Evolution of senior secondary school biology education in New Zealand:

Impact of changes in biological science from 1878 to 2008

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Biological science has undergone exponential growth and change in the past 150 years. These changes have included the nature of biological knowledge, organisation of the discipline, and the process of biological research. As a result, secondary school biology education has also experienced extensive growth and change, influenced by advances in biological science, technology, pedagogy, and educational practice. Advances in science and technology leading to growth in understanding of biology have impacted on society in areas of health, horticulture, agriculture, biotechnology, sustainability and environmental management. The complexity of the biological concepts that 21st century society engages with, and the relevance of biology to daily life mean that development of functional biological literacy is more complex and potentially more important than ever before. New Zealand has a national curriculum statement that is intended as a guiding framework from which communities will set their own school and classroom curricula. Collaboration between teachers, scientists, and communities is required to explore what this will evolve to mean for biology education in 21st century New Zealand schools. While moving forward, it is valuable to look back and to consider where we have come from and how the pathway thus far can assist as we shape the pathway forward.

Introduction

Science entered the formal educational curricula of Europe and the United States during the 19th century. New Zealand, strongly influenced by colonial roots from the United Kingdom, followed this trend. The Education Act of 1878 established a right to a place for science in most New Zealand primary and secondary schools. Early 19th century education was based on the classical model (DeBoer 1991) and required significant convincing of the worth of science both intellectually and practically to see this change occur. The 19th century was a period of extensive growth for science, assisting in the argument for change. *Scientific knowledge* [*was*] *integrated and made significant by the enunciation of four fundamental principles: the atomic concept of Dalton (1808) brought order to chemistry; the cell concept of Schwann (1839) and the evolutionary ideas of Darwin (1859) paved the way for more meaningful study of living things; and finally the concept of energy, arising particularly from the work of Joule (1843) and W. Thompson (1847), provided the key to many practical and theoretical problems and led to spectacular advances in physics* (Searle 1958). Proponents of science education in the 19th century (many of them scientists themselves) argued that scientific knowledge was important for economic prosperity, and the development of skills of observation and inductive reasoning (DeBoer 1991). However the value of education was judged on intellectual merit as much as practical worth. It was argued that the intellectual challenge offered by the development of skills of inductive thinking would be achieved through laboratory investigations and inquiry in science which would develop an attitude of independence in students, ... *enabling them to participate more fully and effectively in an open democratic society* (DeBoer 2000). The arguments that were put forward by scientists such as Huxley, Tyndall, Spencer (DeBoer 1991) and others were not significantly different from those that we propose today *Science is able to inform problem solving and decision making in many areas of life ... By studying science students ... use scientific knowledge and skills to make informed decisions ...* (NZ Ministry of Education 2007).

However, early 19th century science education did not include biology. *When the struggle for recognition of the sciences in the school curriculum occurred, biology was not yet ripe, but physics and chemistry were* (Chelmsford 1933). Nineteenth-century biology was still focused on observation of form and was ill equipped to develop understanding of function. In contrast, greater conceptual advances in chemistry and physics obtained through experimentation were providing explanations of phenomena, and when linked to technology, important developments that would affect the economic well-being of society.[1] The chemistry, physics, and technology required to develop understanding of function at a molecular, cellular, and even organ level and explain the cause of diversity was not yet available. It was not until the second half of the 19th century that biologists would start to realise ... *that only by experimental methods can*

[1] Major developments include Dalton, atomic structure (1808); Morse, the electric telegraph (1835); Lenoir, the first vehicle driven by an internal combustion engine (1862); Swan and Edison, electric light bulbs (1878); Roentgen, X-rays (1896); Thomson, the electron (1897).

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we hope to place the study of zoology on a footing with the sciences of chemistry and physics (Coleman 1971).

Development of biology and its effect on biological education

When science education was introduced in the mid-19th century, biology was lacking in overall conceptual advance. Nevertheless, the knowledge of biodiversity, structure, and to a lesser extent, function that *was* available was to provide the basis of the biological revolution in the last half of the 19th century (Moore 1993) that shaped the development of biology education. Recognition of the commonalities of the requirements of life, and understanding of the variation possible in structures that served these functions increased detail of classification. The integration of this knowledge with Darwinian ideas of evolution saw concepts of homology and analogy further developed, and the introduction of ideas of convergent and divergent evolution. Technological progress allowed the understanding of the cell to advance from Schleiden and Schwann, 1839, proposing that all organisms were made of cells, to Virchow's hypothesis *omnis cellula e cellula,* 1855, all cells come from cells. Weismann then linked the cell and evolution in 1880, proposing that *all cells living today can trace their ancestry back to ancient times.* This simply implied what is now known, that the cell contains inherited information that comprises instructions for growth, function and development. Further developments in microscope technology, combined with the discovery of the selective character of dyes on tissues by Sorby, allowed vital advances to occur. Central to these was the concept that the nucleus was a permanent feature of the cell. The first observations of chromosomes and the process of mitotic cell division were described by Schneider in 1873 and given in detail by Fleming in 1882. Meiotic divisions were described in the late 1880s (ibid).

Throughout the early history of biology education in New Zealand it is clear that what was taught in schools lagged behind current scientific knowledge. At the introduction of science to New Zealand schools in 1878, primary-school science included the study of the natural world in Object Lessons and Elementary Science (AJHR 1879). In secondary schools, biological science was largely represented by the study of botany, described as being lifeless 'book and chart' study (Searle 1958). However, not all schools offered this, with physics and chemistry dominating early New Zealand secondary science education. Zoology, agriculture, physiology, and hygiene emerged as additional subjects in the lower classes of secondary schools in the early 20th century, but were not commonly found in senior secondary education (AJHR 1914). Evidence from examination papers (NZEI 1902, 1903, 1905, 1907) suggests that the courses offered were generally confined to classification, life histories, form and to a lesser extent function in plants and animals. A small amount of ecology was explored with botany in terms of the study of natural habitats. Experimental biology was not apparent. Practical work in botany and zoology was confined to observation of form and function. Cell biology in the form of observation of tissues appears in the late 19th–early 20th century, almost 60 years after Schwann's work. Assessment was confined to knowledge-based questions, with links to practical observations that would have been made during classes: *Explain the naked eye and microscopic characteristics of a muscle such as the biceps, and explain how movements of limbs are affected by means of the muscle* (NZEI 1905).

Biology as a subject (rather than zoology and botany) entered the New Zealand curriculum in 1934,[2] achieved through changes to external examinations. Biology and General Science were introduced as subjects in the new 1934 School Certificate[3] (SC) examination as a result of petitions to the University Senate by the New Zealand Horticultural Institute, which argued that there should be a place for biology and general experimental science equal to that given to chemistry and physics in secondary education (Searle 1958). Still focusing on form rather than function, the biology examination was split into zoology and botany, but did contain some cell biology, requiring students to have an elementary knowledge of protoplasm, the cell as a unit of living tissue, and knowledge of plant and animal cells (NZ Department of Education 1934). It was not until 1945 that the requirements of the New Zealand SC biology syllabus included the process of mitosis and meiosis in addition to general knowledge of the cell (NZ Department of Education 1945). This gives a time lapse between initial discovery of the process of cell division and its inclusion in New Zealand secondary education of more than 50 years.

The Thomas report of 1944 (NZ Department of Education 1944), aimed primarily at addressing curriculum concerns and ensuring equality of opportunity for all pupils in secondary schools, was the catalyst for the integration of botany and zoology within the biology course at SC level. *It was at this point that the emphasis of the New Zealand biology curriculum moved from form to function* (Searle 1958). Although biology was being offered in some sixth-form courses as early as 1940, it was not until 1951 that zoology and botany were replaced by biology in the University Entrance (UE) examinations. Similar changes took place in Britain by the late 1950s. This move towards biology as a subject was as a result of major advances in molecular biology. Concepts of cellular function, metabolism, cellular energetics, and heredity that are central to both plant and animal studies were clearly established. The reorganisation of the discipline that resulted from this encouraged the need for *life sciences to incorporate the relevant biochemistry and the reductionist/experimental approach* (Jenkins 1979). Not only did the structure of the subject change, but the approach to practical work became experimental.

Despite these advances in the structure of New Zealand secondary-school biology courses, the concepts of heredity and evolution were not seen in these courses until the 1950s. The birth of modern genetics came as a result of recognition of the work of Mendel (1865) by deVries and Correns in 1900, and the impact of this on the meaning of Darwin's (1859) *Origin of Species.* By 1903, Sutton, using a comparison of cytological and genetic evidence, proposed that the heredity units responsible for the observations in Mendel's work were in fact parts of the chromosomes (Moore 1993). The concept of sex-linked inheritance was proposed by Morgan in 1910 through his work with *Drosophila* and was followed by theories of linkage (Struvent 1913), crossing-over (Müller 1915) and non-disjunction (Bridges 1916). However, as with concepts of the cell, there is a considerable lag between the development of understanding in the scientific community and the inclusion of these concepts

[2] School Certificate level only. Zoology and Botany continued as separate subjects until 1953 at University Entrance (sixth-form) level (Searle 1958, p. 48.

[3] Fifth form (or in modern equivalent New Zealand Year 11)

in the school biology curricula. New Zealand was not alone in the exclusion of the teaching of heredity and evolution in the first half of the 20th century. While these concepts are not evident in New Zealand biology curricula in the 1930s and 40s, they were also absent from SC biology courses in Britain at the time, possibly in response to societal and political events: *In excluding ... it is possible that the majority of science masters were seeking to dissociate themselves and their Association with the more contentious, even sensational, issues associated with applications of genetics ideas to human society* (Jenkins 1979). Concepts of heredity are first evident in the 1945 New Zealand SC syllabus for human biology but heredity is not specified in the SC biology or general science syllabuses at that time. Mendelian genetics and heredity enter the biology curricula at UE level in the 1950s and at SC level in the 1960s. By the 1960s, the UE biology prescription also included concepts of heredity, an examination of Darwinian principles, and population genetics (Miller *et al.* 1963).

While biology education in the period from 1878 to 1950 was slow to establish and lagged significantly behind in terms of understanding of biological concepts, the period from 1950 saw the beginning of the rapid advances in molecular biology entering the school curricula at a much swifter pace. Scientifically, advances in understanding of the structure and function of genes led by Avery's discovery of the 'blue-print' nature of DNA in 1944 were followed by the unravelling of the structure of DNA by Watson and Crick in 1953 and the explanation of the process of protein synthesis by the end of the decade. By the mid-1960s the structure of DNA was incorporated into New Zealand UE biology courses. By the 1970s, SC biology and general science had incorporated the concepts of DNA structure and function, with protein synthesis included at UE level.

By the 1970s, biology was being presented as a series of topics, within which the processes of life and levels of organisation were explored. The underpinning of evolution was evident, with major functional life processes being studied and comparisons explored between these in various organisms, showing evolutionary patterns. The influence of the discovery and inquiry based teaching models of biological science curriculum study (BSCS) in the United States and Nuffield in the United Kingdom were evident (BSCS 1993). The completion of this shift in the teaching approach that started in the 1960s fully established function or process as the primary concern of biology education rather than form. It presented the study of structure in the context of understanding how an organism survives within its environment rather than as a means to an end.

The influence of biotechnological development on understanding at a molecular level from the 1970s onwards was rapid. While it brought advances to society, it also initiated interactions with complex molecular biology into daily life and introduced significant social and ethical issues such as the use of DNA, reproductive and genetic-engineering technologies. The impact of these developments on biology education triggered the *Science, Technology & Society* movement of the 1970s that influenced New Zealand education in the 1980s, bringing socioethical issues into the biology classroom. In the early 1980s, molecular technologies such as DNA fingerprinting were presented as examples of applications of biotechnologies, but were not specifically stated in curriculum statements or examination syllabi. *Current Issues in Biology* were added to the New Zealand University Bursaries examination syllabus in 1987. Incidence and control of human disease, biological control and conservation issues are examples of early topics, with issues such as the development and use of gentically modified organisms entering the topic range in the early 21st century. Alongside the relevant biological concepts, students were required to consider the social, ethical and biological implications of the issue chosen. The 1994 New Zealand curriculum (NZ Ministry of Education 1993a, 1993b) reflected this change with statements in both the biology and science documents that formally included socio-ethical issues relating to biology. The advent of the National Certificate of Educational Achievement (NCEA) at Level 3 in 2004 saw this aspect of the course continue to develop, with the addition of understanding of economic or environmental implications and a requirement to present differing opinions providing an opportunity for further development of understanding of the ethical implications and the relationship between biology and society.

A change to the University Bursaries examination prescription in 1998 saw bio- and molecular technologies enter the syllabus as a compulsory section, looking at techniques and their application (NZ Qualifications Authority 1998). With this arose the challenge for modern biology curricula relating to the breadth of this area of biology. The array of potential techniques and applications that could be used to assist students to develop an appreciation of the role of molecular biotechnology is extensive. While initially assessment of understanding of a selection of these applications occurred via external examination (University Bursary, 1998–2003; NCEA Level 3, 2004–2006), it became clear that the use of internal assessment, enabling teachers to facilitate learning that allowed development of understanding of selected examples, would be more appropriate (NZ Qualifications Authority 2008). This also assisted in addressing the issue of presentation of applications such as stem cell research or xenotransplantion, understanding of which requires the development of related background biological knowledge not contained in the general Level 3 biology course. Alongside this sits the major dilemma for 21st-century biology curricula: in a subject that is as vast as the study of living organisms, what is considered fundamental for the development of biological understanding and literacy, both for those who will go on to use science in their daily lives and those who will go on to use science in their chosen professions?

Changing purpose of biology education

Advances in biology as a science, changes in the issues facing society, and changes in educational ideologies have altered the emphasis, approach to, and purpose of biology education. Two themes relating to the purpose of science education, although significantly modified over the past century, are recurrent. They are the development of scientific literacy (science for all) and the potential development of understanding for future scientists. Education for the development of future scientists led to the content-driven curricula of the early and mid-20th century, despite the ideologies proposed by Huxley that the development of inductive reasoning through engagement in scientific investigation was one of the most important facets of science education (DeBoer 1991). Hipkins *et al.* (2002) proposed that even in modern New Zealand classrooms delivery of content to develop future scientists is the implicit driver of science teaching. While the quest for some functional biological literacy has been evident in biology education from its inception, the understanding of biological literacy has evolved significantly from a simplistic view of knowledge of useful content, to understanding of biology as a process and the development of an ability to engage in understanding of the impact of biology on society. The focus of much of the science taught in New Zealand schools in the first half of the 20th century was content-driven, and ignored the process of biology. However, it is interesting to note that the enacted curriculum may not truly have reflected the intentions of the early proponents of science education: *The teaching of elementary science ... shall be sufficient for and applied to the purposes of illustrating the laws of health, the structure and operation of simpler machines and philosophical instruments, the simpler processes of agriculture ...* (AJHR 1897). In 1901, the Inspector General of Schools wanted to make all aspects of secondary education more practical and close to the everyday experience of the students, in order to make education more useful to the State (AJHR 1901). These comments reflect a desire to educate for scientific literacy, in terms of an ability to use knowledge of science in daily life.

Current economic and social issues continue to influence biology education and drive the need for a population that is *able to follow science and scientific debates* (Millar & Osborne 1998). The added challenge for the 21st-century classroom is the complexity of the science underpinning issues such as genetic engineering and climate change. The focus therefore changes from the development of a scientific literacy that simply promotes application of understanding of concepts, to the development of understanding of the nature and process of science. The explicit addition of the *Nature of Science* strand in the 1994 New Zealand curriculum statement and its place of prominence and broader meaning in the 2007 statement have provided a structure that has the potential to support the development of increased biological and scientific literacy. The programme for international student assessment study (OECD 2006) proposed that, in addition to including knowledge of and about science, scientific literacy should also include aspects of individuals' attitudes towards science and response to issues of science. The development of an ability to judge the work of scientists, decide whether or not to trust the views of scientists, and respond to the findings of science is essential as the level of conceptual biological and scientific knowledge required to participate in debate of issues in 21st-century society is well beyond most citizens. It is this complexity that challenges 21st-century biology and science education. The New Zealand curriculum recognises this and establishes clearly the role of understanding of the nature of science in equipping students for a world in which they will interact with science which is as yet unknown.

The key to the future success of biology education for New Zealand will be improved communication and the development of partnerships between science and science education in order to facilitate learning that promotes understanding of the nature of science. Student-centred open investigations have been a part of the New Zealand curriculum since 1994 and have been shown to increase understanding of the process of science concepts relating to the specific investigation, and motivation to engage in science (Bay 1999). However, this is only one aspect of the development of understanding of the nature of science. Students must also be able to engage in the culture of science and the work of scientists. This can be achieved through experiences where students enter the culture of scientists either actually, through learning experiences within scientific environments, or virtually, through either engaging electronically with science and scientists or engaging in learning that is based on the work of scientists. Studies of Year 13 students who had engaged in person with scientists and their work, via a learning situation within a scientific research institute designed specifically to link the work of the scientists with the concepts that the students were engaging with at school, showed that these experiences allowed the students to bridge the cultural divide between the scientists and the students (France & Bay in press).

Teachers cannot facilitate learning that supports the development of understanding of biology if they do not have access to current biology and teaching resources that are based on these. The history of biology education in New Zealand shows clearly that education has constantly lagged behind science. The experience of the author as a practicing teacher is that teachers in New Zealand schools have extremely limited access to current science. Traditional models of interaction between scientists and teachers are often designed with little understanding or appreciation of school curricula, teaching methodologies or assessment practices. While always interesting, unless influenced by someone with extensive knowledge of the school curriculum, these are often less than useful. What is required is the collaborative development of resources, learning opportunities for students and professional learning opportunities for teachers, by teachers and scientists working together. Programmes such as the Liggins Education Network for Science (LENS) have achieved this by investing in the immersion of experienced teachers in science institutions with the express role of facilitating the development of learning opportunities that can bring schools and scientists together. Initial data from evaluations of the LENS programme indicate that this is providing an effective bridge that may, through partnership between science and science education, facilitate improved capability for science education.

Finally, of course, there is the debate over which core concepts are most important and, within the framework provided by the New Zealand curriculum, should be developed within school and classroom curricula. This is an ongoing debate that, in a subject as vast as biology, will never be fully resolved. However, the New Zealand curriculum has highlighted the core areas of life processes, ecology, and evolution. Senior school biology in New Zealand has been guilty of extensive detail, particularly in evolution and genetics, leading to a content-heavy curriculum biased towards these learning areas. While the underpinning role of evolution in the development of understanding of biology is unquestionable, the current debate over the depth of concept understanding required in the senior achievement standards is an important one. However, alongside this is the need to create the potential for greater breadth in senior school biology courses within New Zealand schools (Bay & Stone 2008). We have a national curriculum that recognises the diversity of communities but a national assessment system that, for students wanting the option of studying biology at a tertiary level, is extremely narrow. The desire of the universities to limit the courses through which students can gain UE and course entrance is limiting the scope of education that is being offered in secondary schools. While it is undeniable that only a small minority of students go on to study science at a tertiary level, it would be unthinkable for schools to create courses where students who want that option were denied it. The potential to have larger numbers of students developing improved scientific literacy through courses that, for example, linked chemistry, environmental science, and biology is made difficult through the UE and course entrance regulations. There is a need for genuine discussion around the role of assessment in secondary schools and the impact of this on the ability of schools to encourage development of scientific literacy in a broad range of pupils at a senior level.

Twenty-first-century biology education needs to evolve into an environment that will create opportunity for the development of life-long science literacy capability with the potential to develop advanced understanding of science. However, in order to achieve this, key stakeholders need to work to develop a public understanding of the broad role of education and the difference between education that leads to lifelong learning capability and traditional education measured by content knowledge. Key to the development of innovation in the future of biology education is discussion and collaboration between science educators, scientists, science-related industries, and the community.

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