the students first needed to clarify their concept of biotechnology.

In the next lesson (lesson 6) Verity tried to deal with the misconception identified in the previous lessons, by bringing it out in the open. She asked the groups to report on what
genetic engineering is, and what it means to biotechnology. In the group being observed for this lesson one student said "Genetic engineering is when you cut up pieces of DNA and put them in different places". Another explained that you need genetic engineering to make biotechnology work because you need to move genes around to make them perfect. In the concept maps produced in lesson 6 the link between biotechnology and changing things to make them better was still present. For example, one description of biotechnology was “Biotechnology is the manipulation of a living organism etc., making cows with polyunsaturated meat”. None of these later concept maps mentioned traditional types of biotechnology, in spite of the time spent studying bread. And none of the maps included the definition that Verity had given the class. It was as if the amount of time given to finding different ways of defining and classifying biotechnology had generated further confusion. However, these students had no difficulty explaining genetic manipulation and genetic engineering. The concept map shown in Figure 6.1b says of biotechnology, “It is done by taking a strand of DNA, splicing it, taking out a segment and then replacing it.” These terms had been explained in several videos and in the "Cells" topic; the students were familiar with their meaning. This previous knowledge of genetic engineering had not been taken into account when the Biotech-R unit was implemented. The unit was written for students who had not been taught about cells and genetics. That is, the Biotech-R unit was imposed on a situation for which it was not designed, and this may have contributed to the development of the misconceptions that emerged.

Verity was not satisfied with the outcomes of the unit that was taught. As a result of the misconception about the meaning of biotechnology, a number of lessons had to be redesigned so that this misconception could be corrected. This resulted in a departure from the outline provided for the Biotech-R unit and more time had to be devoted to lesson preparation. It also meant that time was spent on defining biotechnology that might have been spent on other areas, such as class discussion of ethical issues. Verity commented that the Biotech-R unit was inadequate for her purposes in a number of respects. These were that:

- the outline included with the unit was not detailed enough and a more complete program should have been provided;
- the work-sheets for the practicals were not appropriate for her classroom conditions and a lot of work was needed to get the practicals into a form where it could be used in the classroom; (She felt that this work should have been done before the unit was offered to a teacher.)
- the Biotech-R unit included more detail about the genetic code and the function of a gene than a year ten class should be expected to learn;
• the unit was too long and she considered that two weeks would be long enough to introduce biotechnology to year ten students.

As the unit progressed and Verity assessed where the students problems lay, she began to make plans for how she would teach a biotechnology topic next year. She also spoke about ideas and resources for doing "Genes in Action" with her 2 Unit biology class. This suggests that her dissatisfaction with the particular unit she had been offered had not convinced her that the students were unable or unwilling to study biotechnology. Rather that it had to be taught in a different way next time.

Having described the background to each case study, it is now possible to consider the implications of these studies in section 6.3.

6.3 Discussion of the assertions made in section 5.3 about the teaching of biotechnology in NSW
The case studies described in section 6.2 were designed to investigate the assertions made in section 5.3. Section 6.3 reports those aspects of the case studies that pertain to each assertion. The findings of the research are reported in section 6.4.

6.3.1 Assertion: That there is not enough practical work
Teachers who responded to the survey agreed that there were not enough practicals for biotechnology, whether in the form of "Genes in Action" or as a junior science topic. With this finding in mind, the role of practicals, and how the teacher intended to deal with them in biotechnology, became a focus of the interviews and the observation during the case studies. Aspects of the case study that deal with this assertion are discussed in this section.

6.3.1.1 An overview of the practical work conducted at Cleland, Rivervale and Drayton High Schools
Cleland
At the time of the first interview at Cleland, Michael explained that in order for the course to be successful for his students the lessons would have to contain activities. He was certain the students “would not stand for it” if there was nothing practical to do. Throughout this conversation there were often indications that the students were fairly assertive about what they were prepared to do and that the teachers paid attention to this. Michael was worried that there were not enough activities for that half of the class which had chosen “Genes in Action”. At that point he had some ideas for using a model he
had previously made of protein synthesis and a work-sheet activity on identifying mutations. He hoped to find some other practical work. This eventually proved to be too difficult to do. Most of the activities that are associated with biotechnology, such as extracting DNA, DNA fingerprinting, or gel electrophoresis are outside the scope of the elective and Michael was worried about the time required to complete the elective. He only had six weeks to teach the material and he could not afford to spend time doing activities that would not count in the exams. In the unit subsequently taught, the only additional activities used were a quick taste test on a genetic marker and a demonstration of a centrifuge.

Although Michael had worried about the shortage of ‘hands on’ activities the survey results (table 6.1) showed that the level of interest in the "Genes in Action" topic had remained high. The fact that the full class was still attending in the last week was evidence of this, in his view. Many students said that they would have liked more practical work and excursions (table 6.1) but they were positive about the elective as a whole, saying that it was interesting and useful. The desire for practicals was probably to liven up what was otherwise a tedious collection of facts. Alicia made several bids to do a DNA extraction from peas. Michael pointed out that this was not really in the course and Alicia said, "Oh but it’s fun". Michael gave this activity serious consideration but decided that he did not have the time to organise and carry out an activity just for fun. As interest and motivation remained high in spite of the lack of practicals, such activities, for the purpose of raising interest and motivation, were desirable rather than necessary.
Table 6.1 Survey of attitudes to the Genes in Action elective given to students at Cleland High School

Results are given as number of students (out of eleven total)

**Question 1-Why did you choose to study Genes in Action?**

<table>
<thead>
<tr>
<th>Answers</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>I was interested in genetics</td>
<td>4</td>
</tr>
<tr>
<td>It was useful for my future career</td>
<td>3</td>
</tr>
<tr>
<td>Both interesting and useful</td>
<td>2</td>
</tr>
<tr>
<td>More interesting than the other elective</td>
<td>1</td>
</tr>
</tbody>
</table>

**Question 2-Was the elective as you expected it to be?**

<table>
<thead>
<tr>
<th>Answers</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Easier than expected</td>
<td>4</td>
</tr>
<tr>
<td>I had no expectations</td>
<td>2</td>
</tr>
<tr>
<td>It was as expected</td>
<td>4</td>
</tr>
<tr>
<td>More experiments expected</td>
<td>2</td>
</tr>
</tbody>
</table>

**Question 3-**

a) **Which topics in the elective did you find easy to understand?**

<table>
<thead>
<tr>
<th>Answers</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple alleles</td>
<td>2</td>
</tr>
<tr>
<td>linkage</td>
<td>3</td>
</tr>
<tr>
<td>polygenic inheritance</td>
<td>2</td>
</tr>
<tr>
<td>DNA mutations</td>
<td>3</td>
</tr>
<tr>
<td>ethics</td>
<td>1</td>
</tr>
</tbody>
</table>

b) **Which topics did you find difficult to understand?**

| chromosome maps | 1 |
| mutations       | 2 |
| protein synthesis| 4 |
| operon theory   | 3 |
| the difference between multiple alleles and polygenic inheritance | 4 |

c) **Which topics did you find impossible to understand?**

Only two put anything in this category, both citing operon theory as impossible.

**Question 4-**

**Which part of the elective did you find the most interesting?**

<table>
<thead>
<tr>
<th>Answers</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>mutations</td>
<td>4</td>
</tr>
<tr>
<td>multiple alleles and linkage</td>
<td>1</td>
</tr>
<tr>
<td>All of it</td>
<td>2</td>
</tr>
<tr>
<td>genetic technologies</td>
<td>3</td>
</tr>
<tr>
<td>protein synthesis</td>
<td>1</td>
</tr>
<tr>
<td>learning about diseases</td>
<td>1</td>
</tr>
</tbody>
</table>

**Question 5- What changes would you make?**

<table>
<thead>
<tr>
<th>Answer</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>more practical work and excursions</td>
<td>5</td>
</tr>
<tr>
<td>more case studies on mutations</td>
<td>1</td>
</tr>
<tr>
<td>none</td>
<td>1</td>
</tr>
<tr>
<td>less things to remember</td>
<td>1</td>
</tr>
<tr>
<td>more history on the researchers eg Mendel</td>
<td>2</td>
</tr>
</tbody>
</table>
Rivervale

The students from Rivervale did the DNA extraction from peas, at the CSIRO workshop on Gene Technology in Action. This was the only practical work that this class carried out that related to the “Genes in Action” topic. It contrasts to the other lessons, which all had a very similar format. Compared to the other classes that were observed during the CSIRO workshop this group were notable for the unhesitating accuracy of their answers to the demonstrators questions. For the most part the class carried out the workshop procedures quietly and competently, showing no signs of being overawed by this opportunity to work in well equipped scientific laboratory. Other classes attending the workshop had exclaimed about the novelty of automatic pipettes, centrifuges and disposable test tubes. Renee was excited about spooling the DNA, describing it as "groovy" and this part of the workshop did seem to elicit interest among these students, although less than among other classes.

In the interview at the end of the elective, the students were asked what they had thought about the CSIRO workshop. The opinion, on which they agreed, was expressed by Louise,

"Largely irrelevant. It was interesting because it was hands on, you could see what they really do."

Kim added, "A lot of the things we knew already from bio or ag."

The question was extended from the workshop in particular to practical work in general, but Louise still insisted, "There is not a whole lot of practical work you can do really, isolate the DNA and that sort of thing but it is largely irrelevant."

When asked if they thought the elective would have been more interesting if they had done more practical work, Kim said, "Probably yes" in a half hearted way and Louise commented, "I am perfectly happy reading the text book."

For these students the presence or absence of practical work was not an important issue. An opinion that was expressed separately by their class teacher. Rob’s view about practical work for the elective was, "There is not much. There is some work you can do with models of protein synthesis but it is not worth setting up wet practicals". Subsequently, in the school, I asked him whether he thought the CSIRO workshop had helped the class to understand "Genes in Action". He said that it probably had not helped them when it came to answering the HSC questions but it had probably helped their general understanding of science. He also commented that they enjoyed the workshop.
Drayton
In the initial interview Verity was asked for her opinion about practicals. She said "I use them to make points. I don't know whether kids get them but that's what I try to do. Sometimes we do practicals just for fun".
Verity also made the point that some practical work can be just for fun but not all practical work can be done for this reason, most have to be leading to a point.
When asked about practicals in the biotechnology unit specifically, Verity commented, "Even if it is being able to grow cells like yeast cells and have a look at them, something like that, that's probably good."
Verity imitated a student voice to illustrate how a student might respond to practical work, "What these guys are doing, they're working with stuff they can't see, this is fantastic".

At the beginning of the biotechnology topic, Verity announced to the class that this topic would include some practicals. A voice from the back said, "Did she say the word prac? What's that miss?", in cynical reference to the previous topic. Verity explained later that the class only calls something a practical when they are moving around doing experiments. The cut and paste activities, done in the previous topic of "Cells", were not practicals as they viewed them. These comments by the class suggested that Verity was under some pressure to provide practical work as part of the biotechnology unit.

Having carried out two practicals, Verity decided that they should be used just for interest and motivation for the students. After the bread making the students showed considerable confusion about where yeast came into the subject of biotechnology. It was also clear that many students thought that yeast made bread rise because they doubled in size rather than as a result of respiration. Verity had to devote some time to correcting this misconception. She observed that the bread making seemed to the students to be separate from the subject matter they had to learn. During the bread dough practical one student said, "That was fun, but I would rather not do practical all the time, I would rather do work where you are actually learning. In practical, you are just sort of doing something, having fun."
When asked if she had learned anything from the practical she replied, "No, nothing I didn't already know."
This student thought the point of the practical was to show that if yeast is present the bread dough rises. In spite of the textbook work that was linked to the experiment, she did not think of the practical as explaining anything about what biotechnology is or about how a yeast works. This student’s comments support Verity’s view that the value of the practicals was in providing motivation, rather than in helping to explain the subject matter of biotechnology.
6.3.1.2 The purpose of practical work versus what can be achieved
Observation of the practical work conducted during the teaching of the three units of showed that the teachers had a number of goals for practical work in biotechnology. Michael was searching for practical work that would enhance the learning of scientific knowledge as well as stimulate interest and enjoyment. He was unwilling to undertake practical work simply for fun. Verity intended to use practical work to illustrate a point and to demonstrate to students some of the skills used in a laboratory, as well as to provide stimulation and enjoyment.

The findings from the case studies are consistent with the findings of Hodson (1993) and Wilkinson and Ward (1997) that teachers have more than one purpose for using practical work. Hodson (1993, p.90) has listed five broad goals of practical work as being to:
1. motivate, by stimulating interest and enjoyment;
2. teach laboratory skills;
3. enhance the learning of scientific knowledge;
4. give insight into scientific method and to develop expertise in using it;
5. develop certain ‘scientific attitudes’ such as open-mindedness.

Wilkinson and Ward (1997) surveyed teachers and students in Victoria about their views of the significance of laboratory work in secondary schools. They found that both teachers and students rated the principal purpose of practical work as being “to make science more interesting and enjoyable through actual experience” (p.51). The teachers surveyed by Wilkinson and Ward (1997, p.51) also gave a high rating to the aim, “to enable students to verify facts and ideas for themselves”.

The findings from these studies are also consistent with the finding of Wilkinson and Ward that students regard enjoyment as a more important reason for practical work than the enhancement of knowledge.

The experience of the teachers in these case studies was that they were not able to find practical work in biotechnology that would satisfy all of their goals. They were able to provide practical work that would stimulate the interest and motivation of the students, where this was necessary, but they were not able to use practical work to enhance the students learning of the subject matter.

Whether practicals are available that explain the subject matter of biotechnology depends to some extent on the subject matter included in the syllabus. As stated in
section 2.2.2, Alan had used practical work to keep his class interested in biotechnology. He had devised a number of practicals that would demonstrate the function of micro-organisms, the action of enzymes and the importance of biotechnology to everyday life. However he did not have a practical that could explain to his students “what a gene really is”. The students taught by Rob and Michael could do the type of practicals used by Alan “for fun” but they could not use these practicals to explain protein synthesis or control of gene expression to the class. Practical work that illustrates these concepts is not available to most school laboratories at this time.

6.3.1.3 Findings from this research
The teachers surveyed indicated that not enough practical work could be done in biotechnology, and it was stated in section 5.2.2 that more research was needed into what purpose the teachers had for practical work in biotechnology. An empirical assertion was made that not enough practical work is available in biotechnology. From the findings of the case studies, and from the work of Hodson (1993) and Wilkinson and Ward (1997), a new assertion can be made. This is, that practical work is available in biotechnology that will stimulate the interest and motivation of the students, but not enough practical work is available in schools to deal directly with the many ideas, concepts and practices in biotechnology.

6.3.2 Assertion: That students find the subject matter of biotechnology difficult
In section 5.2 it was reported that teachers choose not to teach biotechnology to students undertaking an external exam because the subject matter included in the biotechnology options was too difficult for the students. Teachers of junior science also stated that biotechnology is too difficult for the students. Some evidence was presented that those teachers who had experience in the teaching of biotechnology agreed that biotechnology was difficult for the students. The assertion was made that the subject matter of biotechnology is too difficult for the students (section 5.3). It was proposed that more research was needed to investigate the way in which the subject matter of biotechnology was too difficult for the students. In particular, is the subject matter intrinsically difficult or is the difficulty related to teaching the units of biotechnology offered in the NSW curriculum. Observations from the three case studies that provide insight into the reasons teachers consider biotechnology to be difficult are presented in section 6.3.2. These observations are discussed and a new assertion is made.
6.3.2.1 Teachers and students opinion of the difficulty of the subject matter in “Genes in Action”

Both of the teachers doing the 2 Unit biology elective had formed a view of how much each of the class members understood. From his experience in teaching the class Michael was fairly certain that all of the front row (four students including Alicia), as well as Debbie and Tanya, understood what was being taught. He mentioned another student who had only been present at one or two lessons as being hopelessly confused. The rest, he claimed, were somewhere in between. This pattern of understanding seemed to be similar in "Genes in Action" to that attained in other sections of the course.

Near the end of the course at Cleland the students were asked to fill in a short survey and the results from this show that half the class found operon theory and protein synthesis difficult to understand (table 6.1). After the lesson on operon theory, Michael and the researcher agreed that even they had to relearn the steps in the process and the terminology every time it was taught. Tanya asked warily at the end of one session about whether she would have to know all the names of the parts of the operon. The answer was yes, just in case the HSC exam has a "label the missing parts" question. These students found other parts of the elective conceptually less difficult. One comment from the Cleland survey was, "I like learning about diseases I don’t know about." The students were at their most animated in class discussion when discussing inherited traits in personal terms, eg, multiple genes for hair colour and blood types in the family. Students who had rarely spoken in class asked about Rh factors, why we need blood tests, and volunteered opinions on how much they would change the genetic make-up of their children. These areas, mutations, multiple alleles and ethics, were listed in the survey as being easy to understand.

Rob was also able to name which students were still confused and which ones were on the “right track”. He was aware that Louise already knew everything. Rob based some of his estimate on the results of the trial exam. This paper included a full section on the “Genes in Action” elective, consisting of about six questions. These were harder than the average HSC question on this topic. For example one question asked for a diagram to show the mechanism of translation. Usually, in the HSC the diagram is drawn and the examinee is only asked for labels. Another question in the trial asked how TNF (tumour necrosis factor) could be made by genetic engineering. The student was meant to see that TNF can be produced in the same way as insulin but few seem to have realised this. Rob was not happy with the way this exam was answered and, as a result, he was planning to allow some of the better students to revise past papers while he reviewed the elective with the rest.
After the trial exams, and once the main course work had been completed, Rob arranged for three students to be interviewed about their opinion of the elective. These students were selected to represent a range of abilities. Two of the students, Kim and Louise, had often expressed their opinions in class. The third student, Lisa, had not spoken up in class. Even in the interview she said little, but she did make it clear that she felt that she did not understand "Genes in Action". She commented,"The stuff in the course went straight over my head."

When asked which areas of the course she needed to revise she said, "The whole thing step by step."

Lisa also said that she had done some work on this sort of topic in general studies, where they had mainly discussed the cloning of the sheep. She had understood that but she did not understand protein synthesis, polyploidy and mutations. Her comment was "I'm finding it difficult so I do not think I should have done this subject (2U biology). The thing is, it interests me but I just cannot do well in the subject."

Both of the other students were confident that they could do well in the exam on this topic but neither of them really felt that they understood what the topic was about. They regarded the HSC exam as just a memory test. They accepted this but all three students disliked the approach this engendered in their study of biology, and biotechnology in particular.

Louise stated, "It just seems like you are being given a whole lot of facts to memorise. Right you've done that, on we go! That's where the difficulty lies because you do not really know why you are learning it."

Lisa agreed, "If you knew why you were learning it would make it easier to learn."

Kim made similar objections, "I don't get anything about polyploidy and all that. I understand with the mutations, and like frameshift, whatever, I understand what they were but I don't understand how they happen or anything like that. I could answer the question in the exam but I don't understand what it was about."

A feeling that she did not have enough information to allow her to link the parts of the elective together was a source of frustration for Louise. She spoke about this several times. For example, she said, "A lot of the basics are not covered. You have got the dominant and recessive, that you understand, you understand that genes are dominant and recessive but you don't understand other determinants. Take sickle cell anaemia, you've got the heterozygous for the recessive allele and that still has an effect. When you are doing Mendelian genetics you get the feeling it is either dominant or recessive and they have an effect, significantly as it turns out, and you don't really understand why and from then on you are not sure why you are doing this."
This was only one of three detailed questions that Louise posed during the interview, all about areas where she felt she did not have enough information to piece the facts together. For Louise, the elective would have been more satisfying if it had explained fewer things in more depth. Rob expressed the view that Louise was atypical because she was an exceptionally bright student but she did not like the subject of biology. Lisa, for example, was not sure that doing things in more depth was the answer to her problem.

The teachers and students involved in the two case studies on “Genes in Action” considered that parts of this elective were difficult, particularly the area of protein synthesis and operon theory. The students at Rivervale were attending one of the states top selective schools and the students at Cleland had self-selected for their ability and motivation. It is reasonable to argue that they represent the top echelon of students in NSW. Therefore other students are likely to find the subject matter of “Genes in Action” difficult. Observations from the case studies confirm the view of teachers who responded to the survey, that “Genes in Action” is difficult for the students.

Venville and Treagust (1996, p.18) found that students failed to make a connection between such concepts as “DNA structure, the genetic code, protein synthesis and the expression of genes”. A similar lack of understanding of how the subject matter included in “Genes in Action” was linked together to make a coherent story was a problem expressed by the students at Rivervale. These students were able to explain what a gene is and what it does, and they were able to write down the steps of the operon and of protein synthesis, but they had a lot of unanswered questions about how this knowledge explained the genetic control of an organism.

To what extent was this problem a feature of the syllabus and to what extent was it intrinsic to the nature of biotechnology? The answer to this question was difficult to determine because of the circumstances under which “Genes in Action” was taught. The teachers and students were primarily concerned about achieving a high mark in the HSC exam. Little time was available to devote to any activities that were outside this primary aim and students were unwilling to learn material they did not consider directly relevant to their exam. This meant that the teachers did not devote time to explaining how the sub-topics of biotechnology were linked when this information was not a requirement for the exam. Therefore, it is probable that the constraints of the exam and the nature of the syllabus were at least partly responsible for the fact that these very able students failed to make a connection between the gene and the method of expression of the gene. However, it is also possible that the subject matter of biotechnology is intrinsically difficult.
6.3.2.2 The difficulty of the subject matter in Biotechnology in Science for Life

Alan taught Science for Life at a comprehensive school in western Sydney. His students were of a different level of ability from those observed at Rivervale and Cleland. Science for Life has been regarded as an option for less able students than those doing other sciences, and Alan agreed that his students were in this category. In the previous year one of Alan’s student had answered the biotechnology questions in the exam and had achieved the highest mark in the state. Alan stated, “She is quite smart and she could have done biology but she wanted to do Science for Life. In some ways I think the topic (biotechnology) had enough science, it was meaty enough for her to get into it... There were a few concrete ideas she could nail down and she got them and could express them really well which made her grades higher.”

About the other students in the class who hadn’t done the exam questions Alan speculated, “I suspect it is because they find other topics easier to do.” Alan’s assessment of the area that many of his students find difficult, is in the understanding of what a gene and a chromosome comprise, what they are and what they do. He claimed that his students find these abstract concepts meaningless (as explained in section 6.2.2)

Venville (1996) identified five aspects of genetics content that make it difficult for teachers to explain to their students. These were:

1. genetics is not open to common experience and requires the use of models;
2. genetics concepts have process attributes;
3. genetics problems can be solved with instrumental understanding and not relational understanding;
4. it is possible to explain units of genetics without integration;
5. students are expected to switch between macroscopic phenomena, submicroscopic explanations and symbolic representations.

The first of these problems, that genetics was not open to common experience and requires the use of models, was similar to the experience related by Alan. He was able to provide examples from common experience for many aspects of the biotechnology subject matter but he was unable to find resources that would explain “what a gene is” in terms of common experience. An understanding of a gene and a chromosome would be necessary before the gene as a process could be explained and before the students could be expected to switch between macroscopic and microscopic phenomena. Given this difficulty with the concept of a gene, it is not surprising that Alan’s students were
reluctant to answer the exam questions on the biotechnology elective. Alan's experience suggests that, for some students, the subject matter of biotechnology is intrinsically difficult because it requires an understanding of abstract concepts such "gene" and "chromosome", and the relationship between these, which are not open to common experience.

6.3.2.3 Teachers and students experience of the difficulty of the subject matter of biotechnology as part of junior science

Teachers of junior science do not have the pressure of an external exam or a rigid syllabus. Thus a biotechnology unit can be made appropriate for the ability of the students. Verity elected to teach the experimental unit to a higher ability class, but she stated that for a lower ability class she would just modify her approach. As the school had no existing program in this area and no previous years tests that would set a standard, Verity was able to decide how much depth of understanding her class needed in order to meet her stated aim of giving them the basic knowledge they needed to make up their own mind about things that affected their own lives. From the material that she eventually included in the course it can be deduced that Verity had decided that this basic knowledge included:

1. define biotechnology;
2. state some examples of biotechnology;
3. read articles that use the jargon of biotechnology;
4. discuss issues in biotechnology using supporting data.

She did not expect them to know the mechanisms of gene expression or of genetic manipulation, although these topics were briefly covered in the videos.

This class had difficulty with the concept that biotechnology involves using cells or parts of cells to make products, instead they used definitions such as "biotechnology is the manipulation of the genes of a living organism". As explained in section 6.2.2, this view came about as a result of the way the unit was initiated. The students had learned about genetic engineering during the "Cells" program. They were then asked to think about biotechnology and the concept maps showed that they defined biotechnology in terms of genetic engineering. In this respect, the implementation of the unit of biotechnology had created a view of biotechnology that had not been anticipated. However, what these concept maps also show is that the students were able to define and give examples of genetic engineering and that they were able to employ accurately many of the terms used in biotechnology, eg splicing, cloning, manipulating and inserting segments of DNA. These students did not have the difficulty understanding the abstract concept of a gene that was reported by Alan.
The class discussion which took place in lesson 7 (described in detail in section 6.2.5) indicated that the students knew enough about biotechnology to be able to give reasoned opinions when confronted with issues. In her original interview Verity had stated, "At least I can start developing some opinions about them (the issues). That is all I want them to do". She mentioned later that she was pleased to find that on several occasions in the lessons the students had mentioned TV shows they had seen that were relevant to aspects of genetic manipulation. Verity thought that the topic had caused them to notice these shows, which they might otherwise have ignored. The appropriate use of language, the forming of opinions and the awareness of issues in biotechnology indicate that the students at Drayton understood enough about the concepts in biotechnology for Verity to have achieved some of her objectives.

Teachers surveyed agreed with the statement that biotechnology was too difficult for junior students. It is hard to interpret this agreement without knowing what program for biotechnology these teachers had in mind. How difficult the topic is depends largely on the teacher's expectations of what the students should learn. Most of the parts of the unit that was called biotechnology at Drayton could be dealt with elsewhere in the junior curriculum. Enzymes are often dealt with in a topic on digestion, DNA fingerprinting in forensic science, IVF technology in reproduction and DNA as part of introductory genetics. Biotechnology is a way of putting all of these ideas into a new context so that the students see how this technology is interconnected into a field of scientific endeavour. Yet many teachers considered that biotechnology was too difficult for the students.

The "Cells" program at Drayton included the topics of dihybrid crosses, the mechanism of meiosis and the structure of DNA. These topics have been reported by others to be some of the more difficult in biology (Finlay, Stewart & Yarrock, 1982; Stewart & Dale, 1989). Explaining these topics would involve some of the difficulties listed by Venville (1996) that were discussed in the previous section. Therefore it is hard to see how the "Cells" topic was intrinsically less difficult than the one subsequently introduced as "Biotechnology". Many schools in NSW teach year ten programs that are similar in content to the "Cells" topic. This means that students in year ten are expected to learn the concepts in genetics that are also taught as part of biotechnology as it was outlined in the Biotech-R unit. As the teachers surveyed were of the opinion that biotechnology was too difficult for the students, it must be assumed that these teachers expected the subject matter of a unit of biotechnology to differ from that taught at Drayton. It is possible that the presence of "Genes in Action" as the most often taught unit of biotechnology in the senior curriculum caused teachers to expect that
biotechnology as part of junior science must be like “Genes in Action” and therefore it must be difficult. Verity did not attempt to teach the steps of protein synthesis or the theory of the operon. She had different objectives for the unit she taught at Drayton and she was able to meet those objectives. The experience of Verity in the case study at Drayton suggests that biotechnology need not be too difficult for students of junior science.

6.3.2.4 Findings of this research
In section 5.3 the assertion was made that biotechnology is too difficult for the students. The findings of the case studies, interviews and the survey have shown that the degree of difficulty of the subject matter of biotechnology is a function of the perceived ability of the students and the syllabus that is taught. The new assertions that can be made about the difficulty of the subject matter of biotechnology are that:
1. aspects of “Genes in Action” are difficult even for the most able students;
2. for some students biotechnology is intrinsically difficult because it involves the concept of a gene;
3. the topic of biotechnology is no more difficult than some other topics taught in junior science.

6.3.3 Assertion: That teaching controversial issues is not an obstacle to the teaching of biotechnology
Ethical issues and how they were dealt with in the classroom were made a focus of the classroom observation because of the importance attached to scientific literacy as a reason for teaching biotechnology (section 2.2). The results of the survey indicated that teachers did not find dealing with the ethical issues a reason for not teaching biotechnology. Those who had taught biotechnology said that teaching about the ethical issues was not a problem. This section describes the way in which ethical issues were dealt with at three schools where a unit of biotechnology was taught. The findings from these case studies are discussed in the context of the assertion made in section 5.3, that the teaching of controversial ethical issues is not an obstacle to the teaching of biotechnology.

6.3.3.1 Overview of the teaching of ethical issues at Rivervale, Cleland and Drayton High Schools

Rivervale
It is not surprising that ethical issues were not identified as a problem in "Genes in Action" as this section of the syllabus is very small. In previous years there have been few exam questions in this area. In one instance observed at Rivervale, Rob was
reading out an exam question on genetic engineering that asked students to give one reason why genetically engineered insulin is bad and one reason why it is good. No one could think of a reason why it might be bad, including Rob, so he read out a sample answer provided by the HSC markers. The reason given was that the population is genetically weakened by allowing diabetics to persist. This answer caused a commotion in the class; most students were rather indignant at this disregard for the rights of people with diabetes. Rob agreed that he did not think that it was a very good question to ask but all he could do was shrug and present what was written. This example highlighted a problem of ethical discussions, which is that it is difficult to escape the need for a "right" answer when a course is directed to an exam which consists of a series of short answer questions.

With the exception of this example, Rob dealt with the ethical issues as they came up. His class were very ready to discuss and question at all times and he was happy to answer questions. In the interviews he did not express any views that biotechnology was good or bad. He was not committed to teaching it because he felt the students needed to deal with these issues in their lives but rather because it was a subject in which his students could achieve high marks in the exam and it was a subject in which he had experience. The other teachers at Rivervale were more eager to give their opinion on controversial issues in biotechnology when they heard about the proposed research. Of the teachers who participated in this research Rob was the least interested in the ethical issues. Outside the classroom both Michael and Verity expressed concern about specific problems that they saw as being important. However, in the classroom they believed in encouraging open debate and they refrained from expressing their own opinions.

**Cleland**

Michael used a recent ABC documentary which he had taped himself to introduce the topic of ethical issues in genetic engineering to the students at Cleland. At the end of the video there was murmuring about how interesting it had been. The video described recent gene therapy techniques and discussed the ethics of using gene therapy for cosmetic purposes or to enhance intelligence. In the lesson that followed the video session Michael put notes on the board about natural and artificial selection and went through the technical side of genetic engineering. He held up a few newspaper articles that he had collected and left them in the resources box for the students to read in their own time. He did not try to discuss the ethics any further even though he pointed out that they needed to know something about the ethical issues for the exam. The class did not raise any questions on the material in the video, although Alicia had previously shown an awareness of issues. For example, in an earlier lesson, she commented that she had read that the human genome project could be used to support racial persecution
and looked as if she would like to argue about this but Michael had been unwilling to debate the subject then. His reason for doing this was that he did not have the time to spare for an ethical debate when there was so much else that had to be taught.

During the last lesson in the last week of term, time was available for a more informal discussion that took place about the future of genetic manipulation and where it might lead. Michael revealed a degree of cynicism about the ability of laws and government committees to prevent eugenic experiments. Debbie and Alicia were more convinced that governments would never be allowed to get away with it (ie creating a super race). Alicia brought up the issue of eating tomatoes and chips that had been genetically engineered, something about which the rest of the class were not concerned. Having allowed some exchange about the possible disadvantages of the technology Michael deliberately asked, "Well, what are the good things about it". Sharon said that she had read about how cystic fibrosis could now be cured.

For the teachers and students of “Genes in Action” observed in these case studies the discussion of ethical issues was limited by the syllabus, the examination and teacher interest. The discussion of ethics was only a minor part of the syllabus and there have been few questions that relate to ethics in the recent exam papers. As time was needed to cover the other topics in the syllabus, the teachers and students did not follow up many promising avenues for debate. The discussions that took place showed that both teachers and students were capable of an open exchange of ideas when this was warranted.

Drayton
Time also became a major obstacle to the discussion of ethical issues in biotechnology at Drayton. Verity was hampered by time constraints, particularly the need to complete the topic, as programmed, before the term tests which were set by the School Science Department. Verity had thought to direct her biotechnology teaching toward giving the students the basic knowledge they needed to discuss ethical issues. Following lesson six, a period that had been allocated for biotechnology was cancelled due to a school excursion. That left only one more period that could be devoted to biotechnology, and Verity decided that priority should be given to a discussion of some ethical issues. Under other circumstances more time might have been allocated to leading up to this lesson. At various points during the course Verity had speculated on approaches to a lesson on ethics. Debates, role plays and group research on specific issues had been considered. All of these approaches required more time than Verity had available. She also considered that there were insufficient resources available to allow the students to
research an issue for themselves. In the end, Verity based the lesson on a video that she said was effective in presenting the important issues.

This video took the format that a question was posed, e.g. "Is it right to interfere with nature?", some background information was given and then a range of prominent people aired their opinion on the question. After the students had watched the video, Verity asked them to discuss the same question in their groups, record a group opinion and then report to the class. Extracts from this discussion that represent opinions expressed, both in this lesson and in previous lessons, are presented below.

The first question posed by the makers of the video was "Is it right to interfere with nature?".
Most groups expressed similar responses to Hazel’s group, who reported, "People have always interfered with nature. I’m saying that from when he was hunter gatherers man has always changed things."
Verity asked why, and Hazel elaborated, "Because sometimes it’s helpful and other times you are interfering with nature."
Someone else in Hazel’s group called out, "Yes, it depends which way you are interfering with nature."
Damien tried to be more explicit, "I reckon it’s good making insulin and bad choosing the sex of a child."
Verity proposed the situation of parents who could not have a child by any other means than modern genetics, and asked, "Are you going to tell them 'no you can’t' when the techniques are available?"
Damien said, "You just tell them."
Ellie contributed, "With choosing the sex of the child, well you can’t tell them you can’t have kids but you can tell them you can’t choose which baby you have."
Manda described a documentary she had seen, about a family who had two boys with a genetic disease and who were not willing to have another child unless it was a girl. She thought this was a case where the reasons were good enough to allow the parents to choose the sex of the child.

In previous discussions, on a range of specific issues, the students had been of the opinion that it was wrong to interfere with what was natural, particularly if there was "no good purpose". Cloning was seen by a number of students as being a waste of time. Evan said it was "stupid and unnatural". Tracey said, "But why would you want to clone people? If they are not going to be the same person but just look the same?"
All the videos shown to the class had been largely supportive of genetic manipulation. The makers had been careful to present alternative opinions but the overall impression given was that biotechnology has great potential. In spite of this exposure, some of which came directly prior to the discussion, most students were reluctant to give more than qualified support to the use of biotechnology.

The second question the class discussed was, "Is biotechnology a threat to the environment?" and the overall view in the class was "yes". The group recorded by the observer thought that even blue roses might be a risk because aphids could transfer something from plant to plant. Pete reported that his group said, "Yes, it could affect the environment, like changing a plant could affect the animals and other living things that rely on it." Even when challenged Pete was convinced that "the gene stuff" could be passed from plants to animals. Another student reported that we are already killing the rainforest and, if we allow new biotechnology the rainforest might be "eaten away". Is it reassuring or frightening that these students are so convinced that biotechnology is likely to cause damage in spite of all the video presentations that claimed the contrary?

A segment of the discussion on issues dealt with student power and how they could make a difference. During the debate on when it would be right to choose the sex of a child, Verity brought up the question of who had a right to make these decisions. One of the more outspoken members of the class, Lyle, interrupted the discussion with,

"Miss, anything we do say isn't going to stop what they do."

Verity followed up this lead, "What's negative about your statement? Who's they?"
Lyle replied, "It's too easy to make mistakes."

Verity insisted that he explain who "they" are but Lyle was rather vague about this. He loudly reiterated the view that "no matter what we say, they're never going to listen to us." This caused a lot of opinions to be muttered around the room although whether in agreement or disagreement would be hard to say. After some discussion the class identified "they" as the government, the scientists, private business and the community.

Lyle persisted in his argument, "If I go to the government and say my opinions, they will not listen to me."

Verity emphasised that they should all realise that they could influence the people who make decisions. This discussion had given her a useful opportunity to make this point, which she considered to be one of the more important points to be made in any course that deals with the ethical issues in biotechnology. Throughout the discussion Verity had also been consistently reinforcing to her class the need to give reasons for all their answers. This intention to encourage the students to think about the issues that would affect them had been one of her prime objectives in the teaching of biotechnology.
6.3.3.2 Other points about the discussion of ethical issues

The students interviewed at Rivervale were asked whether they were interested in any of the issues, for example about the ethics of human cloning. Of the group Kim was most interested and Lisa expressed some interest but seemed to be inhibited by her lack of confidence that she understood enough about the science of biotechnology. The ensuing discussion, an extract of which is shown below, brought out some other points about dealing with ethical issues in a biotechnology unit.

Kim stated, "I mean, to make biology a more attractive career for kids you could teach more of the ethics and issues of genetic engineering but you can't go into too much depth because it is going to be irrelevant to probably 90% of the class."

Louise replied, "It just comes back to the opinion of the teacher. The teacher feels strongly about it so the kids just say forget it or the teacher doesn't feel strongly about it and the kids don't really care at all. The answers to the questions are just what the teacher thinks."

Kim added, "At least it's good to make them aware of the issues that are there. That's the same when you do evolution, they have this discussion about creation theory and evolution and I remember we used to have debates about that..." (some reminiscences of past classroom wrangles occurred here) and Kim continued, "Yes, but at least they make you aware of the issues and they could do the same in genetics."

Louise's comment was, "When you are exploring ethical questions it always ends up that somebody has got an opinion that gets these people into trouble a lot (murmurs of agreement) and that's not necessarily a good thing. Kids have still got to think for themselves but that can be difficult."

In contrast to Louise's expectations, the teachers observed in this study were able to allow the class to express their own opinion and most students were willing to participate in these discussions. The indications were that students retained their own opinions of the value of specific uses of biotechnology, and the answers were not "just what the teacher thinks." Indeed the teachers revealed very little of their own opinion in the classes observed and any bias that was observed was most evident in the videos. These videos were not selected by the teachers to represent their opinions. In each case, the teacher had tried to find a video that would present both sides of the argument. Although both arguments were presented, the videos placed more emphasis on supporting the use of biotechnology, and in extolling its potential, than they did on pointing out its possible disadvantages. Yet many of the students remained convinced that there were disadvantages even when they did not have the scientific knowledge to explain them. They 'knew' that "things had gone wrong before", that "scientists could
not be trusted” to know all the outcomes of their experiments and they were prepared to assume that mistakes could happen again.

6.3.3.3 Teaching with ethical issues
It has been suggested that ethical issues can be used as a tool to teach students the more abstract concepts in genetics that they have traditionally found to be difficult. Van Rooy (1994) recommends using controversial issues to stimulate student interest and learning in a number of areas of science including biotechnology. The human genome project was suggested by McInerny (1996) as offering a way of broaching some of the more complex concepts in genetics in a more engaging way than is currently used. He also argued that by using an issue as the topic of instruction it was possible to avoid “the tendency to subordinate the central concepts of science to a concentration on facts” (p. 12).

Cross and Price (1994) also recommend the use of ethical issues to teach science content. They chose the topic of Biodiversity for their study. This topic presented a challenge because it was remote from students' experience, required attention to the relation between the realm of observation and theory production and involved tackling some concepts in genetics. Cross and Price (1994) proposed that using ethical issues as a basis for the teaching of this topic would reduce these difficulties.

The obstacles to the teaching of biodiversity are similar to the difficulties identified in the teaching of the subject matter of biotechnology (section 6.3.2). From the findings of the survey, interviews and case studies, it has been established that students are interested in the ethical issues in biotechnology and that teachers do not find dealing with ethical issues to be difficult. Therefore, the teaching of ethical issues may offer a way of designing a program for biotechnology that overcomes some of the problems in the teaching of biotechnology that have been identified by teachers in NSW.

6.3.3.4 Findings of this research
In summary, the studies described support the assertion made in section 5.3 that discussion of ethical issues was not a problem in the teaching of biotechnology. The only problem encountered in dealing with ethical issues was the lack of time available for class discussion as a result of the crowded curriculum.

6.3.4 Assertion: That a program is needed for the teaching of biotechnology in junior science
In section 5.3, the assertion was made that teachers need a program for biotechnology if they are to teach this subject in junior science. As discussed in section 5.2.3, the lack
of a program may have meant that too much time would be needed in the preparation to teach biotechnology (ie writing a program); that the program would need a practical component, and teachers perceived biotechnology to be lacking practical work; and that other topics would have to be replaced. It was reasoned that one way to overcome the obstacle presented by the lack of a program would be to prepare the outline of a unit of biotechnology, developed in response to the concerns of teachers. Such an outline was prepared offered to a number of teachers. This section describes difficulties that were encountered during the trial of this unit of biotechnology at Drayton High school. This leads to a new assertion being made about the need for a program for biotechnology as part of junior science.

6.3.4.1 Experiences with implementing the unit of biotechnology
The unit of biotechnology designed for this research, referred to as the Biotech-R unit, was designed to overcome the problems that there was not enough practical work in biotechnology and that the subject matter was too difficult for the students. The unit incorporated a number of biotechnology practicals that had been tested in classrooms. The experience of Alan was used as a guide and emphasis was placed on relating biotechnology to the everyday experience of the students. The practicals included using micro-organisms to make a product (eg bread), extracting DNA, making a model of DNA, using the enzyme renin to make junket and using the enzymes in pineapple to breakdown the protein collagen. Students were asked to find out more about collagen, from sources relating to cosmetics and some information on the nature of collagen as a protein was provided. The emphasis on collagen was intended to lead into a discussion of how genes code for proteins as collagen contains only three amino acids and it has a very simple code. By including the work on collagen, the unit dealt with the need to explain the concept of a gene and how it works, an area shown to be difficult for some students (section 6.2.4). The unit also provided an opportunity to discuss ethical issues so that students would have the basis for rational decision making, as suggested in section 6.2.5 The principle objective of this unit was stated as “to give students enough understanding of the basic science behind biotechnology to allow them to make informed decisions about what genetic manipulation means to their lives”. What the unit did not do, was specify a method of teaching the material. The intention was to allow the teacher to use an approach consistent with their normal classroom method.

In spite of the importance given to the concerns of teachers during the design of this unit, problems were encountered in carrying out a trial of the unit in the classroom. A number of teachers were approached about participation in this trial and most did not have time to read the material. Two teachers from the science department of one school agreed to conduct the trial after asking for more detailed lesson plans to be provided with
the unit outline. Although these lesson plans were provided these teachers withdrew from the trial, explaining that they did not have time for the preparation that would be required. Lack of time was also a problem for the teacher who subsequently agreed to conduct the trial of the unit. As explained in section 6.1.1, the unit had to be shortened to two weeks because of the requirement to teach the other year ten topics. This meant that further modification of the unit outline was required. The Biotech–R unit also required modification because the students that Verity was teaching had previously been taught about genetic engineering and the lessons had to take into account this prior knowledge.

Another area where time and effort had to be spent was in the implementation of the practical work. Verity had reservations about the practicals that were included in the biotechnology unit. Initially she supported the idea of including practicals but she was less convinced of their fruitfulness after carrying them out in the classroom. In particular, she said that they were not in a form in which they could be used without modification, and they required a lot of time for preparation.

Verity conducted both the bread dough and the DNA extraction practical that were included in the biotechnology unit. At the time of the bread dough practical she commented that she had had to rewrite the work-sheet and this had taken some time. The rewriting was necessary because the work-sheet provided gave instructions for putting one gram of yeast into 50 mL of water and the classroom did not contain a balance that would weigh one gram. The students used spring balances for weighing out 75g of flour and there were very wide variations in the amount of flour acquired by different groups. This resulted in many very sticky doughs and these left a lot of mess in the containers. Verity explained this to the laboratory technician and offered to clean the glassware herself. This was a relatively straightforward practical, but it still caused a lot of work because it was being done for the first time under these particular laboratory conditions.

Similar problems were encountered with the practical involving DNA extraction from peas. This practical came with a detailed protocol as part of the Biotech–R unit. In the light of the students difficulties with the bread dough, the DNA extraction work-sheet was modified so that the students carried out fewer steps. This new procedure required that the laboratory assistant prepare an extract of dried peas and detergent. By accident, the laboratory assistant used split peas instead of dried peas and the detergent extracted nothing. A new extract was made by the researcher and brought into the classroom. Again, much time had to be devoted to sorting out those obstacles to the running of the practical that occurred because it was new to the school.
These two examples illustrate that the biotechnology unit was atypical in that it generated more work, both for the laboratory technician and the teacher, than the often repeated practical work in other topics.

When designing the Biotech-R unit the specific circumstances relating to Verity’s classroom were not foreseen. The result was that the unit outlined was too long, it was designed for students with no prior teaching in genetics and the practical work could not be carried out without modification. Hence the unit was not, nor could it have been, suitable for the particular conditions that prevailed at Drayton High school.

6.3.4.2 Findings of this research
The assertion made in section 5.3 was that the lack of a program prevents teachers from teaching biotechnology as part of junior science. The findings of the survey, interviews and case studies are, that teachers require a program for biotechnology if they are to teach this subject as part of junior science and that program must take into account the particular conditions that prevail in the teachers classroom environment.

6.4 Findings from the case studies, interviews and survey
The main problems associated with the teaching of biotechnology are that:
1. many teachers do not have the knowledge and experience to adequately teach biotechnology;
2. practical work is available that will stimulate interest and motivation but not enough practical work is available to enhance the learning of sophisticated aspects of biotechnology such as protein synthesis;
3. aspects of biotechnology in “Genes in Action” are difficult even for the most able students;
4. some students find biotechnology intrinsically difficult because it involves genetics;
5. teachers do not have a program for biotechnology in junior science.

It has also been shown that:
1. the topic of biotechnology, of itself, is no more difficult than other topics taught in junior science;
2. teachers require a program for biotechnology if they are to teach this subject as a part of junior science and this program must take into account the conditions of each teacher’s classroom;
3. teachers consider biotechnology to be interesting and important;
4. the teaching of controversial ethical issues is not a problem in the teaching of biotechnology.

The implications of these findings are discussed in chapter 7.
Chapter 7
Implications of the study for the teaching of biotechnology

In section 2.4 the problems encountered by teachers in the teaching of biotechnology were listed as:

- lack of teacher expertise in the area (McInerny, 1990; Zeller, 1994);
- lack of resource materials (McInerny, 1990; Zeller, 1994);
- lack of time to fit in another topic (McInerny, 1990; Zeller, 1994);
- lack of student understanding of the concepts (Venville & Treagust, 1996);
- the need for innovative teaching methods (McInerny, 1990);
- difficulties due to the controversial nature of the material (McInerny, 1990).

These problems were used as a basis for the investigation of the teaching of biotechnology in NSW. The findings of the investigation show that problems associated with the teaching of biotechnology are that:

1. many teachers do not have the knowledge and experience to adequately teach biotechnology;
2. practical work is available that will stimulate interest and motivation but not enough practical work is available to enhance the learning of sophisticated aspects of biotechnology, such as protein synthesis;
3. aspects of biotechnology in “Genes in Action” are difficult even for the most able students;
4. some students find biotechnology intrinsically difficult because it involves genetics;
5. teachers do not have a program for biotechnology in junior science.

It has also been shown that:

- the topic of biotechnology, of itself, is no more difficult than other topics taught in junior science;
- teachers require a program for biotechnology if they are to teach this subject as a part of junior science and this program must take into account the conditions of each teacher’s classroom;
- teachers consider biotechnology to be interesting and important;
• the teaching of controversial ethical issues is not a problem in the teaching of biotechnology;

Of the problems listed in section 2.4, those found to be important to the teachers of NSW were those associated with:
• lack of teacher expertise in the area;
• lack of resource materials, in particular the lack of practical work;
• lack of student understanding of the subject matter.

In addition, a new problem was highlighted by the teachers in NSW, the lack of a program for biotechnology as part of junior science. This problem may have been related to the problem, “lack of time to fit in another topic” that was reported by McInerney (1990). However, time to fit in another topic was only one factor that affected the development of a program for biotechnology. The requirements of the NSW syllabus and the lack of time for designing and implementing the program were also found to be an obstacle (section 6.3.4).

In section 2.5 it was stated that it was important to identify the problems that teachers encounter in the teaching of biotechnology in order that these obstacles can be overcome. The findings developed from the evidence presented in chapter 4, 5 and 6 identify the problems. In chapter 7 some suggestions are made as to how the findings of this study can inform the teaching of biotechnology in NSW.

7.1 What is the nature of a successful unit of biotechnology?
Baird and Penna (1996, p.257) have argued that “the extent to which a learner expends effort in learning, and ultimately experiences success, is influenced by the extent to which he or she feels challenged by what is to be done”. These authors define challenge as a balance between cognitive components (demand) and affective components (interest/motivation). In order to be challenging a task must be both demanding and interesting. It is further suggested that the teachers as well as students must be challenged by the science that is conducted in schools. Baird and Penna (1996) found that much of the science taught in school failed to be challenging and the causes of this failure were “dependent on particulars of various pedagogical, curricular, personal and interpersonal, and contextual factors that are operating in a given classroom” (p.268).

Using the framework provided by Baird and Penna (1996), it is contended that much of the existing syllabus for biotechnology in NSW has failed to challenge teachers and
students. The findings of this study suggest reasons why this is the case and these will be discussed below.

7.1.1 Biotechnology in the senior science curriculum

7.1.1.1 Genes in Action
It has been shown that many teachers do not have the knowledge and experience necessary to teach the elective “Genes in Action”. That is, many teachers find the subject matter of this elective difficult. This elective has also been shown to be difficult for most students (section 6.3.2). Using the terminology of Baird and Penna (1996), it can be said that “Genes in Action” is demanding for both teachers and students. Indeed, the findings of this research suggest that “Genes in Action” may be too demanding for both teachers and students.

It has also been shown (section 6.3.1) that there are very few practical activities that are relevant to this elective and that the participation of students in many of the activities that they find interesting (practical work, excursions and class discussion of issues) is limited by the need to complete the topic for the HSC exam. That is, “Genes in Action” is low in interest, particularly when compared with other electives offered in 2U biology.

As this elective does not achieve a balance between demand and interest, the topic does not meet Baird and Penna’s (1996) requirements for challenge.

7.1.1.2 Science for Life
The module of biotechnology taught in Science for Life was interesting for the teacher and students (section 6.2.2.3). Many practical activities could be included because the aims of the syllabus were very broad. Resources for its teaching could be gleaned from the popular media, including newspapers, magazines and television. However, it was also the case that the students of Science for Life found the genetics component of the subject matter of this module to be difficult (section 6.3.2). For these students the biotechnology module was both interesting and demanding, and therefore it would meet Baird and Penna’s (1996) criteria for challenge.

The Biotechnology module in Science for Life was shown to meet the criteria for challenge. Why, then, is this subject studied by so few students in NSW? Two possible reasons for this are that:
1. The Science for Life elective lacks demand
Science for Life has been regarded as a “soft option” by both students and teachers and has been studied by those students who had little interest in traditional school science. That is, the topic of Science for Life as a whole, is seen as lacking in demand. The “biotechnology” module is only a small part of Science for Life and this elective alone is insufficient to make the topic challenging.

2. The biotechnology electives are more demanding than other electives offered for the HSC exam
The findings of this research suggest that, where a number of electives are offered for an external exam, the balance between interest and demand needs to be similar in each of the options. For students who studied Science for Life, the exam questions offered in other electives were easier. In order to achieve the highest mark in the HSC exam, students chose to answer the questions on electives other than “Biotechnology”. Teachers of 2 Unit Biology also found that electives other than “Genes in Action” offered a more satisfactory balance for their students, and these electives were taught in preference. It follows that biotechnology will not be taught as an elective for the HSC, until the unit offered has a similar level of challenge to that of other elective topics.

7.1.2 Junior science
The findings of the survey were that most teachers in NSW did not currently have a program for biotechnology in junior science. Thus the teaching of biotechnology was inhibited by the lack of a unit of work on which teachers could base their planning, teaching and preparation. The question of challenge in a junior science unit of biotechnology did not arise.

7.1.3 Summary
“Genes in Action” fails to be challenging because it is high in demand but low in interest. “Biotechnology” as part of Science for Life is challenging (both demanding and interesting) but in order to achieve high marks in the HSC exam students choose other electives. In junior science, few teachers have developed a program for biotechnology. Thus, the secondary school system in NSW does not offer a curriculum in biotechnology that is both challenging, and of a similar degree of challenge, to other HSC electives. Therefore, few students in NSW are studying biotechnology.

7.2 Development of a challenging program for biotechnology in NSW
How can a curriculum that incorporates a program for biotechnology that meets Baird and Penna’s (1994) criteria for challenge be made available? One solution would be to change the nature of the senior curriculum so that a different set of options for the study of biotechnology are offered. An elective that is both demanding and interesting could
be designed for 2 Unit biology. However, it should be noted that if this approach was taken, all electives for 2U Biology would need to be similarly challenging. Another alternative might be the inclusion of a challenging unit on biotechnology in the core of the senior curriculum. Features of such a unit would include:

- discussion of issues in biotechnology that relate to the students' lives;
- practical work, for example extraction of DNA, digestion of collagen;
- a broad range of examples of biotechnology—from bread making to genetic engineering.

Changes to the syllabus for all HSC subjects are necessarily long term changes. Teachers are not at liberty to design their own curriculum for biotechnology. The interests of many groups, including parents, university educators and politicians influence change to the HSC curriculum. Hall (1997) describes the dynamics of coping with the introduction of the new HSC syllabus for geography. The experiences of teachers in that study show that change to the senior curriculum is very complex. It is possible that, in the future, a syllabus for a biotechnology unit could be designed for the senior curriculum that is both demanding and interesting for students and teachers. However, an investigation of the ways in which such a change may be implemented in the senior syllabus is beyond the scope of the present study.

The Biotech-R unit, prepared for junior science as part of this research, combined the features regarded by teachers as being necessary for the teaching of biotechnology. That is, it included practical work and discussion of issues, and was designed to be no more difficult than other year ten topics. This unit met the criteria set down by Baird and Penna (1996), in that it was both demanding and interesting. Therefore, it was suggested that this unit was a fruitful way to incorporate biotechnology into the school curriculum in NSW. The outcome of the trial of this unit of biotechnology, however, has implications for the way in which a program for biotechnology should be designed and implemented if the teaching of biotechnology is to be successful.

7.2.1 A biotechnology unit: Implementation versus school development
Research has shown that implementing change to the curriculum is not easy (for a review see Kennedy 1997; Cuban 1990). As Duffee and Aikenhead (1992, p.493) state, "programs of study in themselves cannot bring about a change". These authors point out that "teachers adapt a curriculum in ways they think are most appropriate for each specific teaching situation" and they make these adaptations based on feelings and impulses that are learned from life's experiences and past teaching assignments". Connelly and Clandinin (1995, p.7) call this teacher practical knowledge. They define it
as "that body of convictions and meanings, conscious or unconscious, that have arisen from experience (intimate, social and traditional) and that are expressed in a persons practices. Others (Wallace and Louden, 1992; Lantz and Kass, 1987) have also found that the way teachers interpret a given curriculum is a function of the teachers practical knowledge.

Not only are teachers influenced by this practical knowledge, Connelly and Clandinin (1995) assert that teachers are influenced by their 'professional landscape'. That is, the environment in which they operate outside of the classroom. As Lantz and Kass (1987, p.133) state, "the teaching assignment (including both number of students and number of different subjects taught), number of colleagues, and school resources seem to influence curriculum interpretation". Fullan (1991) also concludes that two things that emerge as important for educational change are the teachers functional knowledge (which is analogous to practical knowledge) and the classroom situation.

Similar conclusions were drawn from the study at Drayton. These were, that the school environment in which Verity was located, her own classroom situation and her practical knowledge as an experienced teacher affected the implementation of the unit of biotechnology. The school environment influenced Verity in that she had to deal with the restraints imposed on her by the lack of support from the other science staff, the concerns of the laboratory technician about preparing and cleaning up practicals, and the limited resources available in the school. She had to comply with the school assessment procedures, which meant testing her class separately on the biotechnology topic and giving her class the teaching necessary so that they could complete all of the other topic tests. These school based constraints ensured that Verity had very little time in which to do the teaching of, and the preparation for, the biotechnology unit.

The Biotech-R unit was developed from what Gunstone (1996) calls researcher knowledge. This knowledge is broad but lacks context. Hence, the unit produced was generic, rather than specifically designed for Verity and her class. As a consequence of her practical knowledge, Verity decided to change the outline of the unit and develop new lesson plans and work-sheets (thereby creating extra work) appropriate for her classroom environment. The generic work-sheets that had been provided for the practical work were not appropriate for the specific laboratory conditions in Verity's classroom. Verity had to take into account the previous learning of her class and some sections of the unit outline had to be deleted because the students had already been taught these topics. In response to the confusion that arose over the definition of biotechnology, Verity modified her lesson plans. Her practical experience indicated that her teaching approach was not working in that class at that time and she had to take steps
to correct any misconceptions that were occurring. This meant a further deviation from the Biotech-R unit that was provided.

As a result of the influence of this teacher’s practical knowledge and the teacher’s landscape, the unit that was eventually taught bore little resemblance to the Biotech-R unit that Verity had been offered. This happened despite the fact that this unit had been developed in response to the needs specified by teachers in NSW. The study at Drayton may have been an example of the sort of innovation described by Fullan (1991, p.130) as “rationally sold on the basis of sound theory and principles, but they turn out not to be translatable into practice with the resources at the disposal of teachers”. Because the Biotech-R unit did not take into account the features of Verity’s preferred teaching styles, school and classroom environment, and it could not anticipate the strategies that would be necessary to solve problems that occurred in the classroom, the unit was not, and could never have been, implemented in an unchanged form.

Having struggled with the unit that she eventually taught, Verity made up her mind how she would teach it next year and how she should best present the subject matter so that it would suit her class and her approach to teaching. There may be no short cut to this process. However, teachers often take up a program and teach it with a minimum of modification when that program has already been taught in their school. In that situation the resources are available, the laboratory technician has experience with the practical work, other teachers can suggest explanations of difficult subject matter and the writing of assessment tasks can be shared. The time and effort involved in implementing a program designed in the school is likely to be much less than that needed to implement and adapt a program that has been designed externally. Because Verity was motivated to make the effort for reasons of her own, Drayton High School has now developed a biotechnology unit. If the researcher had a role it was in providing some resources and in providing impetus to start the process. It was not in the provision of a fixed unit to be taken up by all the schools in NSW.

Pendretti and Hodson (1995) have recommended that curriculum development should occur at the level of the local school environment. They state, “It is our contention that effective STS curriculum development requires that groups of teachers who know the students, the locality and the school environment well, are brought together to work on theoretical and practical issues related to the design and implementation of learning experiences in a critical and supportive environment” (p.468). These researchers consider that the researcher has an important role as the facilitator of this school based curriculum development. Parke and Cable (1997) also suggest that teachers should be involved in the design of curriculum and they recommend that professional development
focus on making teachers aware of "the value of continually testing, revising and re-evaluating curriculum and instructional issues" (p.773). The findings of the study at Drayton confirmed the importance of school based curriculum design and the need to encourage teachers to be involved in curriculum development.

However, the observation was also made that the school environment does not support this method of curriculum change. When teachers were asked to collaborate in the development of a program for biotechnology they stated that they did not have time to spare in reading and preparing the material to be included. The researcher could provide resources and ideas but this was not enough to encourage teachers to commit the time that was required for the development of a new program. Teachers will only have time for curriculum development if changes are made to their allocation of work. This in turn requires administrative changes at the level of the school and the education department.

7.3 Further Research
Experience in the implementation of a unit of biotechnology in junior science in NSW led to the proposal that such a unit should be developed within the school. A fruitful area of future research would be to test this proposal. This would involve teachers, in collaboration with a researcher, developing a program for biotechnology. This in situ development and implementation of the program could then be the subject of a detailed investigation. Although this research would concentrate on the topic of biotechnology, because it is an important part of science education which has hitherto been poorly implemented and rarely researched, its findings would lead to recommendations regarding the introduction of new science topics into the school curriculum.

The present study has considered the implementation of changes to the teaching of biotechnology only in the context of the NSW junior science curriculum. Changes to the senior science curriculum were not within the scope of this study. However, two education systems in Australia (Victoria and the ACT) have introduced biotechnology into the core senior science curriculum in recent years. A study of the implementation of these changes, including the approaches adopted by teachers and input from students, would provide valuable information about possible approaches to the inclusion of biotechnology in the senior science curriculum in NSW.

During this study, in particular the preparation of the outline of a biotechnology unit for 10, the Internet was used as a source of resources. Others, White (1991) and McNerny (1990), have also reported the increasing importance of the Internet as a tool for the teaching of biotechnology. A question that could be addressed in future research is "To what extent to NSW teachers consult the internet for biotechnology?"
7.4 Conclusion
The teaching of biotechnology in NSW has been inhibited by the:

- lack of teacher knowledge and experience with this subject;
- difficulty of the subject matter;
- lack of practical work that enhances student understanding of the subject matter;
- lack of a program for biotechnology as part of junior science;
- lack of time to collaborate in the development of a school based biotechnology program.

These problems could be minimised by changing the curriculum in NSW so that the programs of biotechnology offered were both demanding and interesting. Such a program of biotechnology could be developed as part of the science curriculum in years 7-10, and the year 11 and 12 biology course. These programs must be appropriate for the particular school environment in which they are to be taught. It is suggested that a program for biotechnology not be externally devised, but rather be designed and implemented in schools by teachers in collaboration with the researcher. If this is to happen, a school environment must be provided which supports teacher involvement in curriculum development.
Appendix 1

Survey of Biotechnology in the School

Section 1. Personal details.

1. Your gender (please tick)  MALE □  FEMALE □

2. Your highest qualification in education is (please tick)
   Diploma □
   Bachelor □
   Master □
   Doctor □

3. The number of years you have been teaching  ____

4. If you teach Senior Biology please state how many years you have been teaching this subject area  ____

5. What was the major subject of your undergraduate study (please tick)
   Physics □
   Chemistry □
   Biology □
   Geology □

Other (please specify) __________________________

6. Your highest qualification in science is
   Diploma □
   Bachelor □
   Master □
   Doctor □
Section 1 continued overleaf
7. Do you have special expertise in biotechnology e.g. have you worked in industry or a technology lab (please circle)

    Yes    No

8. Have you had special training in teaching biotechnology e.g. in-service course (please circle)

    Yes    No

Section 2. Teaching in 1995/96

9 (a). In 1995/96 have you taught any of the following subjects at HSC level (Please tick)

2U Biology
Science for Life
3/4U Science
General Science

9(b). In 1995/96 have you taught, or are you going to teach, either of the following electives.

Genes in action (2U Biology)
Biotechnology (Science for Life)

Section 2 continued overleaf
10. For each of the following areas of biotechnology please estimate the number of periods you would have taught that topic to the specified year. For example, if you have taught DNA fingerprinting to Year Ten for three periods fill in the table as shown.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Year 7</th>
<th>Year 8</th>
<th>Year 9</th>
<th>Year 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNA fingerprinting</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

**NUMBER OF PERIODS**

<table>
<thead>
<tr>
<th>TOPIC</th>
<th>Year 7</th>
<th>Year 8</th>
<th>Year 9</th>
<th>Year 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>In vitro fertilisation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Genetic engineering</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DNA fingerprinting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monoclonal antibodies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New biological technologies in food production</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New biological technologies in waste management</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>An area of biotechnology not listed above. Please specify:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10. Please specify the length of periods in your school _________

Please turn over for section 3
Section 3: Reasons why you did not teach biotechnology

Research in other countries has shown that the teaching of biotechnology has been hindered by a number of factors. A pilot study for this survey obtained the following comments from teachers about the reasons why they did not teach biotechnology. We wish to find out the importance of these reasons to you.

11. If you did teach 2U Biology but not the elective Genes in Action please rate the following reasons for not doing the elective (circle a number)

<table>
<thead>
<tr>
<th>Reason</th>
<th>strongly disagree</th>
<th>disagree</th>
<th>neutral</th>
<th>agree</th>
<th>strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>There are not enough references</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Others teach that part of the curriculum</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The students find it boring</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I feel I do not know it well enough to teach it</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>It is not important to my students</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Not enough practical work can be done</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I do not have the time to fit in another topic</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>It is too controversial</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The exam questions are too hard</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The school does not have a program for it</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The students find it too difficult</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Please give any other reason why you do not teach this elective.

____________________________________________________________________________________

____________________________________________________________________________________

____________________________________________________________________________________

Section 3 continued overleaf
12. If you did teach Science for Life but **not the module Biotechnology** please rate the following reasons for not teaching the module (*circle a number*)

<table>
<thead>
<tr>
<th>Reason</th>
<th>strongly disagree</th>
<th>disagree</th>
<th>neutral</th>
<th>agree</th>
<th>strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>There are not enough references</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Others teach that part of the curriculum</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The students find it boring</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I feel I do not know it well enough to teach it</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>It is not important to my students</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Not enough practical work can be done</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I do not have the time to fit in another topic</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>It is too controversial</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The exam questions are too hard</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The school does not have a program for it</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The students find it too difficult</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Please give any other reason why you do not teach this module.

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

Section 3 continued
13. If you did not teach **genetic engineering** to Years 7-10 please rate the following reasons why you did not teach this subject *(please circle a number)*

<table>
<thead>
<tr>
<th>Reason</th>
<th>strongly disagree</th>
<th>disagree</th>
<th>neutral</th>
<th>agree</th>
<th>strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>There are not enough references</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Others teach that part of the curriculum</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The students find it boring</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I feel I do not know it well enough to teach it</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>It is not important to my students</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Not enough practical work can be done</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I do not have the time to fit in another topic</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>It is too controversial</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The exam questions are too hard</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The school does not have a program for it</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The students find it too difficult</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Please give any other reason why you do not teach this subject.

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

Please turn over for section 4
Section 4: Experiences of biotechnology teaching.

14. The statements below sum up the experience of some teachers who had taught biotechnology. We wish to know how well these comments sum up your own experience. If you **have taught a unit of work that incorporates all or most of the topics listed in question 10**- please rate the following comments.

<table>
<thead>
<tr>
<th>Reason</th>
<th>strongly disagree</th>
<th>disagree</th>
<th>neutral</th>
<th>agree</th>
<th>strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finding information was difficult</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>There were too many controversial issues</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The students found it boring</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I need to learn more about the topic</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>It is not relevant to the student's lives</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Not enough practical work can be done</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The school did not support this new area</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Discussing the controversial issues was hard</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>It was exciting, the class loved it</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>This is an important area of biology</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The students found it very difficult</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

What other comments would sum up your experience of teaching this unit of work?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Please turn over for section 5.
Section 5. Your opinion of biotechnology

15. Regardless of whether you have taught biotechnology or not, we would like to know what you think of this emerging area of science. Please rate the following comments

<table>
<thead>
<tr>
<th>Reason</th>
<th>strongly disagree</th>
<th>disagree</th>
<th>neutral</th>
<th>agree</th>
<th>strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I enjoy learning about biotechnology</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I would like to teach more biotechnology</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I like to read about biotechnology</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The issues in biotechnology are interesting</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>It is important that we all know more about it</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Biotechnology can improve our quality of life</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Biotechnology is a destructive social element</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I like to watch TV shows about biotechnology</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I am not interested in biotechnology at all</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Are there any other comments you would like to make about biotechnology?

____________________________________________________________________________________

____________________________________________________________________________________

Thankyou for your co-operation in completing our survey.
Appendix 2

The Biotech-R Unit - Program Outline.

Section 1 Introduction.

Explain the meaning of biotechnology. What do we think of as technology and how does biology come into it.

Discuss some examples of traditional biotech-yogurt, wine beer and bread. Examples of modern biotech-genetically engineered tomatoes and potatoes, gene medicines.

Watch a video of a current news item about biotechnology.

Why are we studying this stuff? The future. Cloning a brother for a leukemic child. Choosing your child’s gene make-up so that they are more intelligent, taller, or can live longer. Imagination is not so far from reality these days and the decisions will be made in the lifetime of the people in school now. Newspaper articles could be introduced (some are provided)

Introduce terminology to be used in this course. A list is provided in the folder.

Time estimate-2 or 3 periods

Section 2 Traditional Biotechnology

Activity 1

Aim-to use a microorganism to produce a food product.

Example- make bread dough or make yogurt following standard procedures. Bread dough work-sheet in folder.
Discussion of prac could include:

Draw a yeast cell or bacterial cell using text books.

Explain what the yeast/bacteria is doing to the flour/milk.

Imagine how modern scientists might to "high tech" this ancient process. For example a group at Mauri Foods are trying to alter the yeast genes so that more CO2 is produced in a shorter time.

Time estimate- 1 double and 1 single period

Activity 2

Aim- to make a model of a bacterial cell that contains a bacteriophage.

Work-sheet and cutout model of a phage is given in the folder.

Important points for discussion are the role of DNA and the comparison with the structure of animal and plant cells. Both bacteria and bacteriophages are important to scientists as tool for moving genes about.

NB This activity may be unnecessary if the class has a good understanding of cell structure.

Time estimate- 2 periods

Section 3  DNA

Activity 3

Aim- to extract DNA from various sources, eg onion, pea, liver in order to see what it looks like.
Work-sheet and teacher instructions are provided. Note that it is necessary for the teacher to prepare the extracts prior to the class.

Important points to stress- DNA is the genetic material and it is present in all cells. Jurassic Park makes an interesting example.

The work-sheet explains what the various steps of the extraction involve but this may require extra explanation.

Time estimate- 1 double and 2 single periods

**Activity 4**

**Aim-** to make a model of DNA showing the double helix structure and the sequence of paired bases.

A set of instructions and a cutout is provided in the folder. This is taken from the CSIRO kit.

Time-2 periods

**Section 4 Proteins and Genes.**

This is conceptually the most difficult area. The suggested approach is to take one protein, collagen, and explain how the DNA sequence, ie the gene for collagen can code for a sequence of amino acids. Unless the class is really curious it is not intended that protein synthesis be explained, only the idea that a particular code makes a particular string of amino acids and that the sequence of amino acids is vital to the function of the protein.

**Activity 5**

**Aim-** examine the magazine article about collagen implants and answer the questions on the work-sheet provided
Homework- find magazine articles about collagen treatments and look on the supermarket shelves for cosmetics containing collagen.

Discuss how collagen is made.
Show the amino acid structure of collagen. A summary page on this protein is provided in the folder.

Time-2 periods
Activity 6

Aim- to prepare a collagen (gelatin) solution and look at the action of enzymes on that protein

Work-sheet provided in the folder.

Extension-The enzyme rennet can be bought in packets and these come with instructions for making junket out of milk. Some of the class could try out this enzyme

Discussion-enzymes are also proteins and they are coded for by particular pieces of DNA. A lot of the genetic traits we see are the result of the enzymes in our body acting in certain ways. Haemophilia and phenylketonuria are two diseases where the gene for an enzyme is missing or inactive and the absence of that enzyme means damage to the body chemistry. In both of these diseases, if either the enzyme or the gene can be put back then the person can be healthy.

Pamphlets on some genetic disorders are available in the folder. This is also a possible area for library research.

Time-3 periods

Activity 8

Aim- to work out the gene code for collagen.

The amino acid sequence has already been given. The teacher provides the sequence of bases on DNA that gives rise to the 3 amino acids in collagen. As a group come up with a gene sequence for collagen. Could be a competition?

Time- 1 period
Section 5 DNA Fingerprinting

Activity 9

Aim-to model the process of gel electrophoresis using paper DNA.

Sheets of sequence and an outline of the technique is available in the folder. Some preparation is required to make this activity appropriate for the classroom.

Optional Activity-chromatography of texta colour inks using filter paper.

This activity aims to show that DNA can be cut up into different sized pieces by enzymes that work on particular sequences. Once the pieces are made they can be separated out by a size and charge sorting procedure and marked in some way e.g. by a dye. The fingerprint is unique to individuals.

Time- 1 period

Activity 10

Aim-to solve a crime, given DNA fingerprint evidence.

A good activity is given in Senior Science

The value of DNA fingerprinting is that it is relevant and interesting and it introduces the idea of restriction enzymes and cutting out genes as pieces of DNA

Extension- the work-sheet "DNA Fingerprinting-You be the Judge" goes into the ethics of using DNA evidence in court. It is probably only for interested students.

Time - 1 period

Section 6 Genetic engineering
Activity 11

Aim-to make a bead chain representing your own DNA then cut and transfer one of the genes to your neighbours DNA.

Discuss what characteristic you might have transferred and how your neighbour will be changed.

This activity might be done using one of the models that has already been made in this unit.

Time-1 period

Activity 12

Aim-prepare a debate for and against the proposition "genetically engineered food can only be good for the human race"

Different classes may prefer to approach the ethical questions in different ways. A video of some issue current in genetics may be useful here, to stimulate discussion. Some debate on where these technologies are leading is essential.

Time-5 periods

Section 7 Cloning

Compare the movie image of cloning and the real facts about "Dolly". This is still an area for the imagination. The folder contains some jokes about the potential of cloning. Perhaps the class could draw a cartoon about cloning or write a short science fiction scenario about clones.

Time- 3 periods

Total time-30 periods
A Teaching Unit on Biotechnology

This program has been developed as a result of the survey I conducted into biotechnology teaching. Almost all of the teachers who responded agreed that biotechnology is an important and interesting area of science but they did not teach it because

• they had no program for it
• there were not enough practical activities
• the material is too difficult.

I have tried to develop a program that overcomes each of these objections. The program is set out as a series of activities and suggestions are given at each stage about what theory can be brought into each activity. A range of activities including traditional "wet" practicals, model building and "paper' practicals, debate and discussion activities, and comprehension work-sheets are included. Because it is activity based the program allows a wide range of process skills to be covered.

The principle objective of the program is to give students enough understanding of the basic science behind biotechnology to allow them to make informed decisions about what genetic manipulation means to their lives. This includes things like deciding on safety for the environment of genetically engineered plants and animals, using DNA evidence in a courtroom, and setting limits to human cloning and gene therapy. Therefore it is essential that these types of issues be discussed. Formal activities are listed at the end of the program but the ideal situation would be to discuss these issues as they become relevant throughout the program. Some discussion materials are provided in the folder.

Specific objectives are listed as the Aim of each activity.

The folder provided contains work-sheets for each of the practicals, support information for the teacher, some information sheets for the students and copies of current newspaper articles on biotechnology.
Appendix 3- concept map from lesson 4. Scan from which figure 6.2 b was transcribed
References


Friedman, T. (1997). Overcoming the obstacles to gene therapy. Scientific American, 276 (6), 80-85


Teaching Biotechnology in NSW Schools

by Frances A Steele

Submitted for the degree of Master of Education (Hons)

1999

University of Western Sydney (Nepean)
PLEASE NOTE

The greatest amount of care has been taken while scanning this thesis,

and the best possible result has been obtained.
I, Frances A. Steele, hereby certify that the work reported herein has not been submitted for a higher degree at any other institution.

Signed  

Dated  21-7-99
Acknowledgements

I would like to thank the following people for their help in the conduct of this research, and the preparation of this report, investigating the teaching of biotechnology. First and foremost, I offer many thanks to my supervisor Peter Aubusson, for his support, advice, and those readings of the draft manuscripts. I also thank the teachers whose classes were the subject of case studies, for their tolerance in allowing me to observe their classes and for the time they gave to discussions before, during and after the lessons on biotechnology. The advice of the student postgraduate advisor, Andrew Martin, has been invaluable in all areas concerning the design, analysis and reporting of the survey. Finally, I would like to thank my husband, Jack Steele, for always being willing to take the time to sort out the minor disasters.
Abstract

Teaching Biotechnology in NSW Schools

Agriculture, industry and medicine are being altered by new biological technologies. Examples of these changes are: the development of high yielding crops by genetic engineering; the use of gene therapy to treat cancer; and the production of pharmaceuticals in micro-organisms (reviewed in Morris, 1995). These uses of biological technology bring potential benefits for humanity but they also raise important ethical issues.

Today’s students are the citizens who will make decisions about these ethical issues. They need to have the knowledge that will enable them to make informed choices. Hence biotechnology has an important place in science education.

Few students in NSW are studying biotechnology. McInerny (1990) found that difficulties were encountered in the teaching of biotechnology in other countries. These difficulties that have been encountered elsewhere, were used as a starting point for the investigation of the teaching of biotechnology in the NSW secondary school. The aims of the present work were to:

1. describe the state of biotechnology teaching in NSW;
2. determine whether teachers in NSW do not teach biotechnology because they do not have the knowledge and experience adequate to the ask;
3. identify other reasons why NSW teachers choose not to teach biotechnology;
4. describe problems encountered in teaching biotechnology in NSW;
5. suggest ways in which the problems encountered in the teaching of biotechnology can be overcome.

Quantitative and qualitative methods were used in a complementary way to investigate these aims. A survey of NSW science teachers was used to describe the state of
biotechnology teaching, and to provide data about why teachers choose not to teach biotechnology. Interviews and case studies were used to investigate those problems encountered in the teaching of biotechnology that were identified as important by the respondents to the survey.

In the sample of teachers surveyed, many reported that they chose not to teach biotechnology as part of the senior science curriculum because they did not have the knowledge and experience adequate to the task. Other obstacles to the teaching of biotechnology were identified from the survey, case studies and interviews. These were:

1. the difficulty of the subject matter;
2. the lack of practical work;
3. lack of a program for biotechnology in junior science.

It was suggested that these problems could be minimised by the development of a unit of biotechnology that addressed the concerns identified by the teachers in the survey, interviews and case studies. The outline of a unit of biotechnology for junior science was prepared and a trial was conducted in the classroom. The results of this trial suggested that such a unit should be developed in collaboration with the teacher and that time needs to be made available for school based program development.
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