Using Biotechnology to Develop Values Discourse in School Science

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Introduction

Biotechnology, broadly defined, is the manipulation of living organisms, or parts of living organisms or systems, for specific purposes of benefit to humankind. As such, it has been practiced for centuries—from early domestication of animals and the growing of crops, to the use of micro-organisms for fermentation. However, increasing understanding of living organisms, cells and genetic material has greatly extended the range of biotechnologies that are and will be possible. These more recent advances—frequently associated with genetic technologies—have potential to transform medicine, reduce world-wide hunger, and positively alter humankind's environmental footprint. However, many are values-laden and therefore controversial, and even divisive. For example, the creation of the world's first human-pig embryos was "hailed as a significant first step towards generating human hearts, livers and kidneys from scratch" while at the same time "reignited ethical concerns that have threatened to overshadow the field's clinical promise" (Devlin, 2017). The use of emerging production, engineering and analytical technologies in the development of pharmaceuticals and neutraceuticals from plants first discovered by indigenous communities was recently called ethnophytotechnology. De la Parra and Quave (2017) raise important issues around ownership and profits, and several international conventions, such as the Nagoya Protocol, provide guidance on how to fairly share profits gleaned from the genetic resources of indigenous people.

This chapter explores the potential for using learning about biotechnology to help school students develop their scientific literacy, technological literacy, and values discourse. These outcomes are consistent with the current emphasis on STEM education seen at the policy level across many educational jurisdictions, as well as the emphasis on so-called '21st century skills', which often include competencies

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associated with cultural awareness and social responsibility. Importantly, the overlapping scientific, technological and social dimensions of contemporary biotechnological developments provide rich opportunities for diverse learning pathways to be pursued. Our experience, however, is that the openness resulting from different pathways can be challenging for some teachers, and that structured scaffolds can help provide useful support as they and their students embark on learning in biotechnological contexts.

Background

Internationally, science and technology education are positioned as essential components in the development of a globally-networked knowledge economy and there has recently been an increasing emphasis on the value of STEM (science, technology, engineering and mathematics) education. Historically, there is a rich history of educational initiatives that draw on the synergies between science and technology education. For instance, science curricula have included technological applications of scientific concepts for decades. This approach was driven by recognition of the interrelationship between scientific understanding and technological advancement, spurred on by post-war education and economic policy in the 1940s and 1950s and the USSR's initial forays into space in the 1960s. In the 1970s, the science, technology and society (STS) movement was pioneered. This movement made the inclusion of technology into science more overt, although the representation of technology was often as applied science: technological examples tended to be used to showcase the relevance of science for solving human problems. Against this backdrop, however, historical school structures and traditions, and the separate goals and objectives of different learning areas, mean that siloing of school 'subjects' often remains, particularly at the secondary level. As a result, implementation of STEM and even STEAM (science, technology, engineering, arts and mathematics) education is not straight-forward.

In addition to outlining key learning areas, including learning outcomes for science and/or technology education, many national and state curricula around the world also identify cross-curricular priorities, such as sustainability, ethical behaviour, intercultural understanding, and a future focus; and general or life skills (sometimes identified as skills for the twenty-first century), such as managing information, critical thinking, problem solving, communicating, creativity, self-management, collaborating and contributing, and responsible citizenship. Some curricula also make values education explicit. For example, the Singapore curriculum includes 'character and citizenship' and 'values in action'. In Hong Kong, a key goal for secondary education is that each student becomes "an informed and responsible citizen with a sense of national and global identity, appreciation of positive values and attitudes as well as Chinese culture, and respect for pluralism in society" (Education Bureau, n.d.). The New Zealand curriculum identifies values as "deeply held beliefs about what is important or desirable … expressed through the ways in which people think and act" (Ministry of Education, 2007, p. 10). A goal of the curriculum is that students

> … will develop their ability to: express their own values; explore, with empathy, the values of others; critically analyse values and actions based on them; discuss disagreements that arise from differences in values and negotiate solutions; and make ethical decisions and act on them. (p. 10)

In other words, there is a strong mandate in many educational jurisdictions for values education across young people's school experiences—oft-times with wide scope for how this might be achieved. This chapter argues for the potential of biotechnology to provide a context for students' values development within science and technology education. Specifically, we introduce three key resources: an online portal for accessing contemporary examples of biotechnology research and development, and two thinking scaffolds to help teachers support students to develop their ethical and futures thinking skills. The examples that are provided have been selected to demonstrate a range of values explorations that can occur. Although the findings may be localised to the New Zealand setting in which the resources were developed, key messages can be re-contextualised and trialled in different locations.

An Online Portal as a Window into Biotechnological Practice

One of the challenges for teachers using examples of contemporary biotechnology as a teaching and learning context is keeping their knowledge up to date: scientific understanding continues to increase, new applications are constantly under development, the concepts can be complex, and the biotechnology community of practice can be difficult for teachers to access in sustainable and meaningful ways. Moreland, France, Cowie, and Milne (2004), for instance, present a case study where a secondary science teacher and secondary technology teacher made individual approaches to contacts within the forensics community and were then "referred along the chain to somebody who finally volunteered to help" (p. 185). The outcome of one of these approaches was that a newly graduated forensic scientist visited the school to talk to the science and technology classes. While this visit was considered by students and teachers to be one of the high points of the classroom program, both teachers "were acutely aware of the imposition their demands had on these people" (p. 185). This telling example suggests that while contact with the community of practice significantly enhanced the learning opportunities for both the teachers and their students, it was not an easy process and required commitment and persistence on the part of the two teachers involved. There was also a degree of hesitation about asking for expert involvement.

To help alleviate some of the challenges associated with schools accessing the biotechnology community, and to provide a sustainable mechanism for biotechnologists to connect with schools in meaningful ways, the New Zealand Government supported the development of the Biotechnology Learning Hub, first launched in

2004. The face of this initiative was an online portal with extensive multimedia content showcasing contemporary New Zealand biotechnology, with wrap-around teaching and learning resources. The overall aims were to raise awareness of biotechnology practice and biotechnology education, and to provide a range of materials to support the use of biotechnology examples as contexts for meaningful cross-curricular learning. The resources included computer-mediated interactive activities, virtual tours and stories about people in biotechnology. Explicit consideration of values and ethics was integrated throughout.

By way of example, a suite of resources explores nutrigenomics, or the use of genetic information to guide individualised nutritional plans. Nutrigenomics, therefore, is premised on the different ways in which individuals respond to specific foods, making some foods more helpful (or harmful) to particular people depending on their specific genetic profile. This information can be used to inform a person's food choices in relation to their health, performance, and risk of disease. But what is the value of such research? Will it replace more generic messages around eating a wide range of different fruits and vegetables? Does the cost of genetically testing individuals justify the information that is gained? Even when people know the impacts that specific foods might have on their health and performance, will it lead to behavioural changes? Do the ways in which we value such research differ depending on the context? For example, is nutrigenomics research related to diseases such as inflammatory bowel disease more valuable than nutrigenomics research related to diseases that affect a smaller proportion of the population? What about how the research is conducted? For example, what are our views about the use of animals in research? Does this differ if the research has direct medical benefits, versus more aesthetic benefits? What are the potential cost implications in terms of who can and cannot access the benefits of nutrigenomics? Studying nutrigenomics, therefore, offers scope for an extensive range of learning experiences—about our genetic code, food analysis and interactions between food components and genes, research methods that range from the use of microarrays and animal models to computer models and big data, the purposes and value of such research, and the societal implications and applications that may result.

The Biotechnology Learning Hub was considered to be useful by both the biotechnology sector (as a means of sharing their work), and the teaching community. In 2006, the Science Learning Hub was launched. This second online portal uses multimedia resources to showcase contemporary New Zealand science research, focusing on providing rich contexts that teachers can use to make school science relevant, meaningful and engaging. Over a decade later, in 2017, content from both sites was combined in a new-look platform (www.sciencelearn.org.nz). While this consolidated the resources under one 'brand', it also signalled the Government's valuing of science education over technology education. As a result, technology teachers may be less likely to access learning resources from what they perceive to be a portal targeting the teaching of science, even though the technological aspects of the biotechnology (and other technologies) are also highlighted. Nonetheless, the resources continue to be accessed and used by a vast audience of teachers and students across the compulsory school spectrum, as well as by wider communities, including parents.

Using video clips and other multimedia resources to essentially bring scientists 'into the classroom' provides "an effective, time-efficient and convenient way of supporting student and teacher learning" where "students being able to see and hear local scientists talk about their work and their aspirations for their work's local impact/contribution was important" (Chen & Cowie, 2014, pp. 461–462). Online connections between scientists and groups of teachers and/or students can also be facilitated, and even recorded and published for access by a wider audience. For example, a video conference between leaders of the New Zealand nutrigenomics project and 14-year old students from six secondary schools was recorded, and video clips were subsequently published on the Science Learning Hub. Within the conversation, values were addressed head on. For example, one forward-thinking student asked: "If nutrigenomics finds genes linked to disease, and then aims to manipulate the effects of these genes by changing the diet, is there much of a jump to turning these genes off? Is nutrigenomics likely to lead to genetic manipulation of people?" One of the science leaders responded:

> *I'm really glad you asked that question. Going out and talking to people, they're scared. They're scared that we're going to be genetically manipulating foods or we're going to be genetically manipulating people. Please, please, if you take home no other message, it's not in the least what we're trying to doing. We're really trying to use a very non-invasive way to utilise the information we have about the genes of plants or the genes of people, and to optimise and select. We're not trying to genetically modify anybody. It's utilising genetics. It's not manipulating genetics.*

In other words, public concerns about (and a non-valuing) of genetic manipulation are acknowledged—and are ostensibly supported, in this instance—by the participating scientist. Science concepts also featured in the discussion, a second participating scientist explaining the complexity of the gene interactions and the efficacy of nutritional intervention over genetic manipulation. Later conversations between the students and their teacher led to further unpacking of some of the ethical issues around the genetic modification of humans.

Overall, a key strength of the Science Learning Hub portal is the development of content specifically for educational purposes. Key to user engagement has been an emphasis on the human aspects of science and technology, including the people and stories of science and technology and how science and technology relate to everyday life. A consideration of relevant values is embedded across the content, and the drivers underpinning the research and development projects are explicitly explored. By way of more generic support, the Science Learning Hub also hosts the ethics thinking toolkit and the futures thinking toolkit. As discussed below, these structured scaffolds support students' thinking across a wide range of biotechnological contexts, as well as other socio-scientific issues.

An Ethics Thinking Toolkit

Biotechnology contexts hold enormous potential for values exploration and class debates, and social and ethical issues are often explicitly incorporated in biotechnology units and assessments in senior secondary biology courses. However, much younger students can be supported to develop their values discourse and ethical decision making skills in science contexts, including biotechnological contexts (Buntting & Ryan, 2010). A significant challenge, however, is some teachers' reluctance to engage in such opportunities. For example, a study with Irish science teachers highlighted the tension that they experienced between advocating for biotechnology while holding some personal reservations about future directions and economic implications for some sectors of the community (Michael, Grinyer, & Turner, 1997). Levinson and Turner (2001) found the majority of science teachers considered it their role to present the 'facts' of their subject and not to deal with associated social or ethical issues. They felt that they lacked the skills, confidence and time to initiate and manage classroom discussion. Scottish teachers who participated in a study by Bryce and Gray (2004) similarly felt that they were required to adopt neutral positions—"that science and technology should provide the 'how' but not, of itself, indicate 'whether'" (p. 725). They also wanted greater clarity on the relationship between such discussion and what is formally assessed in the course.

One way to support teachers in their implementation of ethics education, including values articulation and exploration, is to provide structured scaffolds such as the ethics thinking toolkit available on the Science Learning Hub. This toolkit specifically explores five different frameworks for ethical thinking (Reiss, 2010; Saunders & Rennie, 2013):

- Consequences—what are the benefits and risks?
- Rights and responsibilities—what rights need to be protected and who is responsible for this?
- Autonomy—should individuals have the right to choose for themselves, or does one decision count for everyone?
- Virtue ethics—what is the 'good' thing to do?
- Pluralism—what perspectives are held by groups with particular cultural, spiritual or religious identities?

Within each framework, a set of questions can be customised to the particular biotechnological (or other) context being considered. For example, students using a consequentialist approach to guide their ethical decision making could answer the following questions: Who/what is affected? What are the possible benefits/harms to each of these groups? If one benefits and one is harmed, who/what matters most and who decides this? Which option would produce the most benefit and least harm? Students using a pluralist approach could be invited to consider: Which groups of people have views about the issue? What are their views? Why might they think this way? Do all groups voice their views? Do the views of all groups have equal weighting? How is this decided? Can all the groups agree? Do they need to? At the end of their initial considerations, students identify and rank possible responses to the issue, explain their reasoning, identify the ethical framework that they used to reach their decision, and consider why others might not agree with their decision and/or reasoning.

By having access to a range of different frameworks, students are supported to understand that a range of approaches are used by ethicists – and lay people – to make decisions. The first four frameworks resonate with those proposed by others, for example Beauchamp and Childress' (2008) principles of beneficence (promoting good), non-maleficence (avoiding harm), autonomy (maximising the freedom of an individual or community), and justice (acting fairly); and Sadler and Zeidler's (2004) moral philosophies of deontology (which includes justice and autonomy), consequences, and a care-based morality. The fifth framework—pluralism—was included to explicitly acknowledge and take into account cultural, ethnic, religious, and gender perspectives. As Brodwin (2000) has argued, we need to "treat culture not as a new variable to be fitted in to established bioethical formulae, but as a multiple determinant of moral experience in its own right" (p. 7).

In multicultural societies, cultural beliefs, values and attitudes play a large part in people's responses to science and technology developments but there can be significant tensions between traditional beliefs, and the benefits offered by the new biotechnologies. For example, an important ontological principle for Māori, New Zealand's indigenous population, is *whakapapa*. Whakapapa is a genealogical framework that in its broadest form links all animate and inanimate phenomena. Roberts and Wills (1998) explain Māori concerns about the use of recent biotechnologies and their implications not only for *whakapapa* but also personal *tapu* (sacredness) and *mauri* (life force). Specifically, Māori understanding of the interconnectedness of all aspects of the human and physical worlds affects how many biological issues are interpreted. For example, many Māori believe that some newer genetic technologies can irreparably interfere with the relationships between humans and the natural world and that these technologies represent a serious breach of *tikanga* (customs and protocols). Māori also have a strong sense of *kaitiakitanga,* or responsibility and guardianship for the environment and all of its life forms. The collective viewpoint is frequently emphasised over that of individuals. It is not surprising, then, that for Māori, cultural risk assessment needs to be grounded in culturally appropriate *tikanga*, including acknowledgement of spiritual values: "A purely scientific risk/benefit framework is not sufficient for Māori" (Roberts & Fairweather, 2004, p. 72).

Including pluralism as an ethical framework in the ethics thinking toolkit provides explicit opportunities for students' diverse cultural identities to be expressed, recognised, respected and valued. This allows them to more authentically and holistically engage in discussions about controversial issues. For example, research by Saunders (2009) showed that secondary school teachers who used the ethics thinking toolkit with students investigating a range of biotechnological issues (e.g., in vitro fertilisation, pre-natal genetic testing, and the development of future foods through genetic modification) reported that including cultural perspectives provided opportunities for students to reach decisions in which their cultures could be acknowledged and validated: "Being able to use their cultural view helped them to make a decision on an issue—they could make a link and bridge the gap between their own culture and the school culture" (unpublished data).

Saunders' (2009) case study of four classes engaging with the ethics thinking toolkit (with students from ages 13 to 18 years of age) showed that most students could learn to use the five ethical thinking frameworks of the toolkit, and could identify the framework that they, or others, were adopting. The teachers commented that the students' ability to provide ethical justification for their views had been enhanced. There was also some evidence that Māori students, in particular, were empowered to draw on their cultural identity in justifying their decisions. For example, one student of Māori descent argued in a written essay: "I don't agree with donating or receiving an organ, either from another human or an animal, because it breaks the whakapapa" (18 year old) (unpublished data). Practices such as being an organ donor or becoming a donor recipient assume enormous significance within this worldview: despite the high incidence of diabetes and the need for kidney transplants among Māori people, very few participate in such programmes. Another student, participating in a debate, used *whakapapa* to argue from a pluralistic perspective in the context of genetic modification: "I don't think we should genetically modify our food plants—we are messing with the whakapapa in them" (13 year old). A third student drew on the collective responsibility of the whānau, or wider family, rather than individual rights, when presenting arguments related to medical termination of a pregnancy: "If a baby is to be aborted because there is something wrong with it, the decision should not be made by the parents but by the whole whānau, who will think about the whakapapa" (14 year old).

Other case studies using the toolkit demonstrate that the ethics thinking toolkit enabled both primary and secondary school teachers to support their students to think ethically from a variety of perspectives, acknowledging the multiple identities that students bring to decision making (Jones, McKim, & Reiss, 2010). It is postulated that progression in ethical thinking will involve the use of an increasing number of different frameworks, ultimately leading to an ability to evaluate the usefulness of the frameworks for different situations (Reiss, 2010). An important question for future research is whether this approach—giving other worldviews voice in the science and technology classroom—will help students connect their science and technology understandings with their other cultural understandings and worldviews.

A Futures Thinking Toolkit

Futures thinking involves a structured exploration into how society and its physical and cultural environment could be shaped in the future, usually through developing possible, probable and preferable scenarios. Such explorations are premised on the following principles: the future world will likely differ in many respects from the present world; the future is not fixed, but consists of a variety of alternatives; people are responsible for choosing between alternatives; and small changes can become major changes over time (Cornish, 1977). Choosing between alternatives and then working towards a preferred future is clearly values-laden.

Once again, biotechnology provides a rich context for helping students to develop their futures thinking skills alongside their understandings of the nature and processes of science and technology. One study in which we explored the potential for biotechnology contexts to engage students in futures thinking used examples from carefully selected science fiction movies as powerful and engaging entry points into the learning (Buntting & Jones, 2015a). For example, the movie GATTACA, although released in 1997, continues to provide an accessible portrayal of a future society driven by eugenics enabled by pre-birth genetic selection, exploring issues associated with genetic discrimination and providing tangible examples of how contemporary and future genetic understanding might be applied. The 2000 movie *The 6th Day* is set some time in a future when cloning of animals and human organs is routine but the cloning of entire humans is prohibited. However, the accidental cloning of the protagonist and subsequent threats on his ‘first life’ raise issues around identity, genetic ownership, rights of clones, immortality, use and abuse of genetic information, extremism, and the legal control and policing of new technologies. Note, though, that the ‘science’ represented in the movie is very different to the actual techniques currently being used (somatic cell nuclear transfer and induced pluripotency)—providing opportunities to explore the science of cloning, and why fictional processes were introduced in the movie.

The futures thinking toolkit available on the Science Learning Hub is designed to help scaffold students’ exploration of future issues, and to support them to develop and evaluate a variety of evidence-based scenarios. The toolkit draws on work by Jones et al. (2012) in which five elements are considered as part of the scenario development:

– understanding the current situation,
– analysing relevant trends,
– identifying drivers,
– exploring possible and probable futures, and
– selecting preferable futures.

The concept of ‘wild cards’ was subsequently included (Buntting & Jones, 2015b). These are low probability, high impact events that “tend to alter the fundamentals, and create new trajectories which can then create a new basis for additional challenges and opportunities that most stakeholders may not have previously considered or prepared for” (Saritas & Smith, 2011, p. 295). Examples of wild cards include a natural event with large-scale impact; the impact of new and unanticipated disruptive technologies; or a dramatic change in the human lifespan due to a medical breakthrough. Addressing wild cards as part of the futures thinking exercise can therefore help facilitate creative and imaginative thinking.

To encourage students to think beyond how the issue that is being explored affects them personally, each component of the futures thinking toolkit can be considered at a personal, local, national, and global level. This highlights the critical role of the social context in futures thinking, and the existence (and complexity) of multiple perspectives. As with the ethics thinking toolkit, a set of question prompts can be customised for the issue being considered. For example, the issue of future foods could be explored through the following questions:

- Existing situation—What foods are currently available?
- Trends—What differences are there between the food eaten now and the food our parents ate when they were young?
- Drivers—Why is food production changing? (Consider demographic changes; globalisation; environmental changes; developments in science and technology)
- Possible futures—What foods might be available in the future? Why?
- Wild cards—What unlikely events might occur that would have a big impact on future food production?
- Probable futures—Which trends and drivers are likely to persist? What foods are most likely to be available in the future? Why?
- Preferable futures—What foods do you think should be available in the future?

A case study of a Year 10 class (14 year olds) using an early version of this framework is presented by Jones et al. (2012), the six-lesson sequence culminating in student groups promoting the development of a future food they had designed. Students' presentations needed to address the need or opportunity driving the development of the future food (i.e., a values proposition), the scientific techniques that would be required for its development, and the potential risks and benefits associated with its development (i.e., a values analysis). Introductory activities included brainstorming the past and present context in relation to food followed by a teacher discussion facilitated by the teacher to identify trends (e.g., fast food, convenience foods, greater variety) and drivers (e.g., consumer demands, health issues, advertising). Students were also given 15 examples of possible future foods (e.g., 'Potatoes have a gene put in them to protect them from insect attack; farmers don't need to use chemical sprays') to both introduce the concept of genetic modification and guide a values discussion. Each student group was then required to identify trends and drivers in relation to future foods, as well as potential impacts (societal, economic, environmental), that is, possible versus preferable futures. Specific questions that they were asked to address included: What is the problem, and what is the need for the product? What is the science background? What are the benefits and risks of the developing the product?

Food ideas developed by the students indicated that they were able to identify a need (e.g., nutritional, environmental) and propose a solution. During subsequent whole-class discussion focusing on factors that would shape the development of foods in the future, the following ideas were introduced by the students:

- New technologies such as genetic modification;
- Future research, such as identifying useful genes;
- The sharing of such new information;
- Public support for new technologies; and
- Needs, such as feeding a growing population.

This helped the students to link their presentations with the overall aim of developing futures thinking skills by highlighting the central role of trends and drivers – demonstrating the usefulness of the futures thinking toolkit as a thinking scaffold that students can use to develop and evaluate future scenarios. Reflecting on the unit, the teacher identified significant complementarity between learning about the science of genetic modification, futures thinking, and ethics thinking. She also saw value in creating space not only for students to select preferred scenarios, but also to identify ways in which these preferred futures might be pursued by individuals and communities. This latter aspect is particularly important if futures thinking is to have an empowering impact (Rogers & Tough, 1999).

Concluding Comments

Biotechnology is a rapidly advancing field and medical, agricultural and industrial biotechnologies are poised to play increasingly important roles in everyday life. However, many recent and emerging biotechnologies are values-laden and associated with significant public controversy. These examples present science, technology and STEM teachers with engaging contexts in which to situate students' learning—about the science and technology, and the nature of science and technology, and—as demonstrated in this chapter—about their own values, and how these might impact on their perceptions of and support for (or resistance against) particular advancements. However, such values explorations can be intimidating for teachers who have limited experience or training in this area.

This chapter has provided some examples of how a more structured exploration of values in the context of biotechnological developments can be scaffolded. Such learning, with a values, ethics and a critical futures perspective, can assist students to develop the skills needed to evaluate and use scientific and technological ideas and processes to address current and emerging problems. Of course, teacher change is not easy, in part because of the dominating influence of subject subcultures. These subcultures often lead to a consensual view about the nature of the subject, the way it should be taught, the role of the teacher, and what might be expected of students. More widespread integration of values education within science, technology and STEM classrooms will therefore not be straightforward. However, biotechnology offers rich examples for engaging students in values discourse and developing their ethical and futures thinking skills as well as their conceptual and procedural learning in relation to more traditional science and technology outcomes.

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