Pursuing Different Forms of Science Learning Through Innovative Curriculum Implementation

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> *The educator should not forget that the task is not to put knowledge where knowledge does not exist, but rather to turn the mind's eye to the light, so that it might see for itself.*
>
> Plato 400BC

School science argues from a position of foundational knowledge, where physics, chemistry, biology and, in some contexts, earth science are seen as the pillars of creating such foundational knowledge. What is missing from the development of this foundational knowledge is the contexts in which it is generated, developed and applied. The processes of science and how science knowledge is created have suffered from too much attention in school science being placed on the "facts" of science.

Science is a way of thinking (and acting) as it is a knowledge-seeking enterprise that continues to evolve. Grandy and Duschl (2005) have highlighted the ways in which views of the Nature of Science have shifted since the 1950s from a logical positivist view, where hypothetico-deductive explanations have value, to theory change models with science as an agent of conceptual change, to present day perspectives of model-based explanations where science is seen as a cognitive, social and epistemic practice. Science as a discipline has a belief system underpinning its nature.

The values that underpin science as a discipline include curiosity, rational thinking, creativity, open-mindedness, parsimony, empiricism and scepticism, amongst others (Corrigan and Gunstone 2007). Such values help guide learners as to how they need to think and act when they engage with science. The science learning experience in most schools focuses on the cognitive domain, with particular emphasis on the rational thinking aspects, and too often omits the equally important affective domain (including curiosity, creativity and open-mindedness) (Aubusson 2013; see also Goodrum et al. 2001; Tytler 2007). Science is also a way of acting, and the context in which the actions take place is equally important. More contemporary science is responsive to society and its needs. Funding for science

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research is based on the current and futures needs of the society in which scientists practice and work with other scientists and other professionals. The multi/inter/trans-disciplinary nature of practising science needs to be considered as learning of value in our schools (Hart 2012).

Historically, school science has consistently represented the subject as a set of ‘facts’ and has failed to meet the needs of many students in building an understanding about the practices of science and the contexts in which these take place; in other words, students have not been given the opportunity to develop a notion of ‘real science’ (Aikenhead 2006). While the nature of science is often an explicit part of the science curriculum, the focus has frequently been around the products of science, such as the conceptual ideas emerging from scientific endeavours. What is often missing from these curricula, and subsequently student learning, is an understanding of the processes of science. While the inclusion of investigations into science attempts to address this aspect, the highly stylized approach used by teachers often counteracts the intended purpose with students emerging with a distorted view of how science works. Further, while science in schools sometimes considers the scientists involved this rarely includes the social culture in which they live and work (see Shanahan’s chapter, this volume). The curriculum should incorporate the different forms of science, opportunities for various forms of learning, and implementation of the curriculum by teachers that supports the intention of the curriculum.

In this chapter we present case studies of two recent Australian initiatives that attempt to implement innovative science curricula in innovative ways that support both different forms of science and different forms of learning. We begin with an overview of particularly relevant aspects of the recently finalised Australian Curriculum for Science. In the first case a government senior (Grades 10-12) secondary specialist sciences school—the John Monash Science School (JMSS)—is discussed. With the school’s strong design emphasis on open learning spaces and the integration of studio-based work and ICT, the cognitive and physical environments interact to enhance how students are able to engage with learning in science. The second case is the National Virtual School of Emerging Science (NVSES) that set out to create an online, electronic environment so that students across Australia can join their peers and teachers in a virtual classroom. While these two cases are very different in the experiences they offer students in science, and the students themselves are in very different contexts, each provides valuable insights for curriculum developers and implementers elsewhere, particularly in considering what forms of science might be learned.

National Australian Curriculum—Science

School education in Australia is a state not national responsibility. A number of attempts at developing a national curriculum have failed. However the most recent has been more successful, with ACARA [Australian Curriculum, Assessment and

Reporting Authority] (n.d.) coordinating the design, development and writing of the recently published 'Australian Curriculum: Science for Foundation to Year 12' (i.e., students 5–18 years of age). Underpinning its structure are three content strands:

- Science Understanding, which exemplifies the content of science such as facts, theories and models;
- Science as a Human Endeavour, which highlights "the development of science as a unique way of knowing and doing, and the role of science in contemporary decision making and problem solving"; and
- Science Inquiry Skills, which is concerned with the evaluation of "claims, investigating ideas, solving problems, drawing valid conclusions and developing evidence-based argument".

While 'Science Understanding' will be familiar to many teachers and students, the ideas presented in 'Science as a Human Endeavour', and to a lesser extent 'Science Inquiry Skills', give heavy emphasis to aspects of the processes and practices of science that have rarely been considered previously. The Australian Science Curriculum explicitly embraces these characteristics of science by including the strand 'Science as a Human Endeavour' at each level of the curriculum, and by presenting this strand as having equity with the other two more conventional stands ('Science Understanding' and 'Science Inquiry Skills').

The description of the 'Science as a Human Endeavour' strand given in the Australian Science curriculum is:

> Through science, humans seek to improve their understanding and explanations of the natural world. Science involves the construction of explanations based on evidence and science knowledge can be changed as new evidence becomes available. Science influences society by posing, and responding to, social and ethical questions, and scientific research is itself influenced by the needs and priorities of society. This strand highlights the development of science as a unique way of knowing and doing, and the role of science in contemporary decision making and problem solving. It acknowledges that in making decisions about science practices and applications, ethical and social implications must be taken into account. This strand also recognises that science advances through the contributions of many different people from different cultures and that there are many rewarding science-based career paths. (ACARA, n.d.)

The detail of this strand was developed in consultation with a wide range of interested parties from science and science education (Issacs and Corrigan 2013). The paragraph quoted above makes clear that one of three equally important fundamental intentions of the Australian Science curriculum is to both have students learn about the nature of science in the 21st Century and to value this as a valid form of learning in a science curriculum. Embedded within this strand are many of the values of science such as curiosity ('posing and responding to […] questions'), creativity ('unique way of knowing'), open-mindedness ('contributions of many different people from different cultures') and so on.

Table 1 outlines the scope and sequence of 'Science as a Human Endeavour' for Years 7–12, the secondary school levels in Australia, within the science curriculum. At first glance, the content provided in the table may seem obvious to many science

Table 1 Science as a Human Endeavour—Secondary Scope and Sequence

Year	Nature and development of science	Use and influence of science
7 and 8	Scientific knowledge changes as new evidence becomes available, and some scientific discoveries have significantly changed people's understanding of the world	Science and technology contribute to finding solutions to a range of contemporary issues; these solutions may impact on other areas of society and involve ethical considerations
	Science knowledge can develop through collaboration and connecting ideas across the disciplines of science	Science understanding influences the development of practices in areas of human activity such as industry, agriculture and marine and terrestrial resource management
		People use understanding and skills from across the disciplines of science in their occupations
9 and 10	Scientific understanding, including models and theories, are contestable and are refined over time through a process of review by the scientific community	People can use scientific knowledge to evaluate whether they should accept claims, explanations or predictions
	Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries	Advances in science and emerging sciences and technologies can significantly affect people's lives, including generating new career opportunities
		The values and needs of contemporary society can influence the focus of scientific research
Senior secondary	Science is a global enterprise that relies on clear communication, international conventions, peer review and reproducibility	The application of scientific knowledge is influenced by social, economic, cultural and ethical considerations
	Development of complex models and/or theories often requires a wide range of evidence/ideas from multiple individuals and across disciplines	People can use scientific knowledge to assess and evaluate risk
		The application of scientific knowledge may have beneficial and/or harmful and/or unintended consequences
	The development of science models and theories are influenced by the cultural, social, political and economic context in which they are developed	Science knowledge can enable scientists to offer reliable explanations and make accurate predictions
	Advances in science understanding in one field can influence other areas of science	Science is not always able to bring definitive answers to public debate; there may be limited reliable data available, or there may not be accepted theories to explain the phenomena

(continued)

Table 1 (continued)

Year	Nature and development of science	Use and influence of science
	Scientists seek to recognise and minimise bias in their methods to collect data, identify evidence, and draw conclusions	Scientific knowledge can be used to inform decisions about preferred futures
	ICT and other technologies have dramatically increased the size, accuracy and geographic and temporal scope of data sets with which scientists work	Collaboration is required when addressing regional and global issues or investing in large scale projects
	Models and theories are contested and refined or replaced when new evidence challenges them, or when a new model/theory has greater explanatory power	

educators. However, these ideas have often only been at best implicit in many science curricula in Australia, and if present certainly lacking the clear progression indicated in this table. This content strand within the Australian Curriculum: Science also promotes science not only as a way of thinking, but as a way of acting. Again, such an approach has historically only been implicit in Australian science curricula, if present at all.

As identified in the table, there are two main components of the strand: (i) the nature and development of science, and (ii) the use and influence of science. In terms of the nature and development of science, the focus is on developing an appreciation of the practices of science. Examples include observing phenomena with a purpose, recognising patterns, providing explanations for the patterns observed, developing models, and evaluating the robustness of such models. Alternatively, the 'Use and Influence of Science' component draws attention to how science relates to our everyday lives, how it can assist in solving problems, how it may provide exposure to risks of differing magnitude and, while benefits may result, it often identifies new threats. Increasingly, the focus is on how the use and influence of science impacts our actions.

While the curriculum may be developed in ways that validate more contemporary ways of learning science, the implementation of such a curriculum must also be considered if students are to be given the clear message that their engagement in science is also valued. Engaging students in more authentic practices and processes of science will be an essential part of indicating what types of learning will be valued.

In the following sections, two case studies are presented that highlight examples of innovative curriculum implementation that value more authentic forms of learning science for students. The first of these initiatives is the John Monash

Science School, which as a specialist science school has developed a curriculum that is more contemporary in its orientation. The second is the National Virtual School for Emerging Science, which combines different pedagogical approaches to enable students across the country to engage in learning science in emerging fields.

The John Monash Science School

The establishment of the John Monash Science School (JMSS) in 2010 as a specialist science and mathematics school located on one of the campuses of Monash University provided an exciting and unique opportunity to rethink the nature and implementation of contemporary science curricula. A fundamental premise underpinning the foundation of the school was to encourage and support students and teachers to explore learning and science in new ways that inspired and sparked scientific curiosity while encouraging students to connect with the science in their everyday lives. Critically, learning and teaching would allow the exploration of both the processes and practices of science while providing an appreciation of how these approaches have changed over time and contributed to the shaping of our understanding of the natural world along with the impact on society.

Research findings in Australia (Fensham 2006; Goodrum et al. 2001; Tytler 2007) are comparable with those from many other countries where similar goals for a comprehensive science curriculum have fallen short of achieving their aspirations. One of the major hurdles in this regard is that generalist schools are constrained by their objectives to offer a diverse curriculum to all of their students. In contrast, the chance to create a specialist senior science school for Years 10–12 (ages 16–18) provided a unique opportunity to be innovative in the implementation of science learning and teaching.

Importantly, this innovative implementation was structurally supported in two ways. Firstly, the school adopted a curriculum that doubled the instructional time students could devote to the study of the sciences compared to the usual offerings of generalist schools. Although an increased time for science was no surprise given the intended mission of the school, it did afford new opportunities to rethink the nature, purpose and depth of the key ideas that traditionally underpin contemporary science curricula. For students and teachers, the additional time provided the potential for deeper, richer understandings of science to be developed along with a greater appreciation of the multifaceted impact of science on their everyday lives. By increasing the opportunities for students to engage with science in the year (Year 10) prior to the senior secondary curriculum (Year 11 and 12), it was hoped that student expectations of what learning science could be like would be significantly improved. Secondly, the decision was made to select JMSS students on the basis of an interview that aims to assess their ability and passion for the study of science. Unlike other government select entry specialist schools in this state of Australia, where acceptance is based solely on the student's academic performance, the JMSS interview process is designed to help identify students with strong communication and problem solving skills. Selecting students already engaged with science has the obvious and substantial benefits of aligning the interests and expectations of the students with the key goals of the school.

Not surprisingly, the creation of an innovative science curriculum posed significant challenges for the JMSS curriculum planning team charged with the responsibility of the initial design. The approach adopted was a radical departure from the traditional curriculum design undertaken in most Victorian schools, which usually involves a curriculum committee (composed of representatives from each of the key learning domains within the school) meeting to decide issues of time allocation and to align programmes to best fit with the school priorities and human resourcing. In the case of JMSS, the founding curriculum team comprised a range of representatives drawn from the key school stakeholders:

i. academics from the Faculties of Science and Health Sciences at Monash University who contributed highly specialised scientific knowledge from their discipline areas and rich understandings of the practice of science developed during their extensive careers in collaborative research and academic publication;
ii. academics from the Faculty of Education at Monash University with expertise in science education research and practice and significant expertise in science curriculum design; and,
iii. the newly appointed JMSS principal along with several members of the school's leadership team (all representatives of the Department of Education and Early Childhood Development, Government of Victoria) with extensive expertise in school planning and operations.

This mix of members created a highly diverse and multidisciplinary curriculum team contributing very different perspectives, a point captured by an early comment from one of the science academics in an interview conducted by Blackmore from another Victorian university.

> Before the school staff were appointed, academic staff from the Faculties of Education and Science would sit around the table imagining what was possible. That was very exciting. Then the Principal and other teachers were appointed, and the structures of the Department and School life became more apparent, and we all had to think about how we could make this work by all working together. So, we often came in with the big ideas, and the staff grounded us. But none of us gave in, because we all wanted this to be great. So, we worked very hard to make everything happen (Monash academic). (Blackmore et al. 2010, p. 17)

The team set out to meet the challenge: What does a contemporary curriculum look like that seeks to engage students with the fundamental processes and practices of science? How can it provide insights into the content knowledge and conceptual understandings essential for building a strong science foundation while ensuring opportunities critical for students to explore the complex practice of science and its impact on shaping their world, locally, nationally and globally?

Innovative Curriculum Design

At the outset, the multidisciplinary team was keen to adopt a curriculum approach that placed the students' interests at its educational heart while ensuring that the aspirational purposes of the curriculum remained transparent to all members of the school community. To achieve this goal, the JMSS curriculum team adopted the United Nations Educational, Scientific and Cultural Organization's (UNESCO) four aspirational pillars of learning (see Delors 1997), which helped articulate the intent of the curriculum while underpinning the school's philosophy of learning and teaching. The UNESCO four pillars of learning comprise:

- *Learning to Live Together*—the desire to be a socially responsible, capable and tolerant person who is able to manage conflict with respect and mutual understanding (this pillar is seen as the overarching one);
- *Learning to Know*—acquiring the skills to question, research and learn essential so as to benefit from the opportunities education provides throughout life;
- *Learning to Do*—the pursuit of occupational skills and social competence essential for a rewarding and professional career; and
- *Learning to Be*—aspiring to be a productive citizen capable of autonomous, responsible and ethical judgement.

These pillars help to articulate the educational aspirations of the school by reflecting the desire to shape the academic, professional and social qualities of all students and staff. Critically, they exemplify learning as an active process where the emphasis is equally around processes and products—knowledge is viewed not merely as content but as the process of acquiring, manipulating, transforming and challenging ideas for personal, professional and societal improvement. As a foundation, the pillars provide valuable insights into the potentially rich outcomes of effective curriculum implementation on a number of fronts. Firstly, they describe a curriculum intent that extends well beyond just "learning to know". Secondly, their purpose helps to strengthen greatly the importance of including the ideas of 'Science as a Human Endeavour' and the nature of science in the curriculum by emphasising that science and society are fundamentally intertwined.

Effective science requires human creativity, scepticism, ethical decision making and a logical analysis of emerging evidence. The challenges and solutions it provides changes people's lives in fundamental ways, from how they communicate through to the nature of their work. While the use and influence of science in society now features in most contemporary science curricula, its impact in the classroom often remains underplayed by many teachers. For some teachers it may be because they do not see these ideas as 'real science' or they are too difficult to assess, but more likely it is a consequence of the limited time available for science learning in generalist schools. The result is that these critical components are either superficially addressed or overlooked as teachers focus on the products of science without exploring how or why scientific understanding evolves over time.

The JMSS Learner's Development Framework (see Table 2) is an aspirational document that is widely used in the school to describe the desired skills and qualities of JMSS students. A comparison of the objectives listed in Table 1, detailing the scope and sequence of 'Science as a Human Endeavour', helps to

Table 2 JMSS learner's developmental framework

Learning to live together
Focused on building sound relationships
• Our learners build effective collaboration and teamwork by working constructively together, considering and valuing all input and viewpoints fairly
• Our learners build positive, respectful and supportive relationships with all community members, and celebrate diversity
• Our learners contribute to the creation of a safe, welcoming, optimistic and encouraging learning environment and community
• Our learners have a global perspective, know and care about the world and its communities, and seek to live sustainably and impact positively now and in the future
Learning to know
Focused on thinking and understanding
• Our learners are effective inquirers, able to ask meaningful questions which probe understanding, and take risks in their learning
• Our learners are critical thinkers, able to analyse information, evaluate evidence and produce informed conclusions
• Our learners are creative thinkers, open to new ideas, imaginative and resourceful in their use of different strategies and approaches
• Our learners are reflective, aware of their own skills and abilities, and open to feedback to improve their own ideas or performance
Learning to be
Focused on developing good people
• Our learners are well-rounded with a broad range of skills, perspectives and interests
• Our learners are passionate about learning and strive to achieve their personal best in everything they do
• Our learners are able to examine issues from a wide range of perspectives, and understand the need to act honestly and ethically when making decisions
• Our learners develop the dimensions of leadership, within a context of service to and beyond the JMSS community
Learning to do
Focused on knowledge and skill acquisition
• Our learners are adaptable, being able to live effectively with change, skilled in the use of modern technologies, and prepared to meet any challenge with optimism
• Our learners are effective communicators, being attentive listeners and also articulate in both written and spoken media
• Our learners are persistent, being able to work effectively through difficulties, and resilient in the face of set-backs
• Our learners develop the competencies necessary to advance their learning in specific disciplines, and are responsible for their own learning

reveal clear links with many of the objectives listed in each of the 'pillars of learning'.

Not surprisingly, the journey undertaken by the curriculum team to utilise these learning pillars was not an easy one given that the approach adopted was entirely new to all members. The team decided that each unit within the science curriculum science curriculum should be mapped onto each of the four pillars. A crucial benefit of this mapping exercise was the lively debate it prompted across the curriculum team as scientists from different disciplines remained unconvinced that a science curriculum need be more than a sequence of key content knowledge within each unit. Furthermore, the ongoing debate initiated richer discussions around the nature of science and the importance of its inclusion in the curriculum. What was especially interesting was that many of the scientists' views appeared to be derived from individual contexts and experiences rather than being influenced by the general nature of their research disciplines (e.g., chemistry, physics, biology) (Schwartz and Lederman 2008). Even so, the views of many in the team regarding the nature of science were remarkably sophisticated and their recognition of the importance of its inclusion in the curriculum resonated strongly with current science education trends (ACARA 2012).

An area of work undertaken by the curriculum team where these ideas were reflected strongly was in the design of the Year 10 core science unit. The unit was seen as a fundamental opportunity for students to explore the practices of science in some depth. Initial conversations revealed that some team members held a rather narrow view of how this outcome could best be achieved. For them, this unit would be no more than another customary opportunity for students to study the hallmarks and achievements of science through a familiar 'history of science' context. However, the vast majority of the curriculum team were surprisingly passionate that the unit should offer much more than this narrow perspective. Considerable work was undertaken by member scientists from across disciplines to try and identify what they considered to be essential ideas that underpin the nature of scientists' work. These ideas were presented back to the curriculum team and discussed in an effort to focus on common and agreed themes that would help to crystalise the key objectives for the Nature of Science unit.

The ideas from this work helped to provide some clarity around the practices and processes that scientists engage in, resulting in a briefing document entitled 'How do scientists work?' (Morgan 2009) that was used to inform the JMSS curriculum team. The major ideas from the document (p. 1) include:

- The acceptance of scientific ideas is based on consensus by peers, not the authority of individual 'experts'. New evidence leading to new understandings can change established scientific ideas dramatically and the insights of an individual can play a pivotal role in this.
- Ultimately the success of a scientific model is decided by its ability to predict the outcome of natural events. Nature is always the final arbiter.

- They [scientists] may invoke Karl Popper's "skeptical theorist" to falsify "good hypotheses/theories". Although in practice this is not common as it is rare for scientists to invest time in their work only to try and falsify it!
- Doing science is an increasingly complex social activity often involving teams of scientists working in sub-disciplines. New ideas are often generated at the interface between disciplines, or when disciplines are presented with new evidence demanding a re-think of accepted understandings (e.g., Jennie Brand-Miller—glycemic index pioneer, Max Born—instrumental in the development of quantum mechanics).
- The work [of scientists] requires the adoption of acceptable ethical codes of conduct (honesty, integrity, the centrality of the peer review process, sharing of data versus competition for funding, private profit v public good, etc.).
- The majority of science is funded through access to competitive funding by governments or private enterprise and is increasingly used to inform and shape public policy.
- The communication of scientific ideas and the results of investigative research play a central role in informing and challenging the ideas of others in the scientific community and the wider general community.

As expected, an agreement about the precise definition of what constitutes the nature of science (Alters 1997; Loving 1997) remained beyond reach of the curriculum team at the time. However, what is important to recognise is that the majority of ideas expressed in the Morgan (2009) briefing paper are consistent with the 'Science as a Human Endeavour' scope and sequence summarised in Table 2.

A Focus on Emerging Sciences

In addition to the core 'Nature of Science' unit, the team agreed that areas of emerging science were the frontiers most likely to inspire and challenge passionate and high performing Year 10 students. These areas were selected to offer students access to cutting edge science that was undergoing rapid advancement and growth, thereby transforming current scientific ideas. Many of these areas also provided excellent examples of technological breakthroughs that demonstrated a revolutionary capability to reshape the lives of many people, allowing students the opportunity to engage in authentic discussions and debate regarding the societal implications of this emerging research. The JMSS curriculum team was adamant that science is not a history lesson and that students need to understand the transformative and highly dynamic practice of science that makes it an exciting and constantly evolving discipline.

After preliminary 'brainstorming' by the team, nanoscience, nanotechnology, quantum physics, pharmaceutical science, and medical imaging were selected because they represented emerging sciences that required cross-boundary integration of the more traditional science disciplines. The increasing complexity of science and its application is now more than ever reliant on a multidisciplinary approach that requires diverse conceptual understandings to be successfully integrated into many of the emerging science areas. Consistent with this view is the opinion expressed in the curriculum briefing document by Morgan (2009) that new scientific ideas and understandings appear to be increasingly generated at the interface between traditional science disciplines. As such, the approach was welcomed by the curriculum team with the emphases on these sciences providing students with greater opportunities to explore and examine first-hand the impact that contemporary science and its technological applications have on shaping and understanding our world.

Implementation Through Inquiry and Academic Collaboration

Importantly, these emerging sciences lend themselves to the inquiry approach to learning that underpins the JMSS rationale. As learning and communication technologies continue to improve, students now have unprecedented opportunities to undertake active learning through inquiry. Virtual simulations, animated modeling and ease of access via the World Wide Web to authentic large-scale data-sets provide students with the immediate tools required to undertake authentic investigation through guided inquiry. The benefits of scientific inquiry continue to be debated in the research literature (Abd-El-Khalick and Lederman 2000; Anderson 2002) although it appears to be widely appreciated that an active learning approach is central to the practice of ‘good’ science learning and teaching. Many science educators advocate that, when properly implemented, scientific inquiry has the potential to enhance students’ conceptual understanding, and understandings of the nature of science (Hofstein and Lunetta 2004). An attempt at a clear definition of an ‘inquiry’ approach is provided below by the National Research Council, USA:

> Inquiry involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyse, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (NRC 1996, p. 23)

A scientific inquiry approach highlights the active processes associated with learning and knowledge-building, demonstrating close alignment to the JMSS Learner Developmental Framework that underpins the school’s aspirations for its students. The JMSS founding curriculum team were strong advocates for the use of a guided inquiry approach to science learning and this has become one of the underpinning pedagogies in use across the curriculum.

The emphasis on the importance of an inquiry approach in the ‘Nature of Science’ unit is evident from the comments made by an early career teacher after teaching the unit during his first year at JMSS:

> My approach to teaching science has changed as a result of being here [at JMSS] and team-teaching with other teachers, definitely. Here we have tried to set it up so in practicals we try to get them to look at evidence a lot more and how you go about collecting evidence and looking at how we know what we know… So a little bit of the Nature of Science… and how science is done, I suppose. We looked at what a genius Dmitri Mendeleev was and how he committed himself to try and find an answer to a question that was bugging him. For the Science Fair we try to get them to create questions. What questions do you have? What is it you really want to know about? (Vale, Science teacher, JMSS)

The academic collaboration and productive synergies developed between the university and the JMSS have supported this approach to learning since the establishment of the school. This collaboration has been both welcomed by the school and endorsed financially by the university. A number of academic liaison staff from the Science, Education, Information Technology and Health Science faculties have worked closely with the school to develop a diverse range of insightful presentations, workshops and inquiry-based investigations in which academics share their research interests and findings with both JMSS students and teachers. As expected, the main focus of these presentations has frequently been the introduction of cutting edge scientific content. In addition, they have often provided rich insights into the personal stories of success and frustration experienced by the scientific researchers. These narratives have provided powerful and sometimes unexpected insights for the students and teachers into the practice and processes of science.

The JMSS school community has been very fortunate to have at least three Nobel Prize winning scientists discuss their highly successful professional journeys in undertaking cutting edge research. In contrast, they have also engaged with numerous career scientists who have worked tirelessly for many years in an attempt to better understand a particular metabolic pathway or the interaction of a fundamental particle. Many have been humble in the acknowledgement of their particular research contribution to scientific knowledge, recognising that they are not likely to achieve the same worldwide accolades that come from forging radical new understandings as provided by Nobel Prize Laureates.

Through these shared experiences the JMSS students and teachers are better able to appreciate the nature of the human challenges faced by researchers when engaging in the pursuit of fundamental research and gain a better appreciation of how scientists pursue the essential practices of science. The students have opportunities to listen to and speak with authentic scientists engaged in cutting edge science. The engagements with scientists have been very well received by the students because the researchers reveal the human stories that are often so closely intertwined with their professional identities and their fervent quest to answer fundamental questions in their field. A universal characteristic is the shared passion they have for their research and the enthusiasm they demonstrate when communicating their knowledge with a curious and interested audience.

The JMSS teacher quoted above commented on a visit and presentation from a scientist to the school:

> We had a guest professor who recently gave a talk to the whole school at assembly and he was really good. His talk was all about the challenges he faced in trying to get his doctorate out there. About the hardship he faced and about the resilience he had to show and being human and all these other things that were not just about his scientific discovery. (Vale, Science teacher, JMSS)

Such stories often communicated the critical breakthroughs based on extensive and laborious trials, 'brute force' techniques or elegant solutions originating from unlikely but fortunate coincidences. These revealing human stories have helped to expose many of the ideas that underpin the practice of science and provide opportunities for the JMSS students and teachers to better appreciate that science is more than just a process—it is a multidimensional human endeavour.

However, one activity that truly demonstrates the extent of this collaboration is the 'Science Fair', which is held in October every year. At the fair, students present and defend their findings from their own semester-length research project to peers, parents and a number of invited university science academics. This event is the culmination of research investigations that have all been designed, constructed and implemented by individual students. The event is designed to provide opportunities for the students to experience the successes and challenges of experimental design and implementation. It encourages them to showcase how they have been critical thinkers and active problem solvers and affords them a better appreciation of the nature of science and a human understanding of the scientific process.

Another valuable outcome of the collaboration has been the establishment and teaching of first year undergraduate enhancement courses for JMSS students at the university. Initially, these courses were restricted to a number of science disciplines, for example, chemistry and biology, and were targeted at high-performing JMSS students in their final year of study. Now in its third year, the enhancement programmes have been outstandingly successful with the vast majority of JMSS students performing well beyond expectations. This success has opened up opportunities for the establishment of further enhancement courses in more specialist areas, for example, physics, informatics and computing. Although JMSS is still in its infancy the success and achievements of its initial student cohort have begun to challenge the traditional views of science learning and the forms that it should take in the classroom.

Creating a Virtual School of Emerging Sciences

The established links between Monash University scientists, science educators, and JMSS staff in designing an innovative curriculum that embraced different forms of science while facilitating different forms of learning in science provided an ideal foundation for creating a Virtual School of Emerging Sciences. The opportunity for such a venture arose in 2012 with the decision by the federal government to implement a National Broadband Network—NBN across Australia that incorporated the latest optical fibre, fixed wireless and next-generation satellite technologies (Department of Broadband, Communication and Digital Economy 2013). The primary goal of the government initiative was to ensure that over 93 % of the nation's population gained access to significantly improved internet speeds for accessing and downloading data.

Aligned to the rollout of the NBN infrastructure were substantive funds for innovative educational projects that capitalised on the NBN—capacity and capability. An important proviso in designing these projects was that outcomes and benefits would support current Australian policies, curriculum development and accreditation frameworks to enhance established educational and skills services. The project envisioned by academics from Monash University and staff from the JMSS was a virtual school to provide the delivery of emerging sciences curricula unavailable in most Australian schools. Importantly, these subjects supplemented rather than replaced the science on offer in schools adding value to the science opportunities for students. The result was a successful application to establish the National Virtual School of Emerging Sciences, commonly referred to as NVSES (www.nvses.edu).

The Nature of NVSES

The aim of NVSES is to create virtual classrooms comprising like-minded Year 10 students from schools across Australia. At present, students are able to select from four curriculum topics: Astrophysics, Quantum physics, Nanoscience and Nanotechnology. Each of these topics, taught for a period of 8 weeks, comprises two synchronous 1-h sessions per week with a specialist teacher from the JMSS who is the NVSES teacher. In addition, each student is expected to allocate 1-h per week for self-learning (homework). The NVSES teachers work in pairs with a teacher to student ratio of 1:25. In order to participate, students connect via computers in classrooms within their own schools using WebEx to join their virtual classroom. Once connected, students can use their webcams to connect visually, listen without distraction using individual headsets, raise their 'virtual hands' so that teachers can ask individual students for verbal responses, chat with other students or teachers using voice or text in an open forum, and access shared documents through Google Drive using Google Docs (e.g., powerpoint presentations, documents or spreadsheets). Supporting the WebEx platform and Google freeware are a range of proprietary software applications including WordPress and RealSmart, which are collaborative communication and metric tools.

In terms of connecting to NVSES, there are a number of ways in which participating schools may organise their students to engage in a virtual class. For example, in Nightingale High School (all school names are pseudonyms) students sit in one room in their school (e.g., the library) while logging into their NVSES class individually on a computer using a webcam and headset. This setup allows students to interact on a one-to-one basis with the support of the other students on hand for collaborative activities or additional technical support. In contrast to the individual log-in, students at Smithson High School join their NVSES class as a group all seated in the one classroom in their school with the virtual class streamed through onto a Smartboard at the front of the room. This singular audio connection point means that students must move to the front of the class to a microphone in order to ask a question or provide a verbal response given that they are not connected individually. In a sense, this strategy creates a class of students embedded within the broader virtual class with limited opportunities for individual student interaction. Finally, students at Huon High School normally study by distance education so log into NVSES from home using their own computers with no access to any additional teacher support or resources. These three examples demonstrate the flexibility that is possible for schools in connecting their students into the NVSES virtual classroom. Importantly, each of these modes of access has the potential to offer significantly different student interactive experiences within the NVSES class, making it especially challenging for the NVSES teachers.

Ensuring Meaningful and Relevant Science Within an Online Environment

As discussed earlier, innovative curricula in astrophysics, quantum physics, nanoscience and nanotechnology were not only available but also operationalised for face-to-face teaching at the JMSS. Not only did these topics focus on emerging areas of science but they incorporated the expertise of scientists, science educators and the JMSS teachers. However, the challenge before implementation in NVSES was to consider the transferability of this curriculum to an online environment and the changes required, especially around teacher pedagogy. In order to address these two critical components, a curriculum team comprising science educators and the JMSS science teachers involved in teaching NVSES classes met regularly in the year prior to delivery of the first class.

Over a six-month period, the team reviewed each topic with only minor adjustments being made in relation to the types of activities that might be undertaken with students. For example, shared in-class practical work appropriate for face-to-face teaching had to be replaced with a similar activity that could be completed by students electronically. Hence, the major focus with the update became teacher pedagogy and the ways in which it needed to change in order to maximise student learning in the online environment.

Not surprisingly this shift around pedagogy was difficult for teachers even though the majority were highly experienced practitioners. While they had participated in a demonstration provided by an educator from the US who was teaching virtual classes daily, the JMSS teachers were unsure of exactly what an NVSES class might look like and how it might function. One of the NVSES nanoscience teachers was quoted at an introductory session as saying:

> Here we are trying to develop a course for this environment when you are new to the environment yourself and it is only when you are immersed in it that you realise what is going to work!

A clear difficulty was that strategies that were effective in the face-to-face environment did not automatically align to the virtual classroom. One of the examples provided by the NVSES nanotechnology teacher during an interview was in relation to PowerPoint presentations that were used extensively by science teachers at the JMSS given the ICT focus of the school. In their normal teaching situation JMSS teachers use these presentations to structure a lesson, with various activities and internet links identified for students who then access the presentations via their iPads. Within this environment it was common practice for students to work through 15 or so slides in a 75-min lesson facilitated by their teacher. However, this was not functional in the NVSES virtual classroom as it was too time-consuming moving inexperienced students from the classroom into Google Drive in order to access the presentation and then back into the classroom. As a result, NVSES teachers learned that if they were to use a presentation it might consist of only two or three slides with the main purpose of collecting written feedback from students after small group discussions. Hence, pedagogies changed to meet the purpose and nature of the virtual classroom.

Another challenge for JMSS teachers was in rethinking the purpose and nature of practical work in science. While as science educators we consider it imperative that students access real laboratories and undertake scientific investigations in a 'hands-on' manner as part of their cognitive development of scientific concepts and processes, this need not be confined to a school laboratory (Hofstein and Lunetta 2004). Greater student access to computers, the internet and a range of electronic tools provides the opportunity to move practical work from being about "verification activities" (Yager 1991, p. 22) to a focus around investigating, exploring and demonstrating expertise of scientific processes and skills that are difficult or impossible for students to undertake in a laboratory. In reality, these virtual opportunities were especially relevant for NVSES students given the focus on ideas around astrophysics, quantum physics and nanoscience. These topics are conceptually and practically difficult to explore in even well-equipped school laboratories.

As an example, an educational software company was employed to work closely with the NVSES team to develop an online interactive laboratory. Its purpose was to allow students to produce 'virtual' nano-gold particles, investigate their physical properties and their application as chemical sensors. This investigation is not impossible to undertake in a real school laboratory, although it would require a range of relatively expensive equipment and reagents. More importantly it requires sufficient time to boil quantities of liquid and lengthy reaction times for the nanoparticles to be produced before their properties can be explored. The virtual world allows students to reduce reaction times, repeat normally costly experiments and receive guidance when needed via integrated multimedia support.

Similarly, in astrophysics, helping students develop an understanding of black holes or the structure and nature of dark matter can be readily supported in a virtual environment using interactive simulations and 3-D models that can be investigated by students as they repeatedly manipulate and isolate a number of variables. What becomes critical for the NVSES teacher is being able to select the appropriate activity or experience that aligns with the intended purpose rather than merely using a particular technology (e.g., interactive simulation) simply because it is readily available (see Selwyn and Cooper, this volume). While it is possible to identify many other changes in pedagogy observed by NVSES teachers over the course of the year that the innovation involved, the focus of this particular chapter is around student learning. The examples provided here demonstrate that in order to enhance student learning in the virtual environment, a major shift in teacher pedagogical practice was required.

Adding to the complexity of NVSES is that not only did teachers have to re-think their pedagogies but they also had to become relatively proficient with the technologies to ensure that student learning (and not frustration) was an outcome. Clearly, the high dependency on technology with NVSES increases the likelihood of technical issues that may impede student participation in a synchronous session. For example, we noticed a degree of lag when using guest speakers in an NVSES class that is seemingly due to large numbers of students in Smithson High School (not NBN connected) participating in the virtual class using wireless connectivity. However, putting these issues aside, the environment opens up many exciting learning opportunities for working in science that address some of the critical issues evident in the current literature around student learning and engagement in science, especially in the junior years of secondary schooling. The major issues include providing the following:

1. Students with access to teachers who are discipline-experts and experienced practitioners, something which is especially problematic for many students attending rural and regional schools in Australia (Panizzon et al. 2010);
2. Students with access to real scientists working in emerging fields where peer debate and discussion is helping to actively construct scientific knowledge and understanding that will become the ‘scientific facts’ in the textbooks of the future;
3. Opportunities for students to explore different processes and ways of working scientifically that are either difficult to implement or not possible in a traditional classroom environment (Rennie 2012); and
4. Experiences in science that are meaningful and relevant so that students appreciate the applications of science in their everyday lives (Tytler et al. 2008)

So how does NVSES address these issues? In terms of the first issue, NVSES teachers have a high degree of discipline knowledge. Three of the current teachers have PhDs in science, with two holding majors in astrophysics. Supporting these teachers are scientists from the astro/quantum physics and nanoscience/nanotechnology fields along with science education academics from Monash University. Hence, NVSES provides the ideal environment for enhancing the learning opportunities for students in rural and regional schools by enabling them to work with specialist educators with strong understandings in physics and chemistry.

This point is equally relevant for many inner city schools in Australia, where the same subject discipline knowledge may not be available within the school. For example, in a survey of Australian secondary teachers by Harris et al. (2005), it was reported that 45 % of biology teachers had completed 3 years of tertiary study in their specialist discipline, compared with 34 % of chemistry teachers and only 17 % of physics teachers. The obvious strength of NVSES is that it is possible for teachers in participating schools to join a virtual class with their students and so learn and develop their own scientific knowledge, ultimately enriching their own teaching.

Issues 2–4 align closely with the Years 9 and 10 'Science as a Human Endeavour' strand in the Australian Curriculum: Science (ACARA 2012) as extracted from Table 1.

Nature of Science

- Scientific understanding, including models and theories, are contestable and are refined over time through a process of review by the scientific community.
- Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries.

Use and Influence of Science

- People can use scientific knowledge to evaluate whether they should accept claims, explanations or predictions.
- Advances in science and emerging sciences and technologies can significantly affect people's lives, including generating new career opportunities.
- The values and needs of contemporary society can influence the focus of scientific research.

One example illustrates how 'Science as a Human Endeavour' is readily incorporated occurred during a synchronous lesson to 27 astrophysics students led by Dr Marian Anderson from Monash University who spoke about her work as an adviser to NASA. During her interactive chat with the students, Marian was able to not only discuss her role in helping NASA identify possible landing sites for the Mars Rover but was able to respond in real-time to direct questions from students. Building on from this foundation, Marian was able to discuss her own research around the geology of Mars while pointing out and explaining various structural and geological features from what appeared to be her location on the surface of Mars. This practical experience of the geological features was possible using 'green screen', chroma key special effects technology (located in the NVSES teaching space) combined with authentic photographs from the surface of Mars.

Similarly, the same students met with Perry Vlahos, a past president of the Astronomical Society of Victoria, Australia, prominent national radio astronomy science guest and professional astronomy educator. During his virtual class with the students, Perry demonstrated his expert knowledge by addressing students' questions on the formation of black holes, the existence of dark matter and the scale of the cosmos. Another expert encounter for the NVSES students was with

Dr. Grahame Rosolen, principal research scientist from the Commonwealth Scientific and Industrial Research Organization. Grahame, a research graduate in nanotechnology from Cambridge University, was able to connect virtually with one of the NVSES nanoscience classes from his research laboratory in Marsfield, NSW, Australia, to discuss his current research around specialised electron beams using nanotechnology.

As a result of these experiences, the astrophysics and nanoscience students were able to interact 'first-hand' with experts who are generating new knowledge, through their own research, that is contributing to our growing understanding of science in these highly specialised areas. As explained by a teacher during an interviews:

> It was clear from subsequent discussions with students in class that these opportunities with scientists and specialists in the field helped students to understand the tentative nature of scientific knowledge and the way in which new discoveries challenge the thinking of the scientific community. (Brett, Astrophysics teachers, NVSES)

Aligned to these emerging discoveries discussed with students is the critical role of improved technology. For example, following on from the interaction with Perry Vlahos, students learned how the production of the European Extremely Large Telescope, planned for the early 2020s, with mirrors in excess of 39 metres in diameter, will allow astronomers to view remote galaxies and stars at the very edge of the known observable universe.

The engagement of students in the science they experienced through NVSES is highlighted in the following quotes from anonymous surveys completed by students after their participation in the astrophysics, quantum physics and nanoscience courses. Students were invited to respond to the question: 'How have your experiences with Astrophysics, Quantum physics and/or Nanoscience altered or changed your views or ideas about science?' Examples of responses from the 60 students who responded to the three rounds of surveys include:

> I really enjoyed the way the science was explained with Nanoscience—for example using a mars bar and lephrechauns rather than photons. The content has been different to what we cover in our school science class and this has been interesting. (Student 6, Round 2)

> I have never learned anything like this before! These specialised sciences are so different to what we learn in normal science. (Student 2, Round 1)

> The focus on one aspect of science and going into detail is better than in my other science class because we change to totally different topics every 5 weeks or so. I also like the lack of distractions than in a normal classroom—being able to plug in on my own computer. (Student 11, Round 1)

> This course has helped me understand the scale of the universe, and my research about black holes was really interesting. (Student 5, Round 2)

> Astrophysics has changed my view on science by changing my view of physics. I was a bit unsure about taking a physics class as I haven't enjoyed it in the past, but Astrophysics has made physics fun and more interesting for me now. I also understand more concepts from this. (Student 18, Round 2)

> It has cleared up some of the mysteries I had. I was fascinated by the information we learnt. The course has made my interest in outer space much stronger. (Student 21, Round 3)

> I have thought a lot more about the ethical and social implications of space exploration. It has opened my eyes to the complexity of the universe. (Student 16, Round 2)

> It is fascinating to gain an understanding of how technology has helped scientists improve their knowledge of the universe. I had not really thought about this to this extent before. (Student 19, Round 3)

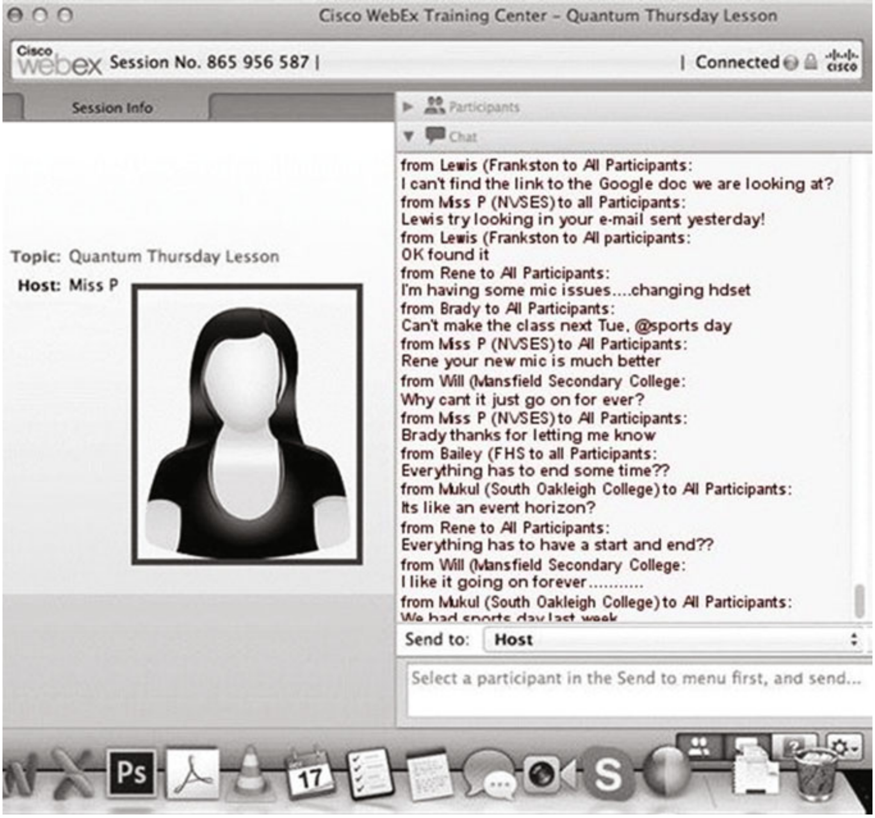
Clearly, the focus for most students in these responses is about how their understanding of science has changed. However, the last two quotes demonstrate wider acknowledgement. The first response indicates that the activities and discussions included during NVSES classes have encouraged students to explore aspects around the ethical and social impacts of science. The second highlights the link between science and the impact of technology. Importantly, these pick up particular components of the 'Science as a Human Endeavour' strand of the Australian Curriculum: Science (see Table 1).

While the discussion so far has focused on the potential for student learning in response to the science and teachable moments provided by NVSES, another advantage for the participating students is the opportunity to collaborate with students in different states and territories across Australia. For participating students, this experience has the potential of offering very different insights or perspectives within the classroom environment. For example, having explored a number of star maps available from NASA, Astrophysics students were introduced to a variable star location and magnitude recording exercise for completion at home over several evenings. While the task sparked a number of questions, suddenly a question from one of the less 'chatty' students in the NVSES class emerged: Will these stars be in the same position for me in Perth? Silence followed. This student resided along the eastern seaboard of Australia but was visiting family in Perth for a period of time. Suddenly his question generated a myriad of related questions as students considered geographic location and the impact on one's view of the night sky. Of course, this question may have emerged in a face-to-face classroom, however the chances improved greatly given the involvement of students from different time zones based upon their geographic location. An interesting aside to this story is that this student connected to his 9am (Eastern Standard Time) NVSES Astrophysics class at 6am (Western Standard Time) in the morning during his holiday and did not miss a class for the duration of his four-week holiday.

A further example of the potential collaborative nature of the NVSES classroom was when students presented findings on their individual research projects in the form of a poster presentation. After students presented an overview of their posters in class, eminent science educator and physicist Professor Richard Gunstone asked each student a number of questions to clarify aspects of their scientific understanding. While students were initially anxious about the task, they emerged excited and enthused by the challenges of the experience. It is these types of opportunities that have increased over the duration of the NVSES classes as teachers improve their own expertise in relation to the technology. For example, through the WebEX environment it is possible for NVSES teachers to divide students into small groups and for them to ‘meet’ in chat rooms to discuss specific topics—just as they might do in a face-to-face class. It is even possible for teachers to ‘visit’ each of these chat rooms to ensure that students are on task and are discussing the topic at hand.

In addition to these formal interactions between students articulated in these various examples, what has become a critical component of the NVSES experience is the chance for students to engage in ‘back-chat’ as they sit in their virtual class (see Fig. 1). Imagine your computer screen with a picture of your NVSES teacher and the other students in your class positioned on the screen. However, just off to the right of your screen (see Fig. 1) is a small section where you are able to type messages, questions and responses to the entire class or to individuals. The experience is similar to chatting with a friend while also uploading photos and updating your status on Facebook.

Over time, the NVSES teachers have noticed a change in student use of the back-chat. Initially, students used it as a means of asking questions of their teachers



Session No. 865 956 587 |

Topic: Quantum Thursday Lesson

Host: Miss P

from Lewis (Frankston to All Participants:
I can't find the link to the Google doc we are looking at?
from Miss P (NVSES) to all Participants:
Lewis try looking in your e-mail sent yesterday!
from Lewis (Frankston to All participants:
OK found it
from Rene to All Participants:
I'm having some mic issues....changing hdset
from Brady to All Participants:
Can't make the class next Tue, @sports day
from Miss P (NVSES) to All Participants:
Rene your new mic is much better
from Will (Mansfield Secondary College:
Why cant it just go on for ever?
from Miss P (NVSES) to All Participants:
Brady thanks for letting me know
from Bailey (FHS to all Participants:
Everything has to end some time??
from Mukul (South Oakleigh College) to All Participants:
Its like an event horizon?
from Rene to All Participants:
Everything has to have a start and end??
from Will (Mansfield Secondary College:
I like it going on forever...........
from Mukul (South Oakleigh College) to All Participants:
We had sports day last week

Send to: Host

Select a participant in the Send to menu first, and send...

Fig. 1 Back-chat as part of NVSES class without needing to switch on their microphone and talk to the class. While one of two NVSES teachers dealt with these questions, picking up on those that could be used to generate discussion in class, the other teacher could maintain the thread of the lesson. As such, students can pose and record a text question that can be dealt with without having to wait for a lapse in the flow of audio conversation during class. The teachers are then able to follow up on these text questions, clarifying points or picking up inconsistencies in student thinking in class or with the individual student by texting a reply. The benefit, though, is that the back-chat is open to all thereby providing an additional opportunity for the rich exchange of ideas to occur between class members, often without interruption to the flow of the main lesson. These chat sessions are also recorded so the teachers can review them later to identify common points of contention. However, what has been observed over time as the students become more familiar with the technology and the learning environment is that once confident with the technology, students begin to engage with one another. In other words, the interactions available through back-chat become teacher to student, student to teacher, and student(s) to student(s).

From a teacher perspective, monitoring this back-chat certainly adds to the complexity of the environment. However, it is one of the key components that the NVSES teachers identify as being especially useful not only for gauging their understanding but also for engaging the students, something that is explained in the following quotes:

> We use the back-chat a lot for this and also asking direct questions. We often get students to PREDICT what they think will happen via the back-chat then do something in class. We put some activities together using collaborative google docs and we give each student a page or slot so they can put their own contribution in and then students can communicate or question one another via the back-chat. (Ann, Nanoscience teacher, NVSES)

> The back chat is our way of keeping track of individual students. You can ask one of the students a question just to see if they are on task and have not wandered off. The other thing is if you haven't heard from one of them for a while, again, you can just send off a comment and ask them what they think—just as I might do during a normal lesson in school. (Brett, Astrophysics teacher, NVSES)

Clearly, NVSES provides an opportunity for students to connect into a virtual classroom and work with like-minded Year 10 students while engaging with emerging sciences and real scientists. For many students without NVSES such an experience would be impossible. Not only can students access scientific knowledge as it is being generated but they are able to engage and participate regardless of their geographical location. The collaborative nature of the learning environment created by NVSES, which is supported by a range of technologies, gives students a chance to experience learning in science in quite different ways. Importantly, however, this environment may not suit the learning needs of all students. The purpose of its inclusion in this chapter is to explore future possibilities recognising that regardless of delivery, it is the needs of individual students that are the highest priority.

Conclusions

In considering what forms of science learning should occur, the two contexts presented here identify some common themes. The most obvious is the collaborative aspects involved in the design and implementation of the science curricula for both the JMSS and NVSES, which appear fundamentally important to their success. The collaboration provides a lived experience for the curriculum developers, who are also implementers, while highlighting the need for providing students with experiences that demonstrate more authentically the nature of science as an evolving discipline. Such collaboration mimics the practices of the scientific community, which has not been common in the majority of science curricula where the focus has been around the products of science (i.e., content).

The focus on the emerging sciences in both the JMSS and NVSES contexts provides further impetus for collaboration as experts from different scientific traditions (e.g., biology, chemistry, physics and geology) work together to develop curricula and scientific experiences that cross traditional boundaries. Such situations flag the very real need for moving the science curriculum away from the current disciplinary silos to the more interdisciplinary sciences including the health sciences, environmental sciences and physical sciences.

An essential component of collaboration is in valuing the expertise of those involved, illustrating first-hand how access to and generation of new knowledge is at the heart of ‘Science as a Human Endeavour’. The active construction of scientific knowledge demonstrated in the JMSS and NVSES allows students to experience how scientific meaning is created and shared through debate and argumentation, with scientists reaching a consensus based on current scientific evidence.

The contexts discussed in this chapter have ensured that the processes and practices of the scientific community are at the heart of the forms of science learned by students thereby moving beyond many science curricula which only value the products of science. Despite the fact that all students participating in these experiences appear inherently interested in science, their ongoing enthusiasm and engagement in science over a sustained period of time is also testament to the relevance of these science experiences for students where the generation of new knowledge is a collaborative effort.

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