Science education in Australia: time of change

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ABSTRACT

The 21st century will be characterised by our successes and failures to solve global issues, and solving our global issues will require a higher quality of science education. However, in science education in Australia it is time to decide to change. In the last decade, enrolments in senior secondary science have declined. With only half of the year 12 cohort completing science, the learning of science in the junior years becomes the only place where future generations of Australians will learn about why science matters. It is in the junior years, however where disenchantment with learning science commences. At all levels of secondary science there is evidence that the majority of students do not understand nor see the relevance of science to their future and the future of Australia. The re-emergence of an "inquiry pedagogy" in the Australian National Curriculum in Science aims to re-engage and challenge students. The issue that concepts in science are difficult to teach and learn remains. A "critical pedagogy", which includes "inquiry" may be more holistic. Whatever the decision on pedagogy, the issue of assessment in science education, which has traditionally been punitive, must be addressed. Science education at the tertiary level raises similar questions about pedagogies of learning, because academics cover content at an accelerated pace. Moreover, academics are under pressure from increased workloads. This is a result of enrolment of a more diverse student body, decreased resources and fierce competition for research funding. The newest development in science education at the tertiary level is the arrival of Massive On-line Open Courses (MOOCs), which has the potential to alter universities and academics. The troubling reality is that science education will not improve at tertiary level until value is placed on education as much as research. Two tertiary discipline networks; Vision and Innovation in Biology Education (VIBEnet) and Collaborative Universities Biomedical Education (CUBEnet) are initiatives of the Office of Learning and Teaching (OLT) in Australia. These networks provide a place for academics to close the gap between research and teaching to so that the academy can benefit from both research and education. There has never been a greater sense of urgency to resolve these issues so science education can contribute to the science of the future.

Key words: inquiry and critical pedagogy, tertiary science education, science education, Massive Open Online Courses (MOOCs), VIBEnet, CUBEnet

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Introduction

"*We live in a society exquisitely dependent on science and technology, in which hardly anyone knows anything about science and technology*." *Carl Sagan (1990 page 1)*

A number of world thinkers agree that in the twenty first century we will need to find solutions to global challenges, if we are to sustain life on Earth (Martin 2007; Savkar and Lokere 2010; Ehrlich 2013). In the twentieth century, scientific discovery led to the eradication of disease, the exploration of the moon and the deepest parts of our oceans, and communication across distances on the planet previously unimaginable. Whether science will be able to make the same contribution to solving global problems in the twenty first century will depend on nurturing young scientists today to become the scientists of tomorrow, and creating a scientifically literate public who value science. World leaders and Nobel scientists are now saying that for science to continue its progress in the twenty first century, it must be backed by high-quality science education at all levels (Weiman 2007; Weiman *et al.* 2010; Chubb 2012; Schmidt 2012; Obama 2013). This approach towards education to solve world problems is neither new nor unique. Prominent educators in the 20th century clearly argued education was the mechanism for social change (Dewey 1916; Freire 1970; Illich 1971). Dewey (1897) article 5, stated "*education is a regulation of the process of coming to share in the social consciousness*". All of these educators agreed that a "*critical pedagogy*" rather than the transmission of facts or content was needed to ensure social progress. In the 21st century, scientists and educators agree that "better" science education is needed to ensure a future of professional scientists and communities, who know that science matters. The purpose of this article is to outline the threats to science education in Australia, and to provide solutions to improve the quality of science education, at all education levels. This article will also describe two tertiary

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discipline networks; Vision and Innovation in Biology Education (VIBEnet), and Collaborative Universities Biomedical Education (CUBEnet); which were created to close the gap between research and education. Our future as a nation in science depends on high-quality science education at all levels. We need this if we are to produce scientifically literate communities, who are well placed to deal with our rapidly evolving and increasingly uncertain and complex world (Barnett 2007; Martin 2007).

The current situation in secondary science education

The first place to assess the quality of science education in Australia is in primary and secondary schools, yet in secondary schools the outlook is particularly unpromising. Studies nationally and internationally have found participation in senior science at secondary schools has declined over a 30 year period from 1976-2007 (National Research Council 1996; Ainley *et al.* 2008; Lyons and Quinn 2010; Goodrum *et al.* 2011). Although there has been some disagreement about the percentage decline in relative proportions to enrolments (Goodrum *et al.* 2011 compared to Ainley *et al.* 2008), Ainley *et al.* (2008) states that since 1976 the proportion taking biology has decreased from 55-25%, chemistry has decreased from 29-18% and physics has almost halved from 28-15%. When teachers were asked why students were not studying senior science they stated this was partly due to students' negative experiences in junior science classrooms (Lyons and Quinn 2010). In the same study students were asked for suggestions to improve enrolments in senior science; the main recommendations were to "*increase the amount of practical work*" and "*make the content more interesting less boring and more relevant*". A study which surveyed Year 11 and 12 students both studying and not studying science in schools in New South Wales (NSW), South Australia (SA) and the Australian Capital Territory (ACT), commissioned by the Office of the Chief Scientist in Australia found similar results. When students were asked why they were **not** studying science, 92% of them said it was boring, difficult to understand and irrelevant to their lives (Goodrum *et al.* 2011). When students studying science were asked the same question, over 50% said it was interesting and relevant to their lives, but more than a third said they chose science because they could attain maximum university entrance scores. When students were asked what approaches to learning science were used by teachers, a staggering 73% of science students indicated that they spend every lesson copying notes from the teacher (Goodrum *et al.* 2011). Even in practical classes, recipe labs were common, requiring students to follow a series of steps to achieve known outcomes (Goodrum *et al.* 2011). In general, students found the curriculum at senior secondary level in science unrelated to everyday life and abstract. For example, when students studying science were asked about the relevance of science to their future and Australia's future, just 33% thought science was "*almost always relevant to their future*", only 19% thought it "almost always *useful in everyday life*", while 47% thought it "*almost always important to Australia's future*". More concerning, of those students not studying science (roughly one-third of the cohort) only 1% thought it "*almost always relevant to their future*" (42% thought almost never), and 4%, thought it "*almost always useful in everyday life*"(42% thought "sometimes" and 18% ,thought "never"), while 29% "*almost always thought it important to Australia's future*." Overall the report challenges us to consider the purpose of science learning in the secondary years of education. It asks the question "*are we as a nation content that only half our secondary students are studying science?*" (Goodrum *et al.* 2011, page 55). It also makes clear that that if we are prepared to have the senior years of secondary science education directed towards preparation for university entrance, then the compulsory high school primary and lower secondary years become critical in developing scientific literacy in our students.

It is in the middle years of secondary school where student disenchantment with learning sciences commences. This leads to low enrolments in science in senior years (Goodrum 2001, 2006; Rennie 2006; Tytler 2007; Cutler 2008). Furthermore, evidence of disenchantment of students in learning science is not only seen in low enrolments at senior levels. During the past decade, Australian student performance in tests such as the Programme for International Student Assessment (PISA) has become static (Organisation for Economic Co-operation and Development , OECD 2006). Although the performance of students on the international scale is still above average, in comparison to the performance of students in other countries who are improving their science achievement scores, ours is decreasing.

Curriculum reform in secondary science education

The findings of the status and quality of year 11 and 12 science in Australian schools is unsurprising for those teachers who have been teaching science in secondary schools for several decades, because they have first-hand experiences of the failure of curriculum reforms. Reforms in science education started almost a century ago when Dewey (1916) criticised the learning and teaching of science, saying that for it to be effective, it had to be taught as it was practised; students needed to "do science" rather than "learn about" science. In the 1960s, other educationalists agreed, with both Bruner (1961) and Schwab (1962) stating that "inquiry" should be the pedagogy that underpins science education. Even earlier than this, philosophers such as Plato instructed policy makers to use inquiry to solve problems. He saw inquiry as "*the best available opinion, open to systematic doubt, incomplete and explicitly encouraging of continuing inquiry*" (Schwab 1962, page7). Yet it took the successful launch of the first artificial satellite, Sputnik, and the start of the space race to spark international curriculum reform in science education. In the late 1960s the "Harvard Project Physics" was implemented in the United States, and in the 1970s and 1980s in Australia. The "Harvard Project Physics" was based on a philosophy of "inquiry", to stem the decline in enrolments and disenchantment of secondary school physics (Welch 1971). Similarly, in 1962 the Nuffield Foundation in the United Kingdom developed curricula in science education based on students hypothesising and designing their own experiments. Unfortunately both these programs failed to deliver on enrolments, and did little to improve conceptual understanding of science. As a result they were overwhelmingly criticised by science educationalists (Novak 1988). Novak (1988) in particular, attacked these curriculum reforms and the pedagogy of "inquiry" for representing the scientific process as simplistic and positivist. Novak (1988) also used the thinking of philosophers of science such as Kuhn (1962) to support his argument. In the 1990s and 2000s, the pedagogy of "inquiry" was further criticised by Tuovinen and Sweller (1999), Mayer (2004) and Kirschner *et al.* (2006), who stated that it was naive and overloaded the cognitive capacities of students, particularly because it used activities which required students to do open-ended problem solving, with little in the way of the core content that provided the scaffolds for such activities.

Despite arguments that are almost a century old, inquiry has re-emerged as a pedagogy in many national and international curricula in science education. In Australia there is an inquiry strand in the Australian National Curriculum in Science (Australian Curriculum Assessment and Reporting Authority, ACARA), and there is also an inquiry strand at tertiary level in the Threshold Learning Outcomes in Science (STLOs). The rise of "inquiry" as an overarching pedagogy in Australia matches similar movements internationally in reports on science education, such as the National Research Council, America's Lab Report 2006. Research on how individuals make sense of the natural world clarifies why inquiry instruction succeeds (Bjork and Linn 2006). By using inquiry skills, learners are more likely to interpret facts and make connections between their existing ideas (Driver *et al.* 1996) and consider alternative perspectives such as those suggested by peers or experiments (Solomon 1988; Scardamalia and Bereiter 1991). The presence of an inquiry strand in these documents provide evidence of the wider acceptance that science education should involve students "doing" and "discovering" in real science research scenarios.

The question is - will this time around, "inquiry –based" methods in science education live up to expectations? Almost certainly, an inquiry pedagogy will provide teachers and students with some relief from a curriculum which is driven by learning more and more facts. The problem with forcing teachers to "cover the content" is that it does not provide students sufficient time and scope to develop an understanding of fundamental scientific concepts (Goodrum 2001, 2006; Rennie 2006; Tytler 2007; Cutler 2008 ; McWilliam *et al.* 2008; Ross and Tronson 2007; Ross 2008; Ross *et al.* 2010; Ross and Gill 2010). In contrast to the past where research demonstrated negative effects on students understanding using inquiry as process, recent studies provide evidence that significant learning gains and identity can be made by students using inquiry (Shanahan 2009; Bronwell *et al.* 2012). Such evidence provides a counter balance to the earlier criticisms of inquiry (Rodrigues *et al.* 2007; Kirkup *et al.* 2010; Ross and Gill 2010; Brownell *et al.* 2012). Perhaps inquiry classes work because students get to take risks and make mistakes often in a context which is meaningful and relevant to their everyday lives (Ross and Gill 2010). This in turn serves to enhance their understanding (Kapur 2008).

Although an inquiry pedagogy may go some way to improving science education at secondary and tertiary level, still left unacknowledged is the difficulty of science content. The teaching and learning of science is difficult because many concepts are counter intuitive and challenging to understand for both students and teachers. The inquiry curricula of the past stumbled because it did not deal adequately with this issue. Consider this: when today's teachers and university academics were students, only the very brightest students at school and university studied science. It was considered even too difficult for most of the top 15% of students. In centuries prior to that, it took years of apprenticeship for a few select young people to become alchemists or philosophers (later "natural philosophers") or astronomers. Even before that, in the days of the ancient Greeks, Plato and Archimedes and all the other great teachers, selected their students with care and taught them carefully over many years. The difficulty in learning science is also not reserved for the well-known difficult disciplines of physics and chemistry. Even in the seemingly easy descriptive discipline of biology, students encounter counter-intuitive ideas that students find difficult to understand and teachers find difficult to teach (Ross *et al.* 2010). In the more recent days of mass education, the issue of "difficulty" in learning science is rarely mentioned. Instead "rote learning" all the rules, formulas, laws and theories are emphasised. The amount of content to be covered is so great that teachers find there is so much to teach in so little time, and that the only way to cope is to revert to formulaic teaching where understanding is a lower priority.

A broader "critical pedagogy", which is inclusive of an "inquiry pedagogy", may allow students to use inquiry and 21st century thinking skills in all aspects of science education. Whatever the approach, the issue of assessment in science education remains high on the agenda. In inquiry mode, students are encouraged to learn from mistakes, whereas traditionally marks are deducted when students fail to provide the "correct" answer. Rather than valuing the end performance of students in science through assessments, which primarily require students to regurgitate content, it is the process of learning science and how students deal with uncertainty that should equally be valued and rewarded.

The current situation in tertiary science education

At the tertiary level, similar questions are raised about which pedagogies are effective in learning science, in a context where academics cover the content at a faster pace. In practice, the curriculum development in undergraduate science education is about students learning facts, especially in the early years. Students who survive these years, mainly in a process of "natural selection", find third year more specialized- requiring independent research and problem solving. Academics, who support such a curriculum structure, express concerns about the preparation of students for learning science at university, because of the removal of pre-requisites. Declining enrolments in university Science and Mathematics courses (Australian Council of Deans of Science, ACDS 2003) and projected shortages of graduates in Engineering and Technology (Prieto *et al.* 2011; Engineers Australia Innovation Taskforce 2012) have also caused alarm across the Science, Technology, Engineering and Mathematics (STEM) sectors. In 2004, Handelsman and colleagues published a seminal article in Science on "*Scientific Teaching*", where they refer to a 1990 AAAS report on "*The liberal art of science*" where it was agreed that "*reform in science education should be founded on scientific teaching in which teaching is approached with the same rigor as science at its best*". Ten years or more down the track, the extent to which this ethos has been embraced by either the academics at the coalface or the policy makers remains debatable. The 2012 report to the President from the President's Council of Advisors on Science and Technology entitled "*Engage to excel: producing one million additional college graduates with degrees in science, technology, engineering and mathematics*" made several recommendations (Executive Office of the President 2012). These include "*catalyze widespread adoption of empirically validated teaching practices*" and "*advocate and provide support for replacing standard laboratory course with discovery-based research courses*". This report makes the point that many, high-achieving students with a passion for science switch to other majors such as social science because the introductory science courses do not provide opportunities to engage in scientific inquiry.

Although these reports provide compelling reasons to reinvigorate and change our tertiary science curriculum, academics, like teachers are already under significant workload pressures. Workloads have increased with increasing class sizes, and widening participation. In the early 1980s, when most of the current crop of academics was being trained, there were less than 0.5 million students enrolled at university. Today there is over 1.2 million. At the same time, funding for universities has decreased, and the already fierce competition for research funding has increased. Academics are thus presented with a troubling reality. Although they personally value education as much as research, they align their work with research rather than education, because research is more valued by the institution (Savkar and Lokere 2010). As a result, instead of prioritising an "*inquiry*" pedagogy to underpin curriculum, the unspoken pedagogy of "*cloning*" to ensure the development of "*future research scientists*", is the dominate practice. However, many academics who focus on education rather than research do so at their peril. Although some say it is changing, in Australian tertiary institutions there are still few promotional opportunities for education focused academics, and almost no opportunities at the most senior level of professor, especially for women (Australian Academy of Science 2013). When science academics have the time to discuss educational practice, they find it difficult to relate and connect the discourse of education to their work (Brownell and Tanner 2012). Academics really have very little time to decide to change in a well-established academic culture which places value on research (Savkar and Lokere 2010; Brownell and Tanner 2012), and those academics can be afraid to come out as teachers, for fear of being marginalised by both their peers and mentors (Brownell and Tanner 2012). This highlights the need for academics who do focus on education to take a scientific and scholarly approach and to do valid and productive research into science education. The need to for universities to better recognise, reward and support academics who are dedicated teachers is highlighted in a 2011 paper in Science "*Changing the culture of science education at research universities*" (Anderson *et al.* 2011). They make several recommendations that reinforce the way forward including, "*Educate faculty about research on learning*", "*Create awards and named professorships that provide research support for outstanding teachers*", "*create cross-disciplinary programs in college level learning*" and "*Engage chairs, deans and presidents*". These are wise recommendations that require strategic implementation from a critical mass of university academics and support from students and other stakeholders.

Institutions are becoming more focussed not only on maintaining teaching quality, but also strategies to ensure that teaching adapts to the various changes in the university sector. There is increasing recognition that training in science at tertiary level is needed for a broad range of careers. The skills acquired though a science degree are both relevant and transferrable to many disciplines and walks of life, not just research alone. This is an issue close to heart of the Chief Scientist. In an Occasional Paper from the Office of the Australian Chief Scientist, West (2012, page 1) writes, "*The creative and analytical talents of Science, Technology Engineering and Mathematics (STEM) graduates can be harnessed in business and other sectors, as well as academic research*". The most recent report by the Australian Council of the Deans of Science (ACDS, Harris 2012) also highlights that a science degree plays a fundamental role in shaping the way people think about problems (Harris 2012). In terms of careers, Harris (2012) found only 40 % of science graduates ended up as working scientists, but 97% of respondents, regardless of where they were working, said their science knowledge or skills were useful in their work especially analytical thinking and problem solving skills. Graduates particularly valued problem-solving skills and a "*way of thinking*" which was analytical, objective, evaluative and questioning, while communication, collaboration and team-work skills were valued by graduates and employers (Harris 2012 page 46). The fundamental role that tertiary science educators have in the training of science graduates (who will transition to education faculties to be trained science teachers of the future) is also being re-emphasised. This then highlights the importance of providing a science based tertiary education to large numbers of students, irrespective of their ultimate career trajectory. If any further evidence is required to support the urgent need for reform in science education, then we need look no further than the special issue of April 19 2013, Vol. 340 Science that is a dedicated exploring "*Grand Challenges in Science Education*" that cover 20 challenges that require urgent attention. The Editor-in-Chief, Bruce Alberts, also poses three additional challenges and echoes the recommendations of the President's Council of Advisors on Science and Technology with his final challenge "*incorporate active science inquiry into all introductory college science classes*". He finishes with an inspiring conclusion – "*the aim is nothing less than a more rational world*" (Alberts 2013, page 249).

It is critical to appreciate the extent to which the tertiary landscape is, however, rapidly changing. The Australian Quality Framework (AQF) and Tertiary Education Quality Standards Agency (TEQSA) are creating a more regulated environment with explicit demonstration of achievement of standards in learning and teaching. This is a further impost on time-poor academics. Universities Australia produced a "Smarter Australia Policy - advice for an incoming government 2013-2016". The last of five points, "Reducing Red Tape" addresses directly the issue saying "*Universities are self-accrediting, autonomous institutions, yet the sector is one of the most heavily regulated in the country. Universities report on numerous fronts to multiple authorities and jurisdictions, and much of this is in relation to regulations and requirements aimed at other sectors. The problem is getting worse. Servicing these obligations diverts resources that would otherwise be directed to teaching, learning and research.*" In response to this report, the Minister for Tertiary Education, Skills, Science and Research commissioned a review in May 2013 entitled "*Assuring quality while reducing the Higher Education regulatory burden.*" The aim of the review is to make recommendations on TEQSA's approach to regulation to reduce the burden of reporting. In the process they will consider the principle of "earned autonomy" in which long-established, compliant, high-performing institutions could have reduced requirements for continued registration. However, it is important to note that this does not imply a relaxation of standards. This highlights the importance of the development of the Science Threshold Learning Outcomes (STLOs) (Jones *et al.* 2011). The STLOs are written as assessable statements and have broadened the basis of expectations of science graduates, and opened the way for graduate assessment and will play a role in informing any articulation of standards. For example "inquiry and problem solving" and "understanding science" now is given equal weight to "scientific knowledge", "communication" and "personal and professional responsibility" (Jones *et al.* 2011).

The tertiary landscape is also changing on a global scale. The exponential growth of Massive Online Open Courses (MOOCs) are questioning the need and purpose of the conventional lecture formats, and presenting potential paradigm shifts in the very essence of what it means to attend university and work as an academic. In Australia, several universities have joined forces with the MOOCs to deliver free online content. For example, the Australian National University (ANU) and The University of Queensland have joined with EdX, formed between Harvard and Massachusetts Institute of Technology (MIT). Melbourne University has joined with Coursera, which has entered into agreement with 62 universities including 24 outside the United States (Gallagher 2013). Indeed, some are starting to question the very existence of universities into the future. In a recent article "*The end of the university as we know* it", Harden makes the claim that "*in 50 years, if not much sooner, half of the roughly 4,500 colleges and universities now operating in the United States will have ceased to exist*" (Harden 2013, page 1). Harden goes on to predict a future in which education is free, with Harvard enrolment reaching 10 million students in 10 years. The provocation continues when he states that "*for the average student, traditional in-classroom university education has proven so ineffective that an online setting could scarcely be worse. But to recognize that would require unvarnished honesty about the current state of play.*" Such gloomy predictions and claims highlight the importance of the universities being able to articulate and demonstrate the worth of their broad degrees to the broader public and government.

How MOOCs will influence the learning and teaching of science is a question of great debate. In essence, MOOCs provide the opportunity to "remix" and "reposition" the course content. Perhaps, as more "content" is delivered online, staff will have more time to devote to students, especially in highly interactive small groups. In these settings lecturers will "morph" into mentors (Barber 2012; Beacon of Enlightenment 2012). Certainly MOOCs appear to be a way to deliver content, but "content" delivery has always been the cause of many problems in the learning of sciences (DiCarlo 2006; Ross and Tronson 2007; Ross 2008; Ross *et al.* 2010). Perhaps with this core product free and highly accessible, there will be more enriching laboratory and field work activities. Could even laboratories be replaced and done in a virtual environment? On-line labs,which are real laboratories accessed via the internet, such as MIT iLabs project can enrich science education (http://ceci.mit.edu/projects/iLabs/). Other sites such as "Labshare" (Labshare http://www.labshare.edu.au/about/institute) raise new interesting possibilities, but how students will respond to such delivery on line is not yet clear. There has been some commentary of the suitability of online learning to develop collaborative team-work skills at the undergraduate level, but not graduate programs (Kellogg 2011). Barber (2012) states that either way, just as the internet has forced newspapers and traditional businesses to face their day of reckoning, universities are the next in line. The arrival of MOOCs suggests we may be nearing a tipping-point in higher education, where the power of the internet may be the mechanism that enables us to personalise student learning. A personalised learning approach means students will advance at their own pace only after having mastered particular tasks (Poole and McManus 2013).

What is in the future for Science learning?

Undeniably, if the future of learning science is to change, such change will be dependent on teachers and academics. How does the future landscape of change look for the tertiary science environment? The most challenging and visionary views have arisen from a recent communique from the New Media Consortium Horizon Project Summit (NMC 2013). At the Horizon Project Summit a group of 100 international leaders determined the five wicked problems/essential challenges for education:

1. Rethink what it means to teach and reinvent everything about teaching
2. Reimagine on-line learning
3. Allow failure to be as powerful a learning mode as success
4. Make innovation part of the learning skills
5. Preserve the digital expressions of our culture and knowledge

These highlight the breadth of the challenges, and encapsulate a paradigmatic shift in the way universities may function in the near future. Other reviews state that transformation of undergraduate tertiary level science education is possible if a university cares (Savkar and

Lokere 2010; Mervis 2013). We all know, however, that caring will not be enough. To enable change, rewards need to be realigned with values, or the gap between education and research in the academy will remain.

Tertiary discipline networks

While all these ideas are theoretically practical they require a consensus among the academic culture (Savkar and Lokere 2010). As the Nobel laureate Carl Wieman stated: "*transformation is possible if a university really cares*" (Mervis 2013 page 292). In response to the threats to tertiary education late in 2011, two tertiary discipline networks - Vision and Innovation in Biology Education (VIBEnet) and Collaborative Universities Biomedical Education (CUBEnet) (www.cubenet.org.au) - were established as initiatives of the Office for Learning and Teaching in Australia (Boxes 1 and 2). Unlike in physics and chemistry, there is no biological or biomedical professional association that provides an accreditation framework or forum for the discussion of the undergraduate curriculum in bioscience. The overall aim of these networks is to create a place for tertiary academics to aggregate, filter and connect ideas and information, to achieve effective, transferable and sustainable solutions in bioscience education. Although pursuing similar goals, both groups took different approaches in developing their networks to experiment with outcomes. The two networks have worked in close collaboration to build a new group of academics devoted to excellence in bioscience education; a group with a unity of purpose and voice.

Box 1 The aims of Vision and Innovation in Biology Education (VIBEnet)

The aims of VIBEnet are to:

i. Develop a **national identity and network** (**VIBEnet**) for university biology teachers to build on the ALTC LTAS Science threshold learning outcomes and develop the **Biology Threshold Learning Outcomes**

ii. Mentor **the next generation of Biology teachers** and curriculum designers to enhance active/inquiry learning in biology, particularly at the first year level.

iii. Create a **Vision and Innovation statement** which reflects the collective understandings about the **direction of the future biological curriculum,** especially at first year level

During the first year of VIBEnet, we produced a draft set of Biology Threshold Learning Outcomes (BTLOs) and a "Vision and Innovation" statement. In these documents we identify the core concepts that our students should understand and key competencies or skills they should possess when they graduate from our universities. Core concepts include: characteristics of life, information flow, evolution and structure and function; while key competencies include: inquiry, communication, critical thinking and quantitative skills. VIBEnet has brought together biologists from across Australia. At the outset of the project, VIBEnet was represented by 150 biologists in 25 Australian universities; we now represent over 200 biologists at more than 29 universities in Australia.

Box 2 The aims of Collaborative Universities Biomedical Education (CUBEnet)

The overall aim is to generate a critical mass of active tertiary biomedical academics at the national level to create a sustainable framework for a program–wide approach to the biomedical curriculum that can harvest expertise across the university sector at the local, national and international levels.

i. provide the critical mass needed to identify, address and solve the central challenges that face us in delivering a forward looking and sustainable curriculum.

ii. maximize the efficiency of development, dissemination and adoption of innovative curriculum. In a complex tertiary environment, such a network is critical to aggregate, filter and connect ideas and information with the appropriate teams of people to achieve effective, transferable and sustainable solutions.

CUBEnet was launched on 12 Dec 2013 at the Shine Dome in Canberra by the Chief Scientist. It arose from an initiative of the National Committee on Biomedical Sciences of the Australian Academy of Science. It represents over 25 universities and has over 200 members, including significant interest from international colleagues. In addition to developing biomedical TLOs, the core activity of CUBEnet is in establishing working groups to address key educational challenges facing the biomedical community.

Conclusion

At all levels of education, both in Australia and internationally, teachers and academics alike, regardless of the barriers they face, have a collective responsibility to nurture the young scientists of the future and create a public which understands how science works and why it matters. If both of these conditions are not met, then the rate of scientific progress will decline over the next generation. Undoubtedly the arguments about which pedagogies will create the desired transformation in science education, which have lasted a century, will continue. At the secondary level, a paradigm shift will be needed in the curriculum, if we decide we are not satisfied with only half our students doing senior secondary science. At the tertiary level, a similar paradigm shift is needed, to resolve the tensions of professional identity and have more academics "come out" as teachers; and be rewarded to do so (Brownell and Tanner 2012). There has never been a greater sense of urgency to resolve these arguments, and to make decisions about science education which will create the science we need in the future to solve our global problems. As Martin (2007 page 9) states, "*It is common today to find people depressed about the future, sometimes abandoning hope that any actions can save us*".Martin (2007 pages 33-34) concludes "*Most of the problems are the consequences of absence of foresight. There is no silver bullet. What is missing is appropriate education, comprehension, and political will as we imagine the "magnificent future" ahead of us. If we get it wrong, we could be plunged into a new type of Dark Age*".

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References

Alberts, B. 2013. Prioritizing science education Science. *Science.***340**: 249

Ainley, J., Kos, J., and Nicholas, M. 2008. Participation in Science, Mathematics and Technology in Australian Education. Australian Council for Educational Research (ACER). http://research.acer.edu.au/acer_monographs/4/ Accessed 27 June 2013. 86 pages.

Anderson, W.A., Banerjee, I.U., Drennan, C.L., Elgin, C.R., Epstein, I.R., Handelsma, J., Hatfull, G.F., Losick, R. O"Dowd, D. K. Olivera, B.M., Strobel, S.A., Walker,G. C. and Warner, L.M. 2011. Changing the culture of science education at research universities. *Science* **331**: 152-153.

Australian Academy of Science, 2013. New Guidelines for Gender Equity in Science. Gender Equity: Current issues, best practice and new ideas. http://www.science.org.au/policy/documents/GenderEquityEMCRForum.pdf Accessed 2 June 2013.

Australian Council of Deans of Science, ACDS, 2003. Is the study of science in decline? ACDS Occasional Paper No. 3. 19 pages.

Barber, J. 2012. Currency of information loses its value. *Higher Education The Australian* October 31, 2012.

Barnett, R. 2007. *A will to learn. Being a student in an age of uncertainty*. Open University Press.

Beacon of Enlightenment, 2012. *Strategic Plan 2013-1023*. University of Adelaide. 17 pages.

Brownell, S.E., Kloser, M.J., Fukami, T. and Shavelson, R. 2012. Undergraduate Biology lab courses: comparing the impact of traditionally based "cookbook" and authentic research-based courses. *Journal of College Science Teaching* **41**(4): 36-45.

Brownell, S.E. and Tanner, K. 2012. Barriers to Faculty Pedagogical Change: Lack of Training, Time, Incentives, and Tensions with professional Identity? *CBE – Life Science Education* **11**: 339-346.

Bjork, R.A. and Linn, M.C. 2006. The Science of Learning and the Learning of Science: Introducing Desirable Difficulties. *American Psychological Society Observer* **19**(3): 1-2.

Bruner, J. S. 1961. The Art of Discovery. *Harvard Educational Review* **31**: 21-32.

Chubb, I. 2012. Office of the Chief Scientist. Health of Australian Science. Australian Government Canberra. 212 pages.

Cutler, T. 2008. Venturous Australia: Building strength through innovation. Cutler and Company Pty., Ltd.

Dewey, J. 1897. My pedagogic creed. *School Journal* **54**: 77-80. Accessed 2 June 2013. http://dewey.pragmatism.org/creed.htm

Dewey, J. 1916. Democracy and Education. An Introduction to the Philosophy of Education. MacMillian Press, New York, 434 pages.

DiCarlo, S.E. 2006. Cell biology should be taught as science is practised. *Nature* **7**:290-296.

Driver, R., Leach, J., Millar, R., and Scott, P. 1996. *Young People's Images of Science*. Buckingham, UK: Open University Press.

Executive Office of the President. 2012. *President's Council of Advisors on Science and Technology* . Report to the president engage to excel: producing one million additional college graduates with degrees in science, technology, engineering and mathematics. 103 pages.

Ehrlich, P. R. 2013. The decoupling of human and natural systems makes me very grumpy. Pp 9-13 in *Grumpy scientists: the ecological conscience of a nation*, edited by D. Lunney, P. Hutchings and H. F. Recher. Royal Zoological Society of NSW, Mosman, NSW, Australia.

Engineers Australia Innovation Taskforce, 2012. Innovation in Engineering Report. 24 pages

Freire, P. 1970. *Pedagogy of the Oppressed* New York, Herder and Herder. 186 pages

Gallagher, S. 2013. MOOC means more time for different types of learning. The Australian. Higher Education supplement. Date 20th March.

Goodrum, D., Hackling, M., and Rennie, L. 2001. *Research report: The status and quality of teaching and learning of science in Australian schools.* Canberra: Department of Education, Training and Youth Affairs. Retrieved January 18, 2007 from http://www.detya.gov.au/schools/publications/index.htm

Goodrum, D. 2006. Inquiry in science classrooms: Rhetoric or reality? *Proceedings of the ACER Research Conference: Boosting Science Learning – what will it take?* (pp. 31-35). Melbourne, Australia: Australian Council for Educational Research.

Goodrum, D., Druhan, A. and Abbs, J. 2011. *The Status and Quality of Year 11 and 12 Science in Australian Schools.* Prepared for the Office of the Chief Scientist Australian Academy of Science. 68 pages.

Handelsman, J. Ebert-May, D, Beichner, R. Bruns, P., Chang, A. DeHaan, R. Gentile, J., Lauffer, S., Stewart, J. Tilghman, S.M. and W.B. 2004. Scientific teaching. *Science* **304**: 521-522.

Harden, N. 2013. Virtualized. The end of the university as we know it. *The American Interest* **8**(3) pages nos

Harris, K.L. 2012. A Background in Science: What sciences means for Australian society. Australian Council of Deans of Science. Centre for the Study of Higher Education University of Melbourne, Melbourne Australia. 75 pages.

Illich, I. 1971. *Deschooling society.* New York. 68 pages.

Jones, S., Yates, B. and Kelder, J.A. 2011. Learning and Teaching Academic Standards Statement Science. Australian Learning and Teaching Council Ltd, Australian Government. 36 pages.

Kapur, M. 2008. Productive Failure. *Cognition and Instruction* **26**(3): 379—424

Kirkup, L., Pizzica, J., Waite, K. and Srinivasan, L. 2010. Realizing a framework for enhancing the laboratory experiences of non-physics majors: from pilot to large-scale implementation *European Journal of Physics* **31**: 1061-1070.

Kellogg, S. 2011. Online education *Nature* **478**: 417-418.

Kirschner, P. A., Sweller, J. and Clark R.E. 2006. Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and enquiry based learning, *Educational Psychologist* **41**(2): 75-86.

Kuhn, T. S. 1962. *The Structure of Scientific Revolutions*, 1st. ed., Chicago: University of Chicago Press.

Lyons, T., and Quinn, R. 2010, Choosing science: Understanding the declines in senior high school science enrolments. National Centre of Science, ICT and Mathematics Education for Rural and Regional Australia (SiMERR Australia), University of New England. http://www.une.edu.au/simerr/pages/projects/131choosingscience.pdf Accessed 27 June 2013. 135 pages.

Martin, J. 2007. *The meaning of the 21st Century*. Riverhead Penguin, New York, 2007. Transworld, London.

Mayer, R.E. 2004. Should there be a three-strikes rule against pure discovery learning? he Case for Guided Methods of Instruction, *American Psychologist* **59 (**1): 14-19.

McWilliam, E., Poronnik, P. and Taylor, P.G. 2008. Re-designing science pedagogy: reversing the flight from science. *Journal of Science and Educational Technology* 17: 226-235.

Mervis, J. 2013. Transformation is Possible if a University Really Cares. *Science* **340**: 292-296.

National Research Council. 1996. *National Science Education Standards.* National Academies Press, Washington DC.

National Research Council America's Lab Report: Investigations in High School Science 2006. Singer, S. R., Hilton, M.L & Sweingruber, H. A. (Eds). National Academies Press, Washington DC.

New Media Consortium Horizon Project Summit Communique 2013. *The future of Education.* The New media Consortium. http://www.nmc.org/pdf/2013-Horizon-Project-Summit-Communique.pdf. Accessed 7 April 2013.

Novak, J.D. 1988. Learning Science and the Science of Learning, *Studies in Science Education* **15:** 77-101.

Obama, B. 2013. President Obama Speech to the National Academy of Science. http://notes.nap.edu/2013/04/30/president-barack-obamas-speech-to-the-national-academy-of-sciences-full-transcript/ Accessed 2 June 2013.

Organisation for Economic Co-operation and Development (OECD). 2006. *Assessing scientific, reading and mathematical literacy.* Paris: OECD.

Poole, G. and McManus, G. 2013. Conversations on Education with Gary Poole and Michael McManus. *Journal of NUS Teaching Academy* **3**(1): 10-17.

Prieto, E., Bourke, S., Holbrook, A., O"Conor, J., Page, A. and Husher, K. 2011. Identification and Development of Strategies for Increasing Engineering Enrolments. Report for the Australian Research Council Linkage grant, University of Newcastle, Engineers Australia and AmpControl Ltd. 150 pages.

Rennie, L. 2006. The community's contribution to science learning: Making it count" http://research.acer.edu.au/research_conference_2006/8

Rodrigues, S., Tytler, R., Darby, L., Hubber, P., Symington, D., and Edwards, J. 2007. The usefulness of a sciences degree: The "lost voices" of science trained professionals. *International Journal of Science Education* **29** (11): 1411-1433.

Ross, P.M. and Tronson, D.A. 2007. "Intervening to create conceptual change", *Proceedings of the assessment in science teaching and learning symposium: science teaching and learning research including threshold concepts, September 28-29, 2007, Sydney*, UniServe Science, Sydney, Australia, pp. 89-94.

Ross, P.M. 2008. "Future directions in representing learning in biology", *Proceedings of the assessment in science teaching and learning symposium: visualisation and concept development, October 2-3, 2008, Sydney, UniServe* Science, Sydney, Australia, pp. 104-107.

Ross, P.M. and Gill, B. 2010. Inquiry as an overarching theme in processes and concepts in the learning and teaching of science. *Journal of learning Design*. **3**(3): 45-57.

Ross, P.M., Taylor, C., Hughes, C., Lutze-Mann, L. and Tzoumis, V. 2010. Using threshold concepts to generate a new understanding of learning and teaching in Biology. *In 3rd International Conference on Threshold Concepts*, edited by E. Meyer and R. Land. Sense Publications, Rotterdam.

Sagan, C. 1990. *Why We Need to Understand Science*, in *Skeptical Enquirer*. Committee for Skeptical Inquiry, **USA**

Savkar, V and Lokere, J. 2010. *Time to Decide: The Ambivalence of the World of Science Toward Education. Nature Education*: Cambridge Massachusetts. Pp1-14.

Scardamalia, M., and Bereiter, C. 1991. Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media. *Journal of the Learning Sciences* **1**(1), 37-68.

Schmidt, B. 2012. Brian Schmidt: in conversation. 26th July 2012. *The Conversation* http://theconversation.com/brian-schmidt-in-conversation-8383Accessed 2 June 2013.

Solomon, J. 1988. Learning through Experiment. *Studies in Science Education* **15**: 103-108.

Schwab, J.J. 1962. *The Teaching of science as Enquiry Harvard* University Press. Pp. 1-104.

Sewell, W.H. 1992. A theory of structure: Duality, agency and transformation. *American Journal of Sociology* **98**: 48-69.

Shanahan, M.C. 2009. Identity in science learning: exploring the attention give to agency and structure in studies of identity. *Studies in Science Education* **45**(1): 43-64.

Tuovinen, J. J. and Sweller, J. 1999. A comparison of cognitive load associated with discovery learning. *Journal of Educational Psychology* **91 (2)**: 334-341.

Tytler, R. 2007. Re-imagining Science Education: Engaging students in science for Australia"s future. *Australian Educational Review,* No. 51. Australian Council for Education Research, ACER press.

Universities Australia. A smarter Australia: Policy advice for an incoming government 2013-2016. 4 pages.

Weiman, C.O. 2007. Why not try a scientific approach to science education? *Change* Sept/October pp 9–15.

Weiman, C., Perkins, K. and Gilbert, S. 2010. Transforming science education at large research universities: A case study in Progress. *Change* Mar/April 1-11.

Welch, W. 1971. Review of the Research and Development Program of Harvard Project Physics http://catalogue.nla.gov.au/Record/5228408

West, M. 2012. STEM education and the workplace. *Occasional Paper Series* **4**: 1-4