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The Challenge in Teaching Biotechnology

F. Steele and P. Aubusson
University of Technology, Sydney

Abstract

Agriculture, industry and medicine are being altered by new biotechnologies. Biotechnology education is important because today's students and citizens will make decisions about the development and application of these new molecular biologies. This article reports an investigation of the teaching of biotechnology in an Australian state, New South Wales (NSW). In NSW few students were electing to answer examination questions related to biotechnology, suggesting that few students were studying the topic. This study looks at why electives relating to biotechnology are chosen or not chosen by students and teachers, with the intention of developing a greater understanding of the requirements for provision of a successful unit of study in this subject. Data was obtained through a survey of secondary science teachers, interviews with teachers and two case studies of the teaching of a biotechnology unit. Teachers reported a range of obstacles to the teaching of biotechnology including the difficulty of the subject matter and a lack of practical work that was suited to the content of the teaching unit. If biotechnology is worth learning in school science, then further research is needed to identify ways to promote the effective teaching of this topic, which teachers regard as important for, and interesting to, students but which most teachers choose not to teach.

Key Words: biotechnology, challenge, interest, motivation, secondary science, senior science

Over the last decade, biotechnology has heralded a revolution in medicine, agriculture and industry (Edmonston, 2000). An Australian Government discussion paper reviewed the state of biotechnology and concluded, "Biotechnology has the potential to provide substantial benefits in the future to health, through new disease prevention measures; and for agriculture, through greater productivity and sustainable production; and the environment, through rectification of damage" (Biotechnology Australia, 1999, p. 12). However, there remain concerns about ethical issues related to the use of many of these new technologies, including gene therapy in medicine (Perry, 2000; Marshall, 2000), pesticide resistant crops (Coghlan, Cohen, Kleiner, MacKenzie, Nowak, & Pearce, 2002) and genetically modified foods (Marchant & Marchant, 1999).

School science is being asked to play a major role in the development of citizenry capable of dealing with the changes, both economic and social, that have been brought about by the developments in biotechnology. In reviewing what teaching for scientific literacy means for curriculum content Solomon (2001) notes that students must prepare for democratic decision making on issues related to medicine, the environment and genetics. As Lock, Miles, and Hughes (1995, p. 47) state, "We expect adults to play a full and responsible role in society, which includes applying

the knowledge, understanding and attitudes gained from their study of science to their everyday life. Biotechnology and genetic engineering are aspects of science content rich with opportunities for work of this kind." McInerney suggests that the Human Genome Project offers an opportunity of this kind, and goes so far as to assert that "done well education about genetics can empower the public to participate knowledgeably in personal and societal decisions about the applications of genetics" (McInerney, 1996, p. 6).

The importance of biotechnology education has been recognised in a number of national curriculum frameworks. The English National Curriculum for science incorporates ethical issues in biotechnology (Solomon, 2001), and the New Zealand Curriculum Framework recognises the importance of biotechnology to that country (Conner, 2000). In Australia the federal and state governments have acknowledged the relevance of biotechnology in the curriculum. The National Curriculum (Australian Education Council, 1994) outcomes emphasise the social consequences of the biological sciences and some teaching of bioethical issues has been incorporated into most state curricula (Dawson, 2001). However, although biotechnology education has gained recognition "less is heard about how to teach effectively in areas that require sensitivities to moral, ethical and social dimensions which are linked to the use of technologies" (Conner, 2000, p. 3).

If biotechnology is to be taught for the purpose of educating students about the social consequences of the new technologies, the question of what to include in such a teaching module must be considered. Solomon and Thomas (1999) have reviewed some of the arguments about the extent to which motivation should be balanced with scientific content in any area of science teaching. Using the example of BSE (Mad Cow Disease) these authors ask whether students should learn the science of such current issues (however exciting) when the story is changing rapidly, or whether the students should be taught a few basic stories covering fundamental concepts. Simmoneaux (2000, p. 619) investigated a similar question, namely "how should the content of biotechnology information be developed for the purpose of teaching today's students?" In interviews with ten fifth form students, he found that they had been influenced by nationwide campaigns on AIDS and often viewed all microbes as harmful, not distinguishing bacteria from viruses. Simmoneaux (2000) suggests that students need to learn about the nature of bacteria if they are to discuss industrial uses of microorganisms. In his view, more rather than less scientific content is required if biotechnology is to be taught successfully.

Venville and Treagust (2002) reviewed the teaching of genetics in Western Australian secondary schools and found that students had a poor understanding of the concept of a gene. According to Venville and Treagust (2002), an understanding of the gene is essential if students are to comprehend the new genetic technologies. These authors were of the opinion that "the challenge for teachers who want their students to construct a modern, fruitful conception of the gene is that somehow they must immerse their students in a sub-microscopic world and motivate them to want to understand it" (Venville & Treagust, 2002, p. 24). Olsher (1999) also finds that the biochemical processes of biotechnology are a black box for most students because

they are remote from their everyday experience, yet the students are required to understand something of these processes. He proposes that teaching modules be based on macro biotechnological processes but student questioning should be developed so that meaningful questions about intracellular processes will be asked.

Olsher (1999), Simmoneaux (2000) and Venville and Treagust (2002) propose that the teaching of biotechnology emphasise the scientific concepts. However, others have advocated the teaching of modules in biotechnology that stimulate student discussion and facilitate responsible decision-making without requiring students to deal with difficult abstract concepts. Issues related to medical ethics (Conner, 2000; Dawson & Taylor, 1999; Van Rooy, 1994), biodiversity (Cross & Price, 1994) and the Human Genome Project (McInerney, 1996) have all been used as the basis for modules that focus on student discussion.

Varying degrees of success have been reported for these modules designed to alter student views. Conner (2000) reported that students' views about bioethical issues were broadened after the teaching of a unit on cancer in which students were able to investigate their own questions. The results of a survey of 118 students, conducted before and after a teaching sequence that encouraged them to discuss some examples of biotechnology, showed that the intervention had led to an increase in approval for genetic engineering (Lock, Miles, & Hughes, 1995). By contrast, Dawson and Taylor (1999) were unable to detect a difference in views between a group of students that had carefully considered a range of ethical dilemmas and a corresponding group that had not. While there may still be doubt about the effectiveness of issues based units in changing student views, controversial issues are nevertheless regarded as motivating for students that are otherwise uninterested in science (Dawson, 2001; Van Rooy, 1994).

The debate about what to include in the teaching of biotechnology to today's students, is relevant in the context of the present study, which focuses on the teaching of two modules of biotechnology that differ markedly in content. These two modules in biotechnology, titled "Genes in Action" and "Biotechnology" were offered as optional study (electives) in the senior school curriculum in the Australian State of New South Wales. Both modules were examined as part of the final school examination, the Higher School Certificate (HSC). "Genes in Action" required an in-depth study of the gene concept, while "Biotechnology" focused on aspects of biotechnology relevant to the students' lives. Despite the fact that these teaching units catered to a wide spectrum of student interests, figures supplied by the NSW Board of Studies (personal communication) indicated that neither module was selected by a high proportion of students. This low uptake of biotechnology electives was of concern and the aim of this study was to discover why students, and/or teachers, were failing to choose this topic. The intention was to develop a greater understanding of the requirements for a more successful unit that would reach a larger number of students.

Braid and Pena (1996) have suggested a theoretical framework with which to assess the competing demands between motivation and content information in order to provide a successful unit of study. These authors argue that a unit of work must be both demanding and interesting for the students. Students must feel challenged

by what is done. They further suggest that many secondary students and many secondary science teachers do not feel challenged by school science. This framework, built around the two dimensions of interest and cognitive demand, has been used to interpret the findings of this research.

Design and Methods

Design of the Study

The research question driving this study was: what factors influence the teaching of biotechnology in the senior sciences in NSW?

Aspects of biotechnology education that might affect motivation and demand were identified from the literature and used as the basis of statements with which teachers were asked to agree or disagree on a questionnaire. Problems that have been reported include the lack of teacher knowledge in the area, the lack of resource materials and the lack of time to fit in another topic (McInerney, 1990; Wilson, Kirby, & Flowers, 2002; Zeller, 1994). The difficulty of the abstract concepts (Venville & Treagust, 1998), the need for innovative teaching methods (McInerney, 1990) and difficulties due to the controversial nature of the material (Dawson, 2001; McInerney, 1990) have also been reported as factors inhibiting the successful implementation of biotechnology in the curriculum. Items investigating teachers' views on these factors were incorporated into survey questions.

Another factor that was of particular relevance in NSW was the existence of an external examination. In a study of the implementation of a new geography syllabus for the HSC, Hall (1997) found that many teachers were hesitant about the inquiry-based content because of the existence of the examination. These teachers saw how the students' results might be used as a measure of their professional competence and this caused them to teach exam techniques at the expense of more interesting subject matter. Rigid assessment practices have been shown by others to influence student interest in participating in open inquiry and the development of higher order thinking skills (Bol & Strage, 1996; Hodson, 1998; Keiler & Woolnough, 2002). Thus it was considered that biotechnology, a subject that involved many potential "grey" areas, might be particularly difficult for teachers and students dealing with an external examination.

The survey was intended to identify some of the barriers to the teaching of biotechnology. However, it was not possible to determine the nature of all of the experiences and problems encountered in teaching biotechnology using a series of short statements. For a more in-depth analysis, qualitative methods of data gathering were employed, thus putting into practice Roberts' (1996, p. 43) recommendation that quantitative and qualitative methods be combined "to provide a (complementary) take on events in science education." Data gathering techniques of qualitative analysis used in this study included interviews and observation of classroom practice, as recommended by Tesch (1990) and Lincoln and Guba (1985). Interviews were used

to obtain teachers' explanations of the reasons why they had not taught biotechnology. To find out more about the problems encountered when a biotechnology topic is undertaken in the classroom, a combination of interview, document analysis and observation (field notes) was used to generate two case studies of teachers teaching the "Genes in Action" biotechnology module.

A Definition of Biotechnology

For the purposes of this research, biotechnology has been defined as a set of technologies, as recommended by Jones (1995). This listing of a specific set of technologies was chosen because of the way that schools often teach aspects of biotechnology under different subject labels, for example, as genetics. The technologies included in the definition were: monoclonal antibodies, in vitro fertilisation, DNA fingerprinting, genetic engineering, new biological technologies in food production and new biological technologies in waste management (from Morris, 1995). 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 many biological technologies used in food production, waste management and human health.

The Modules of Biotechnology

Students in NSW sit for their Higher School Certificate examination at the end of year 12 and the marks from this examination are used to determine a university entrance score. During the period of this study (1996–2000), the senior science curriculum offered two biology units, *Science for Life* and *2Unit Biology*. Both consisted of a core section studied by all students and a number of electives, a subset of which were chosen for study. Teachers had (and students may have had) an input into which electives were taught in a particular school in a particular year. The senior students could study biotechnology within *2Unit Biology*, as an elective called "Genes in Action" or as the "Biotechnology" elective as part of *Science for Life*. The syllabus of "Genes in Action" mandated a study of the flow of information from DNA to protein, mutations, the genetic origin of characteristics and genetic manipulation (Board of Studies, 1996). The syllabus for "Biotechnology" incorporated more flexibility. Students were required to learn about some examples of biotechnology, as it relates to humans and their environment, and to animals and plants. A visit to a farm or sewage treatment works was suggested. Ethical issues were debated as part of the study (Board of Studies, 1994).

A Technical and Further Education (TAFE) module on biotechnology is also referred to in this study, as one participant had some experience in this area. This module prepared students that had left the school system for university level biology. The

students were asked to research chosen topics in depth and write reports for examination. The course was flexible in structure and included some debate of ethical issues.

Ethical Considerations

The NSW Department of Education and the ethics committee of the University of Western Sydney approved this study. All interviewees were informed of the nature of the study being undertaken, advised of their right to withdraw at any time and asked to give permission in writing for their participation in interviews. Pseudonyms for teachers and schools involved in this research have been used in all reports derived from this study. Teachers involved in case studies were shown drafts of all reports for member checking and notes made during class were available for their perusal. Changes suggested by participating teachers were included in the final report.

The Survey

A questionnaire was directed to one randomly selected science teacher from each of 100 NSW government schools and 35 non-government schools. Fifty nine (44%) teachers responded. The teachers were asked to state how much biotechnology they had taught in the preceding school year. In the questionnaire, data was sought about a set of questions designed to explore the influence of the teacher's academic background on the hours of biotechnology that they taught. The analysis included:

- the number of years of teaching experience related to the amount of biotechnology taught;
- the number of years of experience as a biology teacher related to the amount of biotechnology taught;
- the major subject of the teachers degree related to the amount of biotechnology taught; and
- extra training in biotechnology (either as work or as study) related to the amount of biotechnology taught.

The survey was designed to provide preliminary data about why teachers do or do not teach biotechnology, and to identify their perceptions of this topic. A series of statements covering aspects of biotechnology identified in the literature as being relevant to its teaching (e.g., the lack of resource materials, the role of controversial issues), were listed in the questionnaire. Teachers were asked to rate their level of agreement – disagreement with these statements on a scale of 1–5. Statistical analysis of the survey was carried out using SPSS for Windows.

Interviews

The survey sample consisted of a high proportion of science teachers who did not teach biotechnology. In order to further probe the experiences of teachers that had

taught biotechnology it was desirable to locate teachers with some experience in this subject. Eleven teachers who confirmed an interest in the teaching of biotechnology were located at a Commonwealth Scientific and Industrial Research Organisation (CSIRO) workshop called *Gene Technology in Action*. These teachers were asked about their perceptions of biotechnology teaching using an unstructured interview format. Teachers' views were recorded as field notes. Three of the eleven teachers (Sue, Katrina and Rob) reported that they were teaching biotechnology in their schools. The remaining eight teachers indicated that they had attended the workshop for other reasons. It should be noted that teachers who were interviewed were separate from the sample that participated in the survey.

More extensive interviews were conducted with three teachers. Two of the teachers, Sue and Katrina, had attended the CSIRO workshop. Sue was teaching biotechnology as part of the Tertiary Preparation Course (a TAFE course using the HSC biotechnology unit) and Katrina as the elective in *Science for Life*. Initially these teachers agreed to participate in case studies for this research but during subsequent phone interviews both revealed that they had decided not to teach biotechnology in the following year. Their reasons for making that decision are reported here. Data was also obtained from an interview with a third teacher, Alan, from a high school in Western Sydney, who had initially agreed to be part of a case study but who was prevented from teaching "Biotechnology" by administrative changes within his school. Alan was targeted in this research because of his extensive experience in teaching "Biotechnology" and because he had researched his teaching of this subject as part of a Master of Education project.

Case Studies

Two case studies of the teaching of a biotechnology unit were carried out. Rob was initially interviewed at the CSIRO workshop, where he agreed to participate in a case study. His year 12 class from Rivervale, a selective high school in Sydney, was studying the HSC biology elective "Genes in Action." Michael, from Cleland High School, a comprehensive high school in suburban Sydney, was also teaching this elective.

The case study method was based on that recommended by Merriam (1988) and Lincoln and Guba (1985). Teachers were interviewed before teaching the biotechnology elective about what they hoped to achieve in the course and about their opinion of biotechnology. Some background information about the teachers was also obtained. During the teaching of the unit, classes were observed and field notes taken. These notes recorded the progress of the lesson, student questions and conversations and any comments made by the teacher. Reflections made by the researcher during the lesson were also recorded. Where time permitted at the end of the lesson, the teacher was asked for an opinion of the lesson and notes were made from any discussions. Written materials provided to the class were collected. Data was also obtained from students. At Rivervale three students (Louise, Kim, and Lisa) were selected by Rob

Table 1
Interactions of Survey, Interviews and Case Study; Summary.

Method	Sample	Biotechnology module
Survey	59 science teachers, from government and non-government schools	Any school unit on biotechnology
Interviews	Sue	TAFE unit on biotechnology
	Katrina	*Science for Life* "Biotechnology"
	Alan	*Science for Life* "Biotechnology"
Case studies	8 teachers at gene based workshop	
	Rob, selective government high school	*2Unit Biology* "Genes in Action"
	Michael, comprehensive government school	*2Unit Biology* "Genes in Action"

as being representative of a high, middle and low ability group and these students were interviewed at the end of the elective to identify their views of the teaching of biotechnology. At Cleland two students (Debbie and Tanya) gave their opinions of the elective in informal discussions at the close of the lessons. These students were self-selected as Michael was willing to allow students to speak freely to the researcher. At the end of the biotechnology elective the students from Cleland completed a short questionnaire about which parts of the course they had enjoyed, what they had found difficult and what they would like to change.

The case study and interview data were analysed to identify recurring themes in order to generate assertions. These assertions were tested by reviewing the data and justified in consultation with another researcher (after Altrichter, Posch, & Somekh, 1993; Erickson, 1986; Lincoln & Guba, 1985). The data and findings were given to the case study teachers for member checking. Suggestions and criticisms were incorporated into this report. Table 1 summarises the methods of data collection, sample and biotechnology unit about which information was sought.

Results

The survey of the teachers proved useful in providing information and insights about teachers and teaching in the area of biotechnology. Some possible barriers to the delivery of a successful teaching unit in biotechnology were identified. The

findings of the survey are presented in detail below. Aspects of these findings that are illuminated by the case study and interview data are then discussed.

The Amount of Biotechnology Taught

Fifty-nine of the 135 teachers contacted (44%) responded to the survey. Forty-eight of those had taught *2Unit Biology* in the previous two years. Of these, six (12.5%) had taught the "Genes in Action" elective. This survey data is consistent with the number of students completing this elective across the State (Board of Studies, personal communication), which show that typically about 10% of students who do the examination in *2Unit Biology* answer the questions on "Genes in Action." HSC examination figures also revealed that about 2% of students of *Science for Life* typically answered the "Biotechnology" elective in the exam. In this survey of biotechnology, only 14 of the 59 respondents (24%) had taught *Science for Life*, and only 3 of the 14 had taught the "Biotechnology" elective.

Teacher Interest in, and View of the Importance of, Biotechnology

Respondents were asked to rate the extent of their agreement or disagreement (on a 5 point Likert scale where 5 corresponded strongly agree and 1 corresponded strongly disagree) with statements about their interest in biotechnology, and to what extent they consider it to be important. The results are shown in Table 2. The mean scores indicate that in this sample of teachers there was strong agreement that biotechnology is both important and interesting.

Table 2
*Teacher Attitude to Biotechnology (*N = *57).*

Statement	Mean score (SD)
I enjoy learning about biotechnology*	4.42 (0.56)
I would like to teach more biotechnology	4.26 (0.61)
I like to read about biotechnology*	4.09 (0.77)
The issues in biotechnology are interesting*	4.39 (0.49)
It is important that we all know more about biotechnology	4.29 (0.62)
Biotechnology can improve our quality of life	4.14 (0.78)
Biotechnology is a destructive social element	2.12 (0.75)
I like to watch TV shows about biotechnology*	4.14 (0.74)

*Items combined to form a scale of interest.

The scores for the statements marked with an asterisk were tested for internal reliability (Cronbach $\alpha = .84$) then combined to make a scale of interest. Teacher interest in biotechnology was then compared to the number of hours of biotechnology taught, using a Pearson's correlation. A correlation coefficient of .225 ($n = 59$) was obtained, corresponding to a statistical significance of $p < .05$. This result indicates a possible relationship between the amount of biotechnology a teacher teaches and their interest in biotechnology. However, this finding needs to be further tested with a larger sample of teachers.

Teachers' Backgrounds and the Amount of Biotechnology Taught

A number of aspects of the teachers' backgrounds were investigated, and their possible relationship to the amount of biotechnology that they taught was examined. These aspects included: the number of years of teaching experience, the number of years of experience in teaching biology, the major subject of the teacher's degree, and the teacher's extra training in biotechnology.

It was found that for the sample of teachers in this survey:

- The mean years of teaching experience was 18.6, and teaching experience was not significantly related statistically to the amount of biotechnology taught ($r(59) = .14$, $p = .3$).
- The mean years of experience in teaching biology was 12.5, and years of teaching biology was not significantly related statistically to the amount of biotechnology taught ($r(59) = -.06$, $p = .63$).
- There was no statistically significant difference in the amount of biotechnology taught by those who had a degree in biology compared with those who had a degree in another science subject. Teachers were placed into two groups, those who had a degree in biology (79% of the sample) and those who had a degree in another science (21%). When these groups were compared using an independent t-test, no statistically significant difference in the amount of biotechnology taught was found ($t(55) = .32$, $p = .75$). The percentage of respondents who had a degree in biology was higher than might be expected of the total population of science teachers in NSW. This may have occurred because biology teachers were more likely to respond to a survey about biotechnology.

Of the 59 teachers who responded to this survey, 15 indicated that they had some extra training in biotechnology, either as work or as special study (e.g., professional development course). In an independent t-test, the group that had this experience was found to teach significantly more biotechnology at the senior level than those who had no extra training (11.3 hours versus 4.7 hours, $t(57) = 3.52$, $p < .001$). This result could imply that a significant number of teachers do not teach biotechnology at the senior level because they do not have sufficient experience of the topic. However, subsequent interviews identified some teachers who did have the knowledge and experience to teach biotechnology but who had decided not to teach it for other reasons. It follows that lack of experience in biotechnology may be only one factor influencing teachers to avoid teaching biotechnology.

Table 3
*Reasons for not Teaching Biotechnology (*N = *37).*

Suggested reason	Genes in action Mean (SD)	Rank
There are not enough references	2.78 (1.05)	7
The students find it boring	2.50 (0.88)	8
I do not know it well enough to teach it	2.81 (1.35)	6
It is not important to my students	2.39 (1.07)	9
Not enough practical work can be done	3.44 (0.92)	2
I do not have time to fit in another topic	3.08 (1.14)	3
It is too controversial	1.83 (0.74)	10
The exam questions are too hard	2.93 (1.21)	5
The school has no program for it	3.05 (1.16)	4
The students find it too difficult	3.61 (1.09)	1

Teachers' Reasons for not Teaching Biotechnology

The survey asked teachers to respond to a series of statements about reasons for not teaching biotechnology. The statements were rated on a five point Likert scale from strongly disagree to strongly agree. Table 3 shows the results for the "Genes in Action" elective. Results are expressed as a mean score, with standard deviations in brackets, and the scores are ranked from highest to lowest.

The main reasons for not teaching biotechnology at the senior level were "The students find it too difficult" and "Not enough practical work can be done." Lack of teacher knowledge was not emphasised as being a problem, even though accompanying data on teacher training suggested that teachers with more training in biotechnology were more likely to teach this subject. 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.

Experiences of Teachers Who Do Teach Biotechnology

One aim of this research was to find ways to overcome the barriers to the teaching of biotechnology. A possible way to do this was to find out what those teachers who are teaching biotechnology are doing to overcome the problems they encounter, and then use this experience to inform others. Table 4 summarises the responses

Table 4
*Experiences of Teaching Biotechnology and Ranks of Items in Common with Teachers Who Have not Taught Senior Biotechnology (*N = *21).*

Suggested experience	Mean (SD) teachers teaching biotech	Rank teachers teaching biotech	Rank teachers not teaching biotech
This is an important area of biology	4.32 (0.85)		
Finding information was difficult	2.76 (1.01)	4	6
The students found it boring	2.16 (0.9)	8.5	7
I need to learn more about the topic	3.44 (1.00)	2.5	5
It is not relevant to the students' lives	1.72 (0.84)	9	8
Not enough practical work can be done	3.44 (0.87)	2.5	2
Discussing controversial issues was hard	2.44 (1.04)		
There were too many controversial issues	2.16 (0.91)	7.5	9
The exam questions are too hard	2.46 (0.93)	5	4
The school did not support this new area	2.24 (0.83)	6	3
The students find it very difficult	3.46 (0.90)	1	1
It was exciting the class loved it	3.72 (0.68)		

Spearman rank order correlation coefficient $\rho(9) = .783$, $p < .02$

of teachers who do teach senior biotechnology. Where there was overlap between statements shown in Tables 3 and 4, a ranking is given to each statement. The experiences of teachers teaching biotechnology can be compared with the perceptions of biotechnology reported by teachers that are not teaching biotechnology using these rankings.

There was substantial agreement among teachers concerning the statements, "The students find it very difficult," and "Not enough practical work can be done." The respondents indicated that the students found biotechnology interesting and relevant, that the controversial nature of the material was not a problem and that the teachers themselves needed to learn more about biotechnology. Teachers who taught biotechnology considered biotechnology an important area of biology. The comparison of ranks of similar items, between those who taught and those who had not taught senior biotechnology, showed strong agreement between these groups of teachers ($\rho(9) = .783$, $p < .02$). Thus, many of the perceived difficulties reported by teachers who did not teach biotechnology were also found to be difficulties by the sample of teachers that were teaching this subject.

Summary of Findings from the Survey

The main findings from this survey of science teachers are:

- Few students were studying the biotechnology electives in the senior school curriculum in NSW;
- Teachers in this sample regard biotechnology as interesting and important;
- Those teachers with extra training in biotechnology taught more hours of this subject;
- Teachers in this sample showed greatest agreement with the prepared statements, *The students find it very difficult* and *Not enough practical work can be done*;
- Respondents disagreed with statements indicating that students find biotechnology boring or irrelevant to their lives.

Further Analysis and Discussion of the Challenge to Teaching Biotechnology

The interview and case study data were found to be especially helpful regarding the issues of students' learning of biotechnology subject matter and the lack of suitable practical experiences. These two areas of concern are discussed in what follows.

Perceptions of student understanding of the subject matter

Teachers of senior science responding to the survey on biotechnology 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 the survey, many of which stated the view that the "Genes in Action" elective is too difficult for the students. The view that "Genes in Action" is too difficult for the students was endorsed by the teachers interviewed during the CSIRO workshop. 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. However, 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 Higher School Certificate (HSC) examination.

A comment that encapsulated 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 two thirds 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)

Comments such as this raise a number of issues regarding teachers' views:

- All *2Unit 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 about genes;
- 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 HSC examination. Not only is "Genes in Action" perceived to be difficult, but other electives are perceived as easier and teachers think their students will score higher marks in the HSC examination if they choose these other electives;
- Difficulty may be linked to enjoyment. Some teachers feel that 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.

Difficult Subject Matter, Enjoyment and the Role of External Examinations

Science for Life

Katrina was teaching in 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 changed her mind. Her decision was based on the poor examination performance of her students studying biotechnology relative to the performance of students studying other electives in *Science for Life*. She had concluded that the module was too hard for the students and she would not teach it.

Another teacher who had brought her class to the workshop, Sue, was teaching a unit on biotechnology that had recently been introduced by the NSW TAFE. She had more resources than the high 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 similar 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 and comprehend. 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, subsequently in the following year, Sue recommended to students that they choose those options instead of the biotechnology option.

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 from that of other teachers, who reported that the difficulty of the topic reduced the students' enjoyment. Thus, some teachers see the difficulty of biotechnology causing both a lack of interest and a lack of enjoyment. Others see these as separate issues, suggesting that biotechnology is both difficult and enjoyable.

Alan taught *Science for Life* at a comprehensive school. *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 students had answered the biotechnology questions in the exam and one 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. Although Alan was able to provide examples from common experience for many aspects of the biotechnology subject matter, he elaborated: "The bit 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 the kids find hard."

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 as "gene," "chromosome" and the relationship between these, that are not open to common experience.

Wilkinson and Ward (1997, p. 51) found that both teachers and students see the principal purpose of practical work as being "to make science more interesting and enjoyable through actual experience." Along with the difficulty of the subject matter, teachers responding to the survey indicated a lack of practical work as a reason why they did not teach biotechnology. Yet, in his teaching of biotechnology as part of *Science for Life*, Alan had "added a practical" every year of the five years he had been teaching this subject. Many of the activities he used were adapted from other parts of the science curriculum. For example, experiments on enzymes are often used in teaching about digestion, and Alan put a "biotechnology spin" on them. He made a conscious effort to choose practical activities, such as making bread or yogurt, that would allow students to relate biotechnology to their own experience. Alan had a background in scientific research and he may have been more confident in adapting the practical work than other teachers. However, his experience shows that some practical work relevant to biotechnology was available to teachers at the time of this

study. Alan was able to use this practical work to make *Science for Life* interesting and relevant to his students.

The module of biotechnology taught in *Science for Life* was interesting for the teacher and students. 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. The syllabus allowed time for a discussion of ethical issues that were of interest to the students. Although many students studying *Science for Life* found the genetics component of the subject matter of this module to be difficult, this subject was commonly taken by less able students. For the high achieving students, "Biotechnology" was considered by the teachers to be sufficiently "meaty" as to be a challenge. For these students the biotechnology module was both interesting and demanding, meeting the criteria for challenge as defined by Baird and Penna (1996).

Genes in Action

The teachers and students involved in the two case studies on "Genes in Action" (Rob and Michael) considered that parts of this elective were difficult. Rob was partly basing his opinion on the results of trial examinations, where the students had performed poorly on the questions related to "Genes in Action," particularly one question about how Tumour Necrosis Factor could be made using genetic engineering. He had expected the students to relate this question to what they had learned about insulin, but they failed to make this connection. Michael was basing his assessment of student understanding on his experience of the students and classroom discussions. He estimated that six students (about one third of the class) understood what was being taught. As the students at Rivervale were attending one of the state's top high schools, and the students at Cleland had self-selected to study biotechnology because of 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.

The nature of the content of "Genes in Action" is such that it incorporates an understanding of the action of genes (as hereditary conditions or as genetic manipulation) with an understanding of the process of replication, translation and transcription (Board of Studies, 1996). Others have found that when studying genetics, students often fail to make a connection between such concepts as "DNA structure, the genetic code, protein synthesis and the expression of genes" (Venville & Treagust, 1998, p. 18). 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. They were not able to see how what they had learned helped them in understanding issues in biotechnology that they had encountered elsewhere. Louise stated, "It just seems like you are being given a

whole lot of facts to memorize. Right you've done that, on we go! That's where the difficulty lies because you do not know why you are learning it." Another student, Lisa, said that she understood about the cloning of sheep from studies in another subject, but the "the stuff in the course (Genes in Action) went right over my head."

The students in this study found the content of "Genes in Action" difficult. To what extent this was a feature of the syllabus, and to what extent it was intrinsic to the nature of biotechnology, was difficult to determine because of the circumstances under which "Genes in Action" was taught. The teachers and students were facing their final assessment tasks, which would in turn contribute to their university entrance marks. At the time of this study both teachers were under pressure to complete the course before trial examinations. The existence of deadlines meant that the teachers could not devote time to explaining how the sub-topics of biotechnology were linked when this information was not a requirement for the exam. Therefore, the constraints of the exam and the nature of the syllabus were probably partly responsible for these very able students failing to make a connection between the gene, the method of expression of the gene and biotechnologies. However, the findings of this study, together with those of Olsher (1999) and Venville and Treagust (1998), suggest that the complexity of the subject matter may be a broader problem associated with the teaching of those aspects of biotechnology that require an understanding of the molecular processes.

Wilkinson and Ward (1997, p. 51) found that teachers consider that as well as providing motivation, practical work can be used "to enable students to verify ideas and facts for themselves." The teachers in this study would have liked to use more practical work both for motivation and to promote understanding. However, the subject matter of "Genes in Action" is sufficiently complex that a relevant practical, for example, the type of high-tech recombination experiments possible in university laboratories, would be beyond the capability of a school laboratory. Rob's class attended the CSIRO workshop and he reported that while it helped the students' general understanding of science, it probably did not help them when it came to answering the HSC questions. Louise commented about the workshop, "Largely irrelevant. It was interesting because it was hands-on, you can see what they really do."

While Rob was able to use the workshop as motivation for his class, Michael found that the pressures of time prevented the incorporation of practical work in "Genes in Action." One of Michael's students made several bids to conduct an experiment on extraction of DNA from peas. Michael explained that this was not really in the syllabus. When she commented, "Oh but it is fun," Michael gave serious thought to the proposal then decided he did not have the time to organize and carry out an activity just for fun. In general, for the students studying "Genes in Action" practical work was not able either to provide motivation or aid with the understanding of the genetics concepts.

The use of discussion of ethical issues as a way of motivating students met with similar problems to the use of practical work. When one student wished to discuss whether the human genome project could be used to support racial persecution, Michael postponed the discussion until later because of lack of time and relevance

to the syllabus. He was able to devote only the last lesson of the last week of term to the ethical issues of biotechnology, and in that time the class enthusiastically debated whether they should eat genetically modified chips and what benefits gene therapy might offer society. Rob did not have any time to debate ethical issues in class. The students from his class who were interviewed for this study were of mixed opinions about the value of including ethical debate. 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 maybe 90% of the class.

Louise had little faith in voicing student opinion. She believed: "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."

There is some evidence that including debate on ethical issues would have made "Genes in Action" more interesting for students, but the nature of the syllabus prevented teachers spending time on these activities.

Using the terminology of Baird abd 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. Teachers and students commented that there are very few practical activities that are relevant to this elective, and 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 examination. That is, "Genes in Action" is low in interest, particularly when compared with other electives offered in HSC biology. As this elective does not achieve a balance between demand and interest, the topic does not meet the requirement for challenge.

Biotechnology Electives and Examinations

Three different biotechnology units, "Biotechnology," "Genes in Action" and TAFE Biotechnology, were considered by the teachers participating this study, and each unit was regarded as too difficult. One common feature of these units is that they were all being studied for the HSC examination. Hodson (1998, p. 73) comments "withdrawal from science learning and the fostering of performance oriented students is often a direct consequence of our ego-oriented, competitive assessment practices." In a study of the implementation of a new inquiry based geography syllabus for the NSW senior curriculum, Hall (1997) found that teachers taught to the examination. They also viewed the HSC results as a crude measure of their performance, and were therefore concerned that their students be successful. This often influenced them to take time from teaching the subject matter relating to geography and devote time to teaching examination technique. Keiler and Woolnough (2002) reported that students in England studying for the GCSE examination were very

cynical about the value of practical work. They did not expect to enjoy practical work or find it useful for understanding, and reported that they were only interested in getting the marks. Thus the presence of an external examination may run counter to the need for student motivation from interesting activities and hands-on work, the examination providing motivation of its own. This appeared to be the situation in the study of biotechnology electives for the HSC.

The evidence from the survey, interviews and case studies is that the requirements of this external assessment influenced teachers in their decision about whether to teach biotechnology. If the biotechnology module was seen as too difficult for the students, the teachers sometimes chose not to teach that module, even though the students found the topic interesting.

Summary of Research Findings

The main findings associated with the teaching of biotechnology in NSW are that:

- Many teachers may not have the knowledge and experience to adequately teach biotechnology;
- Teachers perceive a lack of appropriate practical work to be an obstacle to their teaching of biotechnology;
- Aspects of biotechnology are considered by teachers to be difficult even for the most able students;
- Teachers consider biotechnology to be interesting and important;
- The "Biotechnology" module offers challenge;
- "Genes in Action" does not meet the requirements for challenge; and
- Teachers with the knowledge and experience to adequately teach biotechnology often choose not to teach it because they feel that students will achieve higher marks in their HSC examination if they study another elective.

Towards a Biotechnology Education?

A number of studies examined the effectiveness of modules of biotechnology (Lock et al., 1995; Olsher, 1999; Simmoneaux, 2000) and found that when students learn about molecular processes they find the subject matter difficult. Others (Conner, 2000; Dawson & Taylor, 1999) find that discussion of ethical issues can motivate students to learn biotechnology, without the need to include the difficult genetics concepts. However, Baird and Penna (1996) and Venville and Treagust (2002) argue that both demand and motivation are important. The current study compared two units of biotechnology taught in NSW and examined the problems associated with achieving the desired balance between difficulty and motivation within the framework of the entire school curriculum. One elective "Genes in Action" was shown not to meet the requirements for challenge, because the level of cognitive demand was too high and the level of interest was too low, and one elective "Biotechnology" was able to offer challenge.

Yet, if challenge is what motivates students and teachers, why are so few students studying the "Biotechnology" elective? One suggestion, based on the findings of our study, is that although the content of the elective may be attractive for students and teachers, the existence of the external examination is all-important. Students and teachers perceive that students studying "Biotechnology" are disadvantaged in the HSC examination. 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 perceived to be easier. In order to achieve the highest mark in the HSC examination, students chose to study electives other than "Biotechnology." Teachers of HSC 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 widely taught as part of school science unless the biotechnology offered has a similar level of challenge to that of other elective topics or biotechnology becomes part of the core curriculum.

How can a curriculum that incorporates a program for biotechnology that meets criteria for challenge be made available? One solution to this problem would be the inclusion of a "challenging" module (like the one offered in *Science for Life*) on biotechnology in the core of the junior and senior curriculum. The findings of the present research suggest that the module should, as suggested by Olsher, 1999, allow students to access the black box of molecular processes. Yet it should also continue to make biotechnology interesting by relating it to the student's lives, either by discussion of ethical issues or by the inclusion of practical activities.

Although the lack of a challenging module and the presence of an external exam are obstacles to teaching biotechnology, we remain suspicious that teachers choose not to teach this topic because they perceive that they do not know enough about this rapidly changing and topical field of science. While teachers reported that they felt a need to learn more about biotechnology themselves, they did not report this as a problem for its teaching. Yet teachers with extra training in biotechnology taught more hours of the difficult "Genes in Action" elective. If biotechnology is worth learning in school science, and we argue that it is, then further research is needed into school science's resistance to a topic that the teachers themselves regard as important and interesting to students, to identify ways to promote its effective teaching.

Conclusion

This study examines some of the problems of providing a successful teaching module in biotechnology to a wide range of school students within the constraints of the whole curriculum. Much of the biotechnology currently offered fails to be appropriately challenging for students and teachers. This acts as a disincentive to the teaching of this subject. External examinations exacerbate the trend to avoid the teaching and learning of biotechnology. We recommend that units of biotechnology

that are both demanding and interesting be offered to students in secondary schools. These units need to contain practical work and deal with issues that relate to students' lives. They need to be examined in such a way that students who study biotechnology are not disadvantaged.

Correspondence: P. Aubusson, Faculty of Education, University of Technology, Sydney, Box 222, NSW 2070, Linsfield, Australia
E-mail: peter.aubusson@uts.edu.au

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