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Developing tomorrow's decision-makers: opportunities for biotechnology education research

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Abstract Globally, science curricula have been described as outdated, and students perceive school science as lacking in relevance. Declines in senior secondary and tertiary student participation in science indicate an urgent need for change if we are to sustain future scientific research and development, and perhaps more importantly, to equip students with the knowledge and skills to make informed decisions related to scientific research. This paper argues that a good starting point would be the inclusion of more contemporary areas of science in middle school curricula. One such area with continually emerging developments is biotechnology. This paper further argues the need for research into the impact of biotechnology education that would allow students to go beyond learning about biotechnological processes and products to explore their benefits and risks through an integrated approach, where biotechnology education were extended to include subject areas beyond science, such as social sciences, health education, and English. Such an approach is important, in light of research that suggests that the general public has a limited understanding of biotechnology and that public dissemination of information is insufficient to allow individuals to make informed decisions about or to develop attitudes towards, the varied applications of biotechnology. If we are to educate students to be tomorrow's informed decision-makers, we must start by addressing their understanding of and attitudes towards emerging sciences. Further research is needed to broaden our understanding of how to achieve these goals.

Keywords Middle schooling · Biotechnology education · Science literacy · Student attitudes · Critical literacy

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Introduction

Research findings advocate the development of teachers' and students' knowledge of cutting-edge science (e.g., Australian Science Teachers' Association 2006; Goodrum et al. 2001; Nichols and Davies 2006). Moreover, globalisation of the world's economy has increased the need to equip students with the knowledge and skills needed to live in a rapidly changing world (Finucane and Holup 2005). Now more than ever before, education needs to keep pace with continually emerging developments in science (Nichols and Davies 2006). This is not easily achieved, and in many cases, education fails to do so (Department of Education Science and Training 2006). An area in which this is becoming increasingly important is biotechnology, defined by France (2007) as 'a group of technologies that are based on applying biological processes to solve problems and make products to benefit people and improve the quality of life' (p. 93)[1].

Emerging scientific areas such as biotechnology are not easily categorised within the more traditional areas of science. At present, however, if they are taught, this is done within the one discipline. A national study conducted by Goodrum et al. (2001) revealed that secondary science lacks contemporary information, taught from a number of perspectives, as it 'is often traditional, discipline-based, and dominated by content' (p. 152). They also found that it fails to prepare students for their future work or personal lives, and many students believe that the science they are taught lacks relevance or usefulness.

Poor experiences in science during the early years of high school, due to the lack of perceived relevance and the disengagement of students, is a predictor of non-enrolment in senior school science subjects (Simpson and Oliver 1990). While home- and self-factors contribute to the decision of students not to continue studying science (Lyons 2006), school-factors are directly under the control of schools and science teachers. Simpson and Oliver found that school-factors predicted a large proportion of the variance in attitudes towards science, while self-factors were the best indicator of science achievement. The key finding of their study, however, was the high degree of precision with which attitudes and commitment towards science predicted the likelihood of students selecting senior science subjects. Students' avoidance of senior sciences has several likely flow-on effects, such as lower tertiary enrolment in science, fewer science professionals, and a 'public' that lacks sufficient scientific literacy to make informed decisions about the impacts of biotechnology on society and their own lives. Niedhardt (1993) defined 'public' as a field populated by speakers, mediators, and audience; the authors of this paper acknowledge this range of views and knowledge of the 'public', but in this paper the 'public' is considered as audience.

The decline in student enrolments in science subjects in the non-compulsory years of schooling is an international phenomenon (Organisation for economic

[1] Biotechnology, in the context of this paper, refers to modern biotechnology as opposed to traditional biotechnologies such as plant and animal breeding, fermentation processes and cheese making. Modern biotechnology may be categorised as green (plant technologies), red (medical), white (industrial) and blue (aquatic). While the discussion contained within cites green biotechnologies, similar arguments can be made for the other modern biotechnologies.

co-operation and development global science forum 2006). Similar findings have been reported in countries as diverse as Japan (Goto 2001), the United Kingdom (Smithers and Robinson 1988), Israel (Trumper 2006), the United States of America (National Science Foundation 2006), India (Garg and Gupta 2003), Australia (Lyons 2006), and Canada (Bordt et al. 2001). As an issue that crosses cultural and political systems, this topic is of local, national, and international significance.

Within Australia, Dekkers and de Laeter (2001) tracked student participation in year 12 science subjects in New South Wales from 1980 to 1998. They found that student numbers in each science discipline (biology, chemistry, and physics) peaked in the early 1990 s and, by the late 1990 s, the numbers in all three disciplines had fallen to just above 1980 levels. An analysis of the Queensland studies authority 2007 data on Queensland students enrolled in Year 12 science subjects revealed a clear downward trend in biology, and relatively stable numbers in chemistry and physics. These figures are shown in Fig. 1. This phenomenon is by no means restricted to Queensland, and is observed both nationally and internationally.

Fullarton et al. (2003), examining data from 1990 to 2001 found similar declines in national participation in Year 12 science subjects. While it may be hypothesised that, measured over a longer time span, participation rates may oscillate as subject popularity rises and falls, in the 20 year period from 1980 to 2000, national student participation in Year 12 rose by 99%, while participation in the sciences only rose by 31% (Goodrum et al. 2001). It is clear that fewer students across Australia are choosing science subjects in the senior years and this may be in part due to their dislike of science, developed during early high school years. This is another reason to ensure an engaging, relevant, and authentic curriculum in the middle years of schooling.

Why the middle years of schooling?

The middle years of schooling (MYS) literature identifies a research-based set of beliefs, assumptions and practices that cater to the unique social, cognitive, moral,

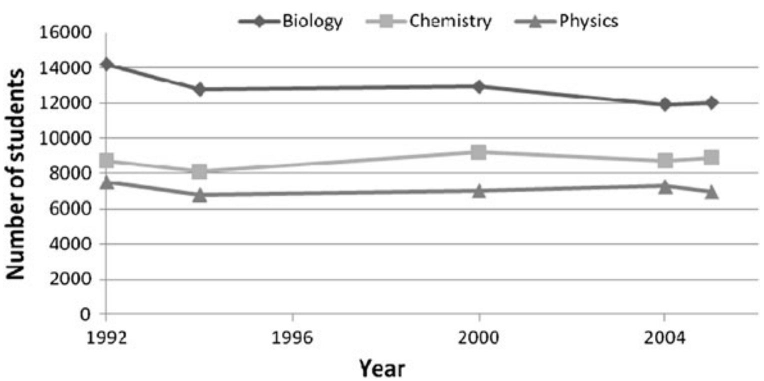

Fig. 1 Year 12 science enrolments in Queensland schools from 1992 to 2005

emotional and physical developmental characteristics of individuals in the early to middle stages of adolescence. Typically, children enter early adolescence around ages 11–14 (Tanner and Davies 1985). The age and grades categorised as MYS vary somewhat across Australia and internationally. While Chadbourne (2001) identified a range of year levels from 5 to 10 for the MYS, a survey of the Australian state education websites finds recommendations ranging from Years 4 to 9 (see Table 1).

Chadbourne (2001) also made a useful distinction between 'middle schools', an organisational unit that may or may not implement the precepts of 'middle schooling', and the stage of compulsory schooling that caters to the developmental needs of adolescents. There are three main reasons to believe the middle years are the most appropriate time to use topical issues, such as biotechnology, as organising ideas for units. Firstly, the MYS are generally recognised as the period of compulsory schooling when students experience the highest sense of alienation and disengagement (Cormack et al. 1996). In relation to science, students regularly report negative attitudes towards their early high school science experiences. Both students and teachers report the teacher-directed nature of science lessons in early high school as a major contributor to these attitudes (Lyons 2004; Rennie et al. 2001). Such teacher-directed approaches are in conflict with the MYS pedagogy described in the literature. According to Chadbourne and Pendergast (2005), MYS approaches are adolescent-centred instead. An important aspect of adolescent-centred approaches is the inclusion of topics of personal interest to adolescents. Fields such as biotechnology, which are widely reported in the media and have a high visibility in students' lives, have the potential to provide topics upon which more relevant and engaging curriculum can be designed, to enhance student engagement and interest in science (Curriculum Council 1998; National Middle School Association 1999). It should be through contexts such as biotechnology, that

Table 1 Education Department recommended level range for the MYS in each Australian state and selected countries

Country	Region	Year level range*
Australia	Australian Capital Territory	5/6–8
	New South Wales	5–9
	Northern Territory	7–9
	Queensland	4–9
	South Australia	6–9
	Tasmania	4–8
	Victoria	5–9
	Western Australia	6–8
China		7–9
Japan		7–9
South Korea		7–9
UK		3–6
North America		5–9

* The age ranges suggested by Chadbourne are consistent with departmental recommendations

the requisite thinking skills are taught to help students develop into tomorrow's decision-makers.

Secondly, making links with parents and community, a key recommendation for the MYS philosophy (Jackson and Davis 2000), is critical. For students to fully develop as future decision makers, other perspectives must be incorporated into the decision-making process. Links with community members, such as family members, scientists, politicians and speakers from interest groups will enrich the learning experiences of the students. Linking to parents and the community in this way further demonstrates how the curriculum is relevant to students' lives and the wider community to which they belong.

Thirdly, innovative pedagogical and curriculum practices (see National Middle School Association 1999) are required, since decision making on topical issues such as biotechnology will necessarily involve epistemological and ontological viewpoints of disciplines other than science. For e.g., an integrated inquiry-based approach, where students formulate personally and socially relevant questions (Crawford 2000; Selby 2006), draws upon relevant knowledge and discipline-based skills to answer those questions and to use their newfound knowledge to impact the real world. This approach has the best chance of positively influencing students' educational outcomes (Krajcik et al. 2003; Roth and Roychoudhury 1993; Zachos et al. 2000). Integrated inquiry-based approaches also facilitate students' ownership of and control over their learning (Songer et al. 2003). These three reasons provide the strongest case for dealing with topical issues such as biotechnology, to help develop the thinking and reasoning abilities of tomorrow's decision makers.

Declining interest in science is significant within the field of biotechnology because, if the products of biotechnology research and development are to progress to commercial viability, the community's acceptance and understanding of biotechnological processes, and willingness to use biomaterials, are vital (Cavanagh et al. 2005). Public perceptions of biotechnology also have the potential to influence the actions of governments, who are cautious in their legislation affecting biotechnology applications. For example, in Australia, several states and territories have only allowed strictly controlled field trials of certain genetically modified (GM) crops, whereas some countries have undertaken commercial cultivation of GM crops. China, the United States, Canada, Brazil, and Argentina account for 94% of the world's land devoted to producing GM products (Doering and Hughes 2006). Other countries have strict controls or moratoria on GM crops and foods. Several European Union (EU) member states ban the importation, sale, or marketing of products of biotechnology such as GM foods (Doering and Hughes 2006). The EU had a freeze on commercially grown GM crops, which ended in 2004; however, no GM seeds have been released for cultivation since 1998 (Waterfield 2007), due to strong opposition by many EU member states.

There are strong arguments for addressing community attitudes to and understanding of biotechnology (see Finucane and Holup 2005; Lusk et al. 2004; Sturgis et al. 2005). The term 'attitude' in this context has been defined as approval or disapproval of a biotechnology process (Bredahl 2001; Chen and Raffan 1999; Dawson 2007). In recent decades, biotechnological applications such as genetic engineering and cloning have captured public attention, raising unresolved ethical, moral, and political questions (Sturgis et al. 2005). Media coverage of issues relating to GM crops, cloning, and gene therapies has raised public awareness of the controversies surrounding various biotechnologies but has done little to advance public knowledge and understanding of them. In general, surveys have shown that the public is sceptical of rather than hostile towards biotechnology, depending on its application, while at the same time, the majority of people understand very little about genetic modification (Sturgis et al. 2005). Coupled with the historically slow acceptance of new technologies that have personal impacts (e.g., the small pox vaccine, see Braun 2002), such research findings suggest the need to increase public understanding of science in general, and more specifically of biotechnologies. This is especially important, given that scientific literacy in the area of biotechnology is believed to be a key determinant of community attitudes to its applications (Sturgis et al. 2005).

This issue is not simple; it needs to be addressed in a number of ways. These include the complex relationship between understanding and attitudes, the variability of attitudes depending on the biotechnology application, the sources from which the general public and school students obtain information about biotechnology, the levels of trust associated with different information sources, students' interests, and the implications of these factors for schools and science curricula.

The development of scientific literacy and understanding of biotechnology in middle years students is an important step in addressing the issue, since these students represent an emerging sub-group of consumers in today's market, as well as tomorrow's (Gunter et al. 1998). Dawson and Schibeci (2003) have noted that scientific knowledge alone is not sufficient for preparing future citizens and that teaching other skills, such as decision-making, is necessary. This supports the argument for positioning biotechnology education within a broader context that considers the ethical, economic, environmental, and health implications that are crucial to holding informed opinions about biotechnologies and making informed decisions. Students need to learn about red (medical), white (industrial), blue (aquatic), and green (agricultural or environmental) biotechnologies in an integrated way. This should include examination of the benefits and risks of various biotechnologies if students are to be truly scientifically literate in ways that allow them to make informed decisions and participate in meaningful decision-making around these applications in their future lives.

Scientific literacy and biotechnology

The concept of scientific literacy has been described in a large body of literature generated over the past five decades (see DeBoer 2000). Historically, scientific literacy has been defined broadly, in terms of the public's knowledge of or familiarity with, science (Laugksch 2000). Clarifying its position on scientific literacy, the United States National Research Council (NRC) (1996) defined it as 'the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity' (National Research Council 1996 p. 22). The OECD defined scientific literacy similarly as 'the capacity to use scientific knowledge, to identify questions, and draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity' (Organisation for Economic Co-operation, Development 2001 p. 76).

According to Goodrum et al. (2001), improving scientific literacy is a necessary aspect of science education in schools since:

> [S]cientifically literate persons are interested in and understand the world around them, are sceptical and questioning of claims made by others about scientific matters, participate in the discourses of and about science, identify questions and draw evidence-based conclusions, and make informed decisions about the environment and their own health and well-being. Such persons will be able to contribute to both the social and economic well-being of Australia (p. 182).

The common theme in these definitions is that scientific literacy is essential for future generations to be equipped with the knowledge and skills necessary for active and informed decision making about applications of science and technology on personal and civic levels. This will become increasingly important as scientific research and technologies continue to become more complex and at times, more controversial.

Scientific literacy is also necessary for the development of stronger, better-informed attitudes to issues of public interest such as biotechnology (Olsher and Dreyfus 1999; Sturgis et al. 2005). Public attitudes towards biotechnology have been surveyed over the past two decades in a number of countries. Examples include surveys conducted by the Commission of the European Community, the US Department of Agriculture, the New Zealand Department of Scientific and Industrial Research, the Australian Commonwealth Scientific and Industrial Research Organisation, the Canadian Institute of Biotechnology, and the International Bioethics Survey conducted in Japan, New Zealand, and Australia (Davison et al. 1997).

Despite their shortcomings (see Davison et al. 1997; Finucane and Holup 2005; Hampel et al. 2000), such surveys have shown that in general, members of the public are sceptical about biotechnology, for a variety of reasons. These include perceptions of associated long-term risks, uncertainty about the adequacy of policy and ability to regulate fast-moving research and technology, and questions of trust in governments and scientists (Gaskell et al. 2004). A growing body of evidence suggests that attitudes to biotechnologies are qualified and nuanced (Poortinga and Pidgeon 2006) and that acceptance of biotechnologies depends upon the nature of the application: for example, gene therapy versus GM crops. Most Europeans accept biotechnologies that have medical benefits, such as diagnosis and treatment of disease (Sturgis et al. 2005); however, genetic modification of crops and applications of biotechnology to food production have been linked to higher levels of public anxiety (Hampel et al. 2000). In respect of genetic modification of crops, attitudes vary, depending on the purpose: for example, modification to improve disease resistance is marginally more supported than opposed, whereas breeding of transgenic animal species is rejected, even by those who generally support the application of genetic engineering in other areas (Finucane and Holup 2005). Despite a lack of scientific evidence for hazards unique to genetic modification (Saher et al. 2006), the genetic modification of plants and animals has been met with concern. A study conducted by Poortinga and Pidgeon (2006) indicated that most people were concerned about long-term and as yet unseen consequences for the environment, and the likelihood of the population becoming dependent on large companies, whereas they saw the advantages of GM crops and food in the amelioration of world hunger.

The knowledge that the public uses to evaluate applications of biotechnology has been found to be generally low in surveys in the United Kingdom, Europe (Sturgis et al. 2005), the United States and Japan (Finucane and Holup 2005). According to Sturgis et al., while providing more information to consumers can change their opinions, an increase in knowledge may also serve to make the previously held opinion more negative or more positive, depending on the issue. Greater levels of understanding influence whether or not a person is likely to have an opinion in one direction or another about biotechnology, rather than remaining ambivalent or indifferent, and generally lead to stronger opinions. Lusk et al. (2004) found that providing information about environmental, health, and social benefits affected consumer attitudes and that individuals who had higher levels of prior knowledge were less influenced by new information.

The question that must be resolved is how best to improve knowledge and understanding. Simply providing more information might not be sufficient. Attempts have been made by various governments to raise the scientific literacy of the populace, with little to no success. For e.g., as a result of the 1985 *Bodmer Report* in the United Kingdom, scientists were encouraged to engage with the media, funds were made available for public education programs, speakers were made available and an annual popular science book prize was awarded (Miller 2001). This was followed by Britain's Research Councils instigating their own public schemes to enhance understanding of science. Both efforts proved fruitless (Miller 2001). Similarly, in the US, despite the best efforts of the American Association for the Advancement of Science (AAAS), surveys have consistently shown that the level of scientific literacy of Americans remains largely unchanged since the 1970 s (Miller 1987; Shamos 1995), and scientific knowledge remains low (Miller, 2001). Attempts such as these, which rely on the deficit model and assume that the public simply needs more knowledge to become more sympathetic towards science, have proved largely unsuccessful.

While the authors acknowledge that a certain amount of knowledge is required to understand the underlying science, obviously this is not sufficient. It is during the compulsory years of schooling that sufficient time and resources are available to equip students (future decision making citizens) with the necessary 'thinking tools' to be able to fully digest modern developments in science and to understand the social, environmental and ethical issues that arise.

Other factors, such as the nature of the information, and its level of complexity, have been found to influence the effectiveness of public information about biotechnology. How consumers respond to new information also depends on their prior knowledge and attitudes (Lusk et al. 2004) and on their perceptions of the credibility of the information source (Frewer et al. 1998). There is a need to inform the public about particular applications of biotechnology, and their benefits and risks, based on economic, ethical, social, and environmental considerations, if decision-making and attitudes are to be informed—that is, there is a need to enhance scientific literacy in the general community. This is, however, a challenging and difficult task, and the implication is that a focus is needed in schools prior to senior schooling (where students may not study any sciences or technologies) as a means of enhancing their knowledge, decision-making, and critical thinking skills to better equip them for civic and personal participation in their lives beyond school.

Students' understanding of biotechnology

Several studies have examined adolescents' understanding of biotechnology (see Cavanagh et al. 2005; Chen and Raffan 1999; Dawson 2007; Dawson and Schibeci 2003; Dawson and Soames 2006; Gunter et al. 1998; Lock and Miles 1993). For example, Gunter et al. examined the knowledge and perceptions of biotechnology of 16 to 19 years old, as part of a larger British study. Their data suggested that this age group typically has a simplistic level of understanding of the meaning of the term biotechnology and the activities represented by it. While the participants had a higher level of awareness of biotechnologies that had been featured in the media, they showed a lack of clear understanding. Gunter et al (1998) also found that the teenagers in the study recognised net risks over benefits for many biotechnological applications, although they were consistently less pessimistic than were older participants. The majority of the teenage participants said that they needed more information about areas such as GM foods. Other researchers examining teenagers' understanding of biotechnology reported findings similar to those of Gunter et al. Chen and Raffan (1999) found that post-16-year-old school students do not understand biotechnology well. An earlier survey of 188 high school students by Lock and Miles (1993) found that a third of the sample did not know what the term 'biotechnology' meant. A further 20% gave simplistic explanations, and only a quarter of the sample knew that biotechnology involved living organisms. Nearly 50% could not give an example of biotechnology. Again this evidence suggests that current levels of biotechnology education are not achieving the goal of enhancing students' understanding of it.

Australian studies have also examined students' knowledge of biotechnology. Dawson and Schibeci (2003) found that a third of students were unable to give any examples of biotechnology, and many could not distinguish between cloning and genetic engineering. Students were also confused about the difference between GM foods and foods produced through selective breeding. Another study, by Dawson and Soames (2006), revealed a similar lack of understanding in these areas, and a study of 12 to 17 years-old conducted by Dawson (2007) found that students' ability to define and provide examples of biotechnology, GM foods, and cloning was poor for younger students but improved with age.

According to Cavanagh et al. (2005), when considering students' understanding of biotechnology, it is important to consider the sources of information used by students to obtain information about biotechnology, and the level of trust they place in information sources. Gunter et al. (1998) reported a number of potential sources of information regarded as important by teenagers. Television news and documentaries, followed by newspapers and magazines, were identified as their main information sources. Interestingly, learning from these sources has been found to be more effective when used under controlled conditions, such as when students will be tested on the knowledge gained from them. Increased access to the internet might be expected to have changed the relative importance of these sources in the years since the study by Gunter et al. (1998); however, Cavanagh et al. (2005) also reported that high school students identified newspapers, television, and radio as their preferred information sources. This was so despite a lack of trust in the accuracy of information from these sources. An interesting finding of the study by Gunter et al. (1998) was the extent to which teenagers nominated school science lessons as a major source of biotechnology information. Twenty-nine percent of teenagers nominated school science, compared with only 5% of general respondents. Harnessing and building the trust placed in school science learning by students is important in developing their understanding and attitudes.

Unfortunately, studies have also shown that understanding of genetics, after studying it in school, remains poor (Richards 1996 cited in Gunter et al. 1998). Gunter et al. suggested that this might be because genetics is taught in an abstract way and not in a way that allows students to see its relevance to their lives. Dawson and Soames (2006) reported that a 10 weeks biotechnology course was effective in increasing Year 10 students' understanding of genetic engineering, cloning, and to a lesser extent, GM foods. According to Cavanagh et al. (2005), providing a general understanding of science, and how it interacts with society, may be more beneficial than teaching detailed information. This suggests that research needs to examine the effect of teaching students about biotechnology in school through context-based and integrated approaches that emphasise aspects beyond scientific content, that contextualise it socially, environmentally, and ethically, and that engage students in the critical evaluation of information. To date, no studies in Australia have examined the link between biotechnology education that includes these broader areas and understanding of or attitudes towards, biotechnology.

Students' attitudes towards, and interest in, biotechnology

If students are to be effective consumers and future decision-makers, a sufficient level of knowledge and understanding must be coupled with attitudes and abilities to develop informed opinions about biotechnology. Research findings generally indicate that biology students who are taught about biotechnology have increased knowledge and are more likely to have positive attitudes towards biotechnology than students who are not studying biology (Chen and Raffan 1999; Dawson 2007; Hill et al. 1998). Chen and Raffan found that while education in biology affected attitudes to various aspects of biotechnology, this was more evident for students from the UK than Taiwan and they suggested that this might be due to differences in teaching approaches. Saher et al. (2006) attributed differences to increased knowledge, as well as being more comfortable and familiar with practical scientific and technological applications.

Hill et al. (1998) surveyed students about GM foods. They compared the responses of students who studied 'A' level biology with those of students who did not, and found that students who had studied 'A' level biology were less opposed to GM foods and saw more advantages and fewer disadvantages. Hill et al. (1998) argued that this showed that increased background knowledge tends to shift opinions from neutral to more positive views of GM foods. If this is the case, there is an argument for ensuring that students in secondary school have an opportunity to learn about biotechnology so that they can develop informed opinions. There appears to be an assumption common to the studies that have examined students' understanding of and attitudes towards biotechnology, that biology is the most suitable or most likely subject in which students might gain an understanding of biotechnology. While it must be acknowledged that biology is indeed an important area for biotechnology education, there are several arguments to support its inclusion in other areas of school science.

Kidman (2008, 2009) has argued that students' awareness of and interest in learning about biotechnology is related to their exposure to television, particularly to popular shows such as *House* and *CSI.* She investigated the attitudes and interests of senior biology students and teachers towards biotechnology and found that students are particularly interested in 'red biotechnologies'—those with medical applications—and bioethics, whereas they are less interested in learning about other areas such as environmental, food, or agricultural biotechnologies. Kidman's work reminds us of the importance of determining and acknowledging students' interests in their learning, particularly in light of the comments made earlier in this paper regarding students' perceptions that school science is irrelevant and uninteresting. However, we argue that in the middle years of schooling, while students will be interested in human biotechnologies because of their exposure to television, in the right context their interest in learning about other areas of biotechnologies can be stimulated. For e.g., students in these years are interested in topics related to environmental protection (see Hunter and Park 2005), and this interest could be used to explore white, blue, or green biotechnologies and their potential for enhancing the environment, addressing issues such as problems with landfill, pollution, habitat destruction, and environmental degradation.

Kidman (2009) also noted a discrepancy between the interests of teachers and senior biology students and found that the aspects of biotechnology that teachers were interested in teaching were not those in which students were interested in learning. Further, Steele and Aubusson (2004), whose research also focussed on senior biology, identified a number of challenges to the teaching of biotechnology including a lack of practical work and difficulty of the subject matter. Again, this paper argues that these challenges might be addressed through a study of biotechnologies in the middle years. France (2007) described the continuum from traditional to modern biotechnologies. We argue that instruction at this level could begin with the traditional applications of biotechnology, such as food production applications, and then move to examine more complex modern biotechnologies. There are abundant resources and many interesting inquiries that students can undertake around traditional applications. Teachers who work in this phase of schooling engage in cooperative curriculum planning teams to develop integrated units, so they are likely to be less reliant on textbooks, and not so bound by the rigorous expectations of senior syllabuses, in terms of the content they deliver. This is not to say that in these years students will not be expected to learn rigorous or challenging material, simply that the ways in which it is presented can be more flexible and more contextual in nature.

Broadening the scope of biotechnology education

Global and Australian findings indicate declining enrolments in science beyond the compulsory years (Goodrum et al. 2001; Organisation for Economic Co-operation and Development Global Science Forum 2006). Perhaps some biotechnology education needs to occur before students decide against studying science subjects in senior schooling—for example, in middle school science. Educating students about biotechnology in the MYS would serve two purposes. Firstly, it would expose students to biotechnology prior to their opting out of senior sciences. Secondly, it might reduce the number of students choosing not to study science by addressing an area with more relevance and significance to their current and future lives. In the middle years context, opportunities also exist to teach students about biotechnologies in a way that integrates perspectives from a number of subjects in addition to science, as integrated curriculum is regarded as a signifying MYS practice (Chadbourne and Pendergast 2005). For these reasons a good starting point from which to learn about biotechnology is the middle years of schooling. Then, beyond this phase, in the senior years of schooling, the scope for educating students about biotechnology could be broadened to include other subjects—for example, by teaching students about white biotechnology in chemistry, examining the potential local and global economic impacts of biotechnologies in economics, or examining health benefits and social issues in health education. Indeed, France (2007) argues that biotechnology could also be taught from the technology syllabus.

Chen and Raffan (1999) have argued that sound biotechnology education does more than increase understanding of the science of biotechnology. It also provides students with an understanding of the benefits, risks, advantages, and disadvantages of biotechnology. They suggest that students should be given more opportunities to discuss issues associated with biotechnology, such as ethics and risks. Dawson and Schibeci (2003) also argue that knowledge alone is not sufficient, although it is the basis of informed decision-making, and that when students are secure in their understanding, uncertainty about biotechnology is likely to be reduced. According to Harms (2002), biotechnology education should be taught in an interdisciplinary way so that students can use ethical questions and knowledge about the effects of biotechnology in making and justifying decisions. Approaching biotechnology in this way would provide students with the opportunity to develop scientific argumentation skills. Harms (2002) describes approaches that could be adopted at different levels of schooling. For e.g., at the middle school level, biotechnology could be integrated into broader topics such as ecology and health education, while in senior schooling, ethical and social aspects need to be integrated with the study of biotechnology applications. Additionally, Harms argued the need to address student interests when teaching biotechnology since students' interest in a topic has an effect on their learning outcomes. According to Harms, girls are more interested in social and ethical aspects of biotechnology, while boys are more interested in economic and technological aspects. It is important to realise that this interest is not directly related to knowledge.

Conclusions and research opportunities

The arguments put forward throughout this paper lead to the question of what makes an appropriate biotechnology curriculum. In already crowded curricula, educators need to explore creative ways by which new biotechnologies can be examined at an appropriate level of complexity, in context, and with consideration for other aspects that accompany scientific understanding such as ethics, benefits, and risks. Goodrum et al. (2001) have argued that:

> Australian curriculum frameworks do not preclude (some even gently encourage) exploration of contemporary topics, but these documents are grounded in the traditional disciplines and provide little help or incentive to teachers to move beyond the traditionally taught content of biology, physics, chemistry and earth sciences. In fact, much contemporary science transcends the boundaries between these disciplines. Biotechnology is one example. (p. 166)

An approach such as that advocated by Goodrum et al. (2001) may be feasible in middle school science, for a number of reasons. The need for curriculum that is challenging, integrated, and exploratory is a key feature of middle schooling advocated in Australia (e.g., Barratt 1998; Cumming 1998; Eyers et al. 1992; Centre for Applied Educational Research 2003) and the United States (Carnegie Council on Adolescent Development 1999; Jackson and Davis 2000). Not only is an integrated curriculum required for students to understand the chemical and biological knowledge underlying many biotechnologies, but when it is integrated with social sciences, students will be able to explore societal, economic, and political impacts of biotechnologies. However, it must be ensured that teachers are sufficiently trained not only in the prerequisite content but also in the pedagogies required to teach these areas in an integrative manner.

The challenges for senior schooling are more systemic in nature, such as the boundaries that exist between traditional scientific disciplines created by curriculum documents. These curriculum documents are often written at the state or national level, and a shift in attitude towards curriculum would therefore be required at that level. At the school level, it will require willingness on the part of teachers to collaborate and to operate in a mode that may be foreign to many traditionally trained high school teachers. It will also require professional development and support for those teachers who are willing to adopt such non-traditional approaches.

There is a need for research that examines biotechnology education when it serves, not only to increase students' knowledge and understanding of particular applications of biotechnology, but also to contextualise learning within a framework that allows an examination of the benefits and risks of that application. Such research would add to the field by providing data about how this approach supports students in their decision-making and whether it affects their attitudes to biotechnology. There is also a need to examine the effect of biotechnology education beyond the biology classroom. For example, Harms (2002) identified a number of topics developed by the European Initiative for Biotechnology Education (EIBE) that might be well suited to a chemistry curriculum. These include fermentation technology, enzyme action, and environmental biotechnology. Other areas include production and biodegradation of biopolymers and bioremediation. Teaching students about biotechnology in other science subjects would allow students who are not studying life sciences to obtain an understanding of several applications of biotechnology and afford an opportunity to consider the benefits and risks associated with them.

In conclusion, it is clear from the literature that increasing students' understanding of the science of biotechnology may not be sufficient to truly develop tomorrow's decision-makers. There is a need to examine how biotechnology is taught and whether examining other aspects such as the benefits and risks of its applications affects students' attitudes. There is also a need for research that investigates aspects of curriculum design, and pedagogy that ensures students have sufficient scientific and critical literacies to be able to evaluate the credibility of information sources and to evaluate critically, information and arguments put forth by proponent and opponent groups. Future research also needs to investigate ways that foster student and teacher abilities to discern subtle differences between terms used in relation to biotechnology. For example, the issues associated with GM foods and crops are often blurred, and the terms are sometimes used interchangeably. Students need the skills to interpret and communicate information, and to develop and justify arguments to support their opinions. Teachers need professional learning opportunities that demonstrate how to facilitate these skills in their students. Biotechnology education with a focus on modern biotechnologies and their applications and impacts, would provide the ideal context within which to foster these skills.

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