Deborah Corrigan · Cathy Buntting
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The Future in Learning Science: What's in it for the Learner?

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Preface

This is the fourth book in a series initiated by the Monash University—Kings' College London International Centre for Study of Science and Mathematics Curriculum and in partnership with University of Waikato. The Monash-Kings' College Centre was established in 2002 with initial support from the Monash University Research Fund (new areas). The Centre for Science and Technology Education Research at University of Waikato and the Centre for Science, Mathematics and Technology Education at Monash University have had a formal partnership agreement since 2003 and have worked cooperatively in many areas.

The first book in the series, *The Re-Emergence of Values in Science Education* (D. Corrigan, J. Dillon & R. Gunstone [Eds.], Rotterdam: Sense Publishers, 2007), considered the state of science education in the twenty-first century through the lens of values. The book presented a 'big picture' of what science education might be like if values once again became central to science education. A decade ago (when this first book was conceptualized) the overwhelming experiences of those who were teaching science were in an environment which had seen the de-emphasizing of values fundamentally inherent in both science and science education. There was a disparity between the evolutionary process that science was—and still is—undertaking and that undertaken by science education (and school science education in particular).

In the second book, *The Professional Knowledge Base of Science Teachers* (D. Corrigan, J. Dillon & R. Gunstone [Eds.], Dordrecht, Springer, 2011), our focus was on exploring what expert science education knowledge and practices may look like in the then slowly emerging 'bigger picture' of the re-emergence of values, a focus we saw as a logical step on from the focus on values in the first. In the third volume, *Valuing Assessment in Science Education: Pedagogy, Curriculum, Policy* (D. Corrigan, R. Gunstone & A. Jones [Eds.], Dordrecht, Springer, 2013), we took what we saw as the next step in the sequence of foci begun with our exploration of *The Re-Emergence of Values in Science Education*; the reality of education is that assessment almost always the strongest force shaping implemented curriculum, teacher development and behaviour, student approaches to learning, etc. This book considered the ‘big picture’ of assessment in science education, from the strategic/policy to individual classroom levels. While some classroom case studies were presented, they focused more on teachers than students, and so considered assessment more in terms of what teachers plan and do than in terms of the impacts on students.

This fourth book moves on again from *Re-emergence of Values/Professional Knowledge Base/Assessment* to consider learning—the forms of science that better represent the nature of science in the twenty-first century, the purposes we might adopt for the learning of school science, the forms this learning might take, and how this learning happens (with particular concern for the need to better engage students with their school science and the need to place the burgeoning range of digital technologies into a more informed context than the narrow and uncritical contexts in which these are too commonly considered). An important overarching theme we seek is to represent and value the perspective of the learner.

We used the same approach to the creation of this fourth book as we did with the previous three. In a desire to achieve in this edited collection both the creation of a cohesive contribution to the literature and having authors able to assert their own voices without restrictive briefs from us as editors, we again organised a workshop involving the authors and ourselves to enable a more interactive and formative writing process. Authors completed a first draft of their chapters in time to distribute them to all workshop participants before we met. The workshop then involved intensive discussions of individual chapters and feedback to authors, and considerations of the overall structure and cohesion of the volume. Authors then rewrote their chapters in the light of these forms of feedback. As with the previous books, the workshop was scheduled around the European Science Education Research Association (ESERA) conference, and took place at the Monash University Centre in Prato (Italy).

This procedure had previously been used very successfully in the production of two other books in which the editors had variously been involved P. Fensham, R. Gunstone & R. White. *The Content of Science: A Constructivist Approach to its Teaching and Learning* London Falmer; R. Millar, J. Leach & J. Osborne *Improving Science Education: The Contributions of Research*. Milton Keynes Open University, and has been more recently adopted by other science education researchers. We believe that this process significantly improves the quality of the final product and provides an opportunity for what is sadly a very rare form of professional development—considered and formative and highly collaborative (and totally open) discussions of one’s work by one’s peers.

We gratefully acknowledge the funding of the workshop through contributions from Monash University, University of Waikato and King's College London, and the commitment, openness and sharing of the participants in the workshop—all authors and editors—who shaped the book.

Clayton, Australia
November 2014

The Editors

Contents

About the Authors

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Deborah Corrigan is a Professor in science education and Deputy Dean of the Faculty of Education at Monash University. After working as a chemistry and biology teacher, she worked at Monash University in chemistry and science education, particularly in teacher preparation. Her research interests include industry and technology links with science, curriculum design, science education policy and the values that underpin science education. However, her main research interest remains improving the quality of chemistry and science education so that it is relevant to students and improving the professional practice of teachers and other industry professionals.

Bronwen Cowie is Professor and Director of the Wilf Malcolm Institute of Educational Research, The University of Waikato, New Zealand. Bronwen has worked on a number of large national research projects including the Laptops for Teachers Evaluation and the New Zealand Curriculum Implementation Exploratory Studies. She has extensive experience in classroom-based research with years 1 to 10 teachers and students using interviews, observations, and the collection of student work and video as a data generation tools. Her research interests include the links between assessment for learning [AfL] and culturally responsive pedagogy, the use of ICTs in science education and classroom interactions and networked inquiry in science classrooms.

Paul Davies is a Lecturer in Science Education at the Institute of Education, London. He has a background in biology and having completed his doctoral work and teacher training, taught in London secondary schools for 10 years. He currently leads the Postgraduate Certificate in Education science teacher education programme and teaches on the Master's in Science Education and Master of Teaching programmes, as well as supervising doctoral students. Paul's research interests include the role of non-formal learning in biology education and teaching and learning in science using technology.

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Greg Lancaster has extensive experience in teaching secondary science and senior physics while undertaking a variety of professional roles in secondary schools in Victoria. For a number of years he worked part-time in the tertiary and secondary sectors as a science teacher and science teacher educator, which afforded him with rich insights into the changing nature of teacher professional practice, the challenges of curriculum design and authentic teacher professional learning. He currently works part-time for the Faculty of Education at Monash University across a number of roles, including the Faculty academic liaison to the John Monash Science School, a science education researcher, and lecturer in physics education. His research interests include the development of conceptual understanding in physics, inquiry based learning and science teacher professional learning.

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The Future in Learning Science: Themes, Issues and Big Ideas

Cathy Buntting, Richard Gunstone, Deborah Corrigan, Justin Dillon and Alister Jones

Introduction

It is typical for experienced science educators to have moved through major shifts in priorities in their work—broadly, shifts from a focus on curriculum and teaching to a focus on student learning. This book series, too, has moved through such shifts. In the first book, our concern was the re-emergence of values in the science curriculum, particularly in terms of policy and implementation issues. In the second book our focus was on exploring what expert science education knowledge and practices may look like in the emerging 'bigger picture' of the re-emergence of values in science education. The third volume shifted to assessment, and its relationship to and impact on policy, curriculum, practice and, of course, learning. In this fourth book in the series, our focus moves to be centrally on learning.

In looking back over the series, it is clear that there has been an omission in terms of the different participant voices from science education that have been represented in the previous three volumes. Not only is the focus squarely on learning in this present book, we have considered science learning from the per-

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spectives of the learners rather than the perspectives of teachers and other adults—hence the title: *The Future of Learning: What's in it for the Learners?*

Science teachers beginning their careers are highly focussed on understanding what they have to teach and then planning for that teaching. As they become more experienced, and their understanding of their classrooms widens and deepens, their focus shifts more to the learning that is occurring in their classrooms rather than the teaching they are doing. The quest to become an effective teacher requires an acknowledgement that the prime foci of the planning and implementing of teaching are the learners and their learning. Assessing learning, formatively and summatively, across its breadth and depth, provides opportunities to reflect on the effectiveness of particular pedagogic approaches and aspects of particular curriculum structures and sequences. If we can assess learning then we can begin to see what successes students have, what difficulties they have, and find ways to assist students and engage them. But beyond this, if we understand how learning happens and the factors that promote or inhibit both learning and student engagement then we are in a better position to help. Further, in this age of continuing increases in the rate of change for so many areas of society, if we can make some sense of the future that may lie ahead for us and our students, then we will be in an even better position to support student learning of and engagement with science.

In this latest of this series of books on science education, the authors consider learners and learning in science education, and do so with a particular emphasis on the future. Considering any future landscape and identifying possible, probable and preferable scenarios is a complex but important task if one is to be empowered to contribute to change. It is our hope that this book offers insights into possibilities for the learning of science that are relevant and engaging for learners, and that will thus enable curriculum and pedagogy to instil in learners a lifelong interest in science and ways in which it can positively contribute to life in the 21st Century. The purpose of this introductory chapter is to outline the arguments presented in this book, and help identify themes and issues that might be of particular interest.

Background to the Book

What's the Problem?

There is widespread recognition of the importance of developing scientific literacy among all students of school science. The response of many countries has been to redevelop their science curriculum—something we commonly see occurring on 5–10 year cycles. However, there are many problematic consequences of this approach. At the core of many of these is that writing a new curriculum is in essence the *beginning* of the change process, but it is very often assumed to be the *end* of this process. And, of course, the more substantial the change in the intended curriculum, the more important it is that the curriculum writing is recognised as only an early step in the change process.

A further complication arises in that the rationale behind and the intentions of a substantially changed intended curriculum are frequently not explicit or easy to identify. It is not surprising, then, that those responsible for implementing the new curriculum do not adopt the intentions of the curriculum. Rather, it is often easier for teachers to take the conservative approach of comparing the new curriculum with their current practices to see what has changed and to what extent they can fit their current practice to the new curriculum.

Of course, most teachers have wholehearted concern for the best interests of their students, for "doing the right thing" for their students. However, systematic approaches that recognise that the learning of complex issues (curriculum rationale and intent) and changing one's behaviours (implementing the curriculum according to rationale and intent) take time and effort and support. In the absence of this, taking the conservative approach described above is often appropriate for "doing the right thing", most particularly in situations of high stakes for students. Such conservatism extends to pedagogy as well, where science education uses a restricted range of pedagogical approaches to science learning because they are seen as "tried and true"—yet many of these pedagogies were honed in an era of curriculum designed to build the content knowledge of a select group of students, and prepare them for traditional science careers.

The most pervasive influence of conservatism, particularly at more senior levels of schooling, is assessment. In the extreme context of assessment by summative examination determined externally to the school, it is the form of assessment that is the overriding driver of an individual teacher's selection and emphasis from the curriculum and the pedagogies s/he uses.

Students very often are even more conservative in their responses to major curriculum and/or pedagogy change. Students (and their parents and the wider community) have expectations of what school is like based on what they have experienced and what they believe those before them have experienced. They know how different teachers approach their teaching and what "success" looks like in different subjects. In addition, science is but one subject of many, and one of perhaps four or five (or more) different types of experiences, approaches, pedagogies, and assessments in a single day. It is hardly surprising then that students in such contexts often see their science classes, held on different days of the week, as separated and discrete episodes that do not link with each other (e.g. Gunstone 1995). In addition, many students see school as something necessary and to be coped with (perhaps better expressed as "survived"), and they often do not associate their learning with understanding the present and future world or even with equipping them to prosper in their post-school future. In this context, many students see science as something they "have to do" in the compulsory years of schooling, and not as a way of viewing the world and the multiple possible futures that exist.

The continued general failure of curriculum change to impact on student engagement with science, student acceptance of the importance of science, and student learning of science as it is undertaken in the 21st Century, remains a profound and multifaceted problem.

What Has Been Advocated and Tried Already—And What Happened?

The traditional view of science, and consequently of the learning of science, changed significantly in the Anglophone world with the revolution of the first major curriculum projects in the late 1950s/early 1960s, the so-called ‘alphabet projects’ (Fensham 2015). These senior secondary school USA-developed curricula were concerned with those who would study science post-school, and focussed strongly on a conceptual understanding of science with stylised and generalised approaches to the practice of science. This was at the expense of other emphases, particularly applications of science and the history of the development of the conceptual ideas (Fensham 1988). While “The Scientific Method” was not a new inclusion in these projects, it received much greater emphasis and still appears in many curricula as *the* approach to science investigation and practice. In fact, the heavy reliance on experiments as *the* valid form of science investigations that had been prominent in UK curricula in the first decade of the 20th Century returned in the alphabet projects—and remains today.

However, in the 65 years since the first of the alphabet projects (such as the globally influential Physical Sciences Study Committee, or PSSC, course) the nature of science per se has changed considerably. At the time of such projects it embraced a logical positivist view where hypothetico-deductive explanations were pre-eminently valued. It then moved through theory change models with science as an agent of conceptual change, to the present focus on model-based explanations where science is seen as a cognitive, social and epistemic practice (Grandy and Duschl 2005).

There have been a number of initiatives implemented since the latter part of the 1960s to try to better reflect these changes in the nature of science in school science education. These include inquiry-learning models (that have re-emerged in different detail at a number of times in the last 60 years), Science-Technology-Society (STS), argumentation approaches, Twenty–first Century science, and others. Many of these initiatives were also designed to provide greater “relevance” of science for students beyond schooling.

Some initiatives were coupled with professional development and learning opportunities for teachers, such as the large projects that have gone with the introductions of Twenty-first Century Science in the United Kingdom and the national science standards in the US. In Australia, the introduction of primary science textbooks developed with the backing of the Australian Academy of Science—Primary Connections—was accompanied by a very explicit training programme for teachers if they were going to use these resources. However, such opportunities have been extremely uncommon when there is a whole system curriculum change (that is, a change where all teachers are involved, rather than teachers or schools with an existing enthusiasm for the change).

Attempts have also been made to address more authentic assessment of learning science practices as part of some initiatives. Formative assessment rather than a reliance on summative assessment has received significant attention (e.g. Corrigan et al. 2013), yet summative practices remain a major part of final certification of student learning at the completion of secondary school. Of course, if certification requirements are linked with the assessment of student science learning at some level, then a summative function remains. However, there is widespread conservatism in approaches adopted in summative assessment that is often at odds with the intentions of the curriculum being assessed. Assessment types such as ‘assessment of learning’, ‘assessment for learning’ and ‘assessment as learning’ have also been developed as mechanisms for capturing more accurately the types of learning students engage with in science classrooms. While these assessment types have gained some momentum in more recent times, there is still no evidence that they have become the more accepted views of what counts as assessment—particularly, as just noted, when the assessment is of a high stakes nature.

In more recent times the various forms of initiative we briefly referred to above have been introduced in a substantially changed context: computers and the Internet have substantially changed the way we view knowledge. No longer is knowledge confined to a noun, indicating *what we know*, but has now also become a verb to indicate that it is equally important *how we use* such knowledge. The change in how we access knowledge has resulted in a continuing knowledge explosion. Yet educational systems seem to have responded by implementing accountability systems and the measuring of “knowledge” as in TIMSS or “scientific literacy” as in PISA—something that is to a major extent a consequence of political drives for accountability. Tragically, these political agendas remain ignorant of questions about the validity of the ways data are generated—data from which accountability is judged.

What has remained persistent across so many science education initiatives—across all these things that have been advocated and tried—is the outdated belief that science as represented by school science relies on a body of knowledge in the form of concepts that can be supported by data generated through experimentation. Such a common value held by many involved in school science has been extremely difficult to shift, in part because this is the very system that has rewarded teachers as successful science learners in their own schooling and university study.

The Underpinnings of This Book

One could feel extremely pessimistic at this point in the argument. How can such conservative beliefs and values persist in the light of so many initiatives over a long period of time? More productively, we could optimistically seek out and learn from the inspirational practices that we need to celebrate and embed.

The increasingly rapid pace of change in today’s world has also meant that changes in science include the forms science takes. Shifts in the forms of science that are researched and taught post-school are not just a function of the 21st Century, but the pace of development and acceptance of these changes is more rapid than ever before—emerging sciences, new sciences that are new integrations, "futures science", and the consequences of a lessening (perhaps even removal) in some fields of a focus on the fundamental "Renaissance" assumptions of reductionism. These changes have been characterised by an increase in the complexity and multi-disciplinarity of science, including a multi-disciplinarity that embraces ways of knowing beyond science. Sometimes these shifts are driven by developments in a traditional area of science, for example, the dramatic transformation of biology research and post-school teaching to embrace essentially all other 'traditional' areas, including mathematics (Bialek and Botstein 2004). In other circumstances it is a new area that initiates the shift. For example, the inclusion of Sustainability as a new topic in school science involves "a changing paradigm of science, a new one that fully embraces a mix of mono-, multi-, inter-, and trans-disciplinary research, that enables social innovation as well as marketing-driven technological innovation …." (Chabay 2015, p. 1026).

As we have just noted, none of this is new; rather, we argue, these developments are both greater/more pervasive and occurring at a greater pace than ever before. Even so, school science almost never recognises these shifts. In fact, school science has yet to seriously catch up with such major shifts from the now very distant past. For example, there is a case to argue that "Biochemistry" as a distinct field of science began with the first synthesis of an organic compound (urea in 1828) or the discovery of the first enzyme in 1833. And it is now more than half a century since the DNA discoveries of Crick and Watson (and Franklin and Wilkins). Yet, is there anywhere in the world that has a subject called biochemistry at school level? This is of course a completely rhetorical question—the point of the example is to emphasise that while there are 21st Century advances in science that need to be reflected in what is learned, there is also a long past yet to be seriously addressed in the school science curriculum.

In addition to shifts in the forms of science, shifts are also urgently needed in what learning is valued. These need to include shifts of two forms: first, shifts in the learning that is valued that reflect the changes in the forms of science we describe above; second, shifts in learning to be valued that reflect the ways that the contexts in which these new forms of science are developed and applied are themselves significant components of the science. For example, curriculum foci that are increasingly talked about today, such as 'Science as a Human Endeavour' or 'Science in Social Contexts', explicitly seek to embrace the ways science knowledge has been constructed and the ways it impacts on and interacts with the societies in which it is constructed and used.

A logical—and necessary—step from these ideas is to consider how such learning happens from the perspectives of students. We see two central aspects of this in terms of the future of learning science. The first, and most critical, is the urgent need to engage students, including their non-cognitive and affective motivation, passion and desire to learn science. We need to see this as *the* central issue in learning science, both for an educated citizenry and for a productive response to the ubiquitous concerns about future numbers of science-skilled and science-literate professionals. Too many contemporary considerations of learning science are still focussed on what it was fashionable to call in the late 1980s “cold cognition”, that is, the intellectual, the rational, the objective. The demonstrable urgency to better understand and then develop student engagement challenges the value base of this “old”, “cold” science education. While it is the most obvious of observations, it is important to note here that any consideration of the voice of students in this context today immediately challenges any view of there being merit in “cold cognition”.

The second of the central aspects we see in students’ perspectives of science learning is what could be characterised as “the real impact of ICT on science learning and teaching”. In simple terms, it is no longer of any use to teach slabs of propositional knowledge (‘encyclopaedias’); people can, and do, look at the ‘encyclopaedia’ wherever they want on their phone or tablet or [insert some other device not yet invented]. Broadly, the younger the student, the more common is this behaviour, and hence this behaviour will continue to increase exponentially. In this new context, learning happens without the same assumed requirements of “propositional building blocks”. All this is another—of very, very many—reasons to reject the common view that school science should focus as strongly as it so often still does on propositional knowledge. The iconic and powerful and pejorative description of this clearly inadequate representation of science that was coined by Schwab in 1962, that the science curriculum is a “rhetoric of conclusions” (p. 24), remains sadly relevant today.

The Chapters of This Book

As forms of science change—from (largely) reductionist, disciplinary-based approaches, to multi/inter/trans-disciplinary/contextually rich systems approaches to understanding complex phenomena—it follows that the forms of science learning deserve extended scrutiny. This is particularly true from the perspective of students. What is the purpose of their school science learning? What does it prepare them for in the context of engaging with real-world science, whether as citizens or in a science-related career? What learning will be relevant when they leave the school gates, both on a daily basis, and after completing their school career?

The chapters of this book explore aspects of these questions about science learning from a wide range of perspectives and in a wide range of contexts. These are now summarised as we give outlines of each chapter. We begin with the fundamental issue of the purposes of learning science, the broad focus of each of chapter “Learning for a Better World: Futures in Science Education” and “Connoisseurs of Science: A Next Goal for Science Education?”.

In considering the forms of science that should be learned, **Michael Reiss’s** chapter carries the provocative title: “Learning for a Better World: Futures in Science Education”. His premise is that science education as currently undertaken in schools is generally too narrow in its conceptualisation, aims, teaching and assessment—and at risk of being a “living fossil”, unlike science, which, he reminds us, never stands still. He also argues that school science generally does not take sufficient account of student diversity, including how students learn science, where they learn it and what they find engaging about it. In order to engage today's and future students in science, and develop in them a lifelong interest in science, Reiss recommends an aims-based approach to curriculum development. Here, the aims of schooling are used to drive what students learn. This in contrast to the more common approach to developing curricula, which starts from a set of subjects and the knowledge that these embody, and then works to fit the aims around these.

To build his argument, Reiss takes the position that an important aim of formal education is to enable students to lead "a flourishing life" with "autonomous, whole-hearted and successful engagement in worthwhile relationships, activities and experiences" where individuals also want others to lead fulfilling lives. He admits the potential controversy: "some might consider such an idea to be utopian; others that it is not sufficiently radical". Nevertheless, he goes on to explore how human flourishing as a core curriculum value might shape a science curriculum. At pre-school level, he supports science learning that focuses on observing and exploring, highlighting the importance of learning that is closely connected to the child's family. At primary school level, he supports opportunities in which children can develop their inquiry skills and their understanding of some of science's Big Ideas, as well as how science skills and knowledge can be of value in other school subjects (and vice versa). At secondary school, Reiss promotes the use of relevant contexts for creating engaging science education programmes, including capitalising on the diversity among people—human variation—as a context for learning. Finally, he points to the many out-of-school opportunities for science engagement and reminds us that school science education is only part of the science learning that is available to individuals—but that schools are distinctive in that they reach such a large group of people for substantial chunks of time. For this reason, school science needs to be seen by learners to be relevant to who they want to be, and to their developing identities.

Also considering the forms of science that should be learned at school, **Peter Fensham** (chapter "Connoisseurs of Science: A Next Goal for Science Education?" *of science:*) argues for installing a discerning trust in science as a central learning goal for school science education. He begins by convincingly outlining why understanding how and when to trust science meets a major public need of 21st Century citizenship. In addition, trust is essential within the teams of multi-disciplinary scientists working on contemporary scientific questions. To elaborate on what "trust in science" might look like, Fensham develops the concept of "connoisseurs of science". Through this concept, he contributes to our thinking about the forms of science that should be learned.

Drawing on his vast experience in the development of science education internationally, Fensham considers the development of students' understanding of when and why science understanding is appropriate. Interestingly, he reminds us of the lists of "strengths and limitations of science" that were common in earlier curricular aims for science learning, but that are rarely included in more recent curricula, despite greater attention being given more recently to how science functions, and the nature of science. Fensham goes on to offer examples of the importance of a science curriculum that addresses: how scientific knowledge is established, including the possibility of competing models and theories co-existing; the probabilistic nature of much scientific knowledge, and therefore the nature of uncertainty (and the difference between ‘don’t know’, and ‘know, but not sure of the value’); differences between correlation and causation; and the multi-disciplinary nature of socio-scientific issues. While he specifically states that he does not give attention to the level of schooling that is most appropriate, he does argue that students need to acquire these learnings during the compulsory years, when science is studied by all. He is also careful to point out that school science cannot be expected to offer individual students the range of experiences that embrace the nuances of investigating scientific issues. Rather, his call for the development of connoisseurship is grounded in developing in all students the ability to be discerning and make informed judgements about the knowledge that may be presented to them as ‘science’.

Marie-Claire Shanahan builds on Fensham’s ideas in chapter “When Science Changes: The Impact of ICTs on Preparing Students for Science Outside of School”. In particular, she explores ways in which information and communication technologies (ICTs) have changed public access to new scientific developments, or “science-in-the-making”. For example, anyone with an Internet connection can now access scientific findings, press releases, media reports, public and professional commentaries, and often the researchers themselves. In this environment, Shanahan argues,

> … one of the most pressing impacts of ICTs on school science is not how they change the pedagogical possibilities of the classroom but how profoundly they have changed the public scientific landscape students find themselves in currently and will find themselves in as adults.

To demonstrate the shift that has happened in public access to scientific debate, Shanahan uses the example of a provocative NASA press release and the publication of experimental findings that were subsequently critiqued in a publicly accessible forum. Through this example, she illustrates how what once took place behind the closed doors of the science academy now occurs out in the open. The issue is not that new scientific findings lead to debate (which they invariably do), but that this debate has hitherto not been as evident to the public, particularly in the “raw” form exemplified by the NASA press release and critiques. For non-scientists, the result can be quite unsettling, even confusing. Shanahan therefore uses the example to raise important questions about the scientific literacy aims of many contemporary curricula (which, she argues, don’t go far enough in preparing students for negotiating the controversies associated with “unsettled science”); the purposes for introducing media articles into science lessons; and student and public understandings of the larger context of scientific development. Many of these aspects echo issues that concern Fensham and that underpin his notion of science connoisseurship. Shanahan’s emphasis, however, is on the ways in which the changing landscape of public access to science-in-making makes science connoisseurship so important.

May Cheng (chapter "Forms of Learning in Senior Secondary Science as Represented Through an Integrated Curriculum") picks up the theme of alternative forms of science learning that can occur in school by considering Hong Kong's recent curriculum reforms at the senior secondary school level, and in particular the introduction of Liberal Studies as a core subject in the senior years of schooling. Although students are still able to take science subjects within their choice of electives, Liberal Studies offers opportunities for *all* students to continue their science learning, particularly through two of the six Liberal Studies modules: 'Public health', and 'Energy, technology and the environment'. The Liberal Studies curriculum is deliberately integrative and inquiry-based, with an emphasis Inquiry-based science education on the development of thinking skills and citizenship education rather than specific content. Examples of questions for inquiry include: *Can science and technology provide new solutions in the prevention and control of diseases?* and *What are the implications of environmental change on the development of energy technology?*

Cheng points out the specific links to science content in these particular inquiry questions, and others like them, and argues that sound understanding of the nature and history of science are required to develop a comprehensive response—a response that also needs to take into account other dimensions of understanding, such as cultural, social and economic perspectives. However, Cheng notes that students are not required to develop the skills of practical scientific inquiry. She also raises concerns about the enormous pressure placed on teachers—many of whom will not themselves have a science background—to teach science within an integrated curriculum, pointing out the need for further research into the nuanced differences between teaching discipline-based subjects and interdisciplinary subjects. In doing so, she echoes concerns introduced earlier in the chapter regarding curriculum innovation, including the need for teacher professional learning and support. The age-old issue of high-stakes assessment is not to be ignored. Further, there is also some concern that the Liberal Studies curriculum may in the future become more limited in scope in terms of themes that are addressed. In spite of these uncertainties and challenges, however, the chapter offers the promise of a system-wide curriculum initiative that re-casts science education within inter-disciplinary contexts, where new forms of science learning are not only possible, but required.

In chapter "Pursuing Different Forms of Science Learning Through Innovative Curriculum Implementation", **Greg Lancaster, Debra Panizzon and Deborah Corrigan** also explore new forms of science learning from a curriculum perspective. Using two examples—the John Monash Science School (JMSS) and the National Virtual School of Emerging Science (NVSES)—they demonstrate the potential of innovative curricula based on emerging sciences to engage students and broaden their science learning experiences. Although the examples feature Year 10 students who are already interested in science, there are salient lessons for any new curriculum development. These include the diverse opportunities for innovative inquiry learning in fields such as nanoscience, nanotechnology, quantum physics, pharmaceutical science and medical imaging; the value of a diverse, multidisciplinary team approach (science researchers, science teachers, science education researchers and school leaders were all involved in the curriculum design); and the importance of aligning the school structures and classroom pedagogies with the curriculum goals. For example, moving the curriculum from the face-to-face environment at JMSS to the online environment of NVSES provided new and different opportunities for student interactions and learning, but also required significant pedagogical change. The chapter also demonstrates the value of getting practising scientists to contribute to the learning programme, and this theme is picked up again in chapter "Making Science Beyond the Classroom Accessible to Students" (by Léonie Rennie) and "Children Learning Science in and for a Participatory Culture" (by Bronwen Cowie and Elaine Khoo). In elaborations of both the JMSS and NVSES curricula, the chapter demonstrates the curriculum team's view "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".

Unfortunately, the way in which the content of science curricula is selected and sequenced is rarely influenced by contemporary understandings of how science learning occurs. **Colette Murphy** addresses this in chapter "Reconceptualising the Learning and Teaching of Scientific Concepts". Using a sociocultural view of learning, she asserts that scientific concepts can be theorised as *tools* to explain specific phenomena. Drawing on the work of Lev Vygostky and his followers, she argues for a shift in science education from a focus on *learning* scientific concepts, to *using* scientific concepts. From this perspective, the context in which the concepts are *used* becomes important—and gives the concepts their meaning.

Murphy also considers the zone of proximal development (ZPD) in concept development, and highlights the teacher's role in helping students consider the relationships between everyday and scientific concepts. She goes on to address the importance of developing a shared language in the science classroom, demonstrating how environments that promote dialogue can support students' development—and use—of scientific concepts in contexts that matter to them. Throughout the chapter, a school science is presented in which scientific concepts are reconceptualised as 'tools' for learning science, rather than as 'entities' to be learned. For the learner, science concepts take on a different purpose, having explanatory power rather than being something 'to be learned'.

In chapter "Making Science Beyond the Classroom Accessible to Students", **Léonie Rennie** adopts a place-based view of learning science. She uses three Australian-based case studies to demonstrate the potential for students to engage in real science of local relevance. The first case study, *Mildew Mania*, is an example of a citizen science project where students grow barley and send in samples of mildew for a university project investigating the spread of fungicide-resistant mildew strains and the development of new barley cultivars with a high yield and genetic resistance to mildew. Such 'citizen science' programmes, sometimes called 'participatory science', are growing rapidly in number, with various levels of participation—from citizens (including students) acting as data collectors, to citizens participating in the whole of the research design and analysis, including sometimes initiating the research. Another example is provided by Bronwen Cowie and Elaine Khoo, in chapter "Making Science Beyond the Classroom Accessible to Students".

Rennie's second example of student access to real-world science is Australia's Primary Industry Centre for Science Education (PICSE) programme, which is funded nationally by the Australian government and several industry bodies and cooperative research centres. A key part of the programme is the provision of scholarships to selected senior high school students who participate in a week-long science camp and subsequent work placements. In her third example, Rennie offers insights into the Scientists in Schools (SiS) project, another nation-wide programme designed to establish teacher-scientist partnerships that bring real-world science into classrooms, inspire and motivate teachers and students, and increase scientists' engagement with the public.

Across these examples, Rennie argues that the science students learn at school should enable them to become scientifically literate citizens. This is promoted by students experiencing explicit connections between science in school and science outside of school. In other words, Rennie advocates science learning that is made meaningful through its connections with science beyond the classroom. She suggests that knowledge that is meaningful to students has the potential to be more useful to them than strong, disciplinary science knowledge, and that such knowledge empowers them to become more active participants in their world. Importantly, there are many ways in which the development of relevant knowledge might be fostered. While Rennie's chapter outlines three large-scale, funded initiatives, she also discusses the value of connecting with informal science education providers (e.g., museums) as well as local community projects, and sometimes global ones, such as GLOBE (Global Learning and Observations to Benefit the Environment).

The theme of connecting with the wider community is picked up by **Bronwen Cowie and Elaine Khoo** in chapter "Children Learning Science in and for a Participatory Culture". Like Léonie Rennie's chapter, this chapter is also structured around three case studies. These case studies are used to explore ways in which a "participatory culture" might be fostered with young learners of science—a culture where there is a focus on community involvement and contribution. The case studies also highlight the opportunities provided by ICTs to support the development of a participatory culture.

The first case study focuses on 10 and 11 year old students investigating rock origins in a local river, and Masters students from the nearby University meeting with the class and subsequently contributing to online discussions via the students' blogs and class noticeboard. The second case study is an example of a citizen science project where students tagged and released Monarch butterflies as part of a national monitoring and conservation project, logging their information into an online database that also linked them to a wider community of interest. In the third case study, 6 and 7 year old children shared their learning about stars and constellations, day and night, seasons, and shadows with their families. Deliberate efforts were made to foster this communication, including an afternoon tea to introduce the parents to the learning, the use of 'Home Learning Books', and via the class website. In addition, the class in New Zealand teamed up with a class on the other side of the world, in Austria, to share and extend their learning. For example, both classes were intrigued at the differences in time zones, seasons and star constellations, and the teacher considered that these interactions gave added purpose and context to the students' learning. Across all three examples Cowie and Khoo highlight the value of students having opportunities to enact a science identity grounded in sharing what they are learning with other interested communities—in the case of young children, their peers and families; for older children this can include community groups as well as science experts.

Brian Matthews focuses on the emotional engagement of students in their science learning in chapter "The Elephant in the Room: Emotional Literacy/Intelligence, Science Education, and Gender". Taking the position that emotions play an important role in learning and require explicit attention in the classroom, Matthews argues that students need to engaging with emotions in their science lessons if they are to develop a personal response and a positive emotional connection with science education. He goes on to suggest that girls in particular are likely to relate better to science education if it is seen to incorporate emotions, values and social contexts. Furthermore, Matthews argues that science itself is an emotional endeavour: "The impetus for science is to begin with ideas and passion and end dispassionately. However, the emphasis on the 'objective' summary can hide the social and emotional parts that occurred within the process of science inquiry."

Matthews provides an example of how emotion can be explicitly considered in science education. First, students were placed in multi-ethnic groups comprising both boys and girls, and required to work co-operatively on a science task. They subsequently consider their emotional responses to the task, guided by a series of questions such as: *Did you say what you wanted to say? After talking, did you change any of your views? How did you feel towards other members of the group who held very different views to you?* A small research study using this approach indicated that not only did the classroom culture change, but students became aware that science learning involves social and emotional dimensions. There were also indications that participating girls were as likely as boys to continue with science. It is not difficult to imagine how emotional participation might be further embedded and valued by making emotional responses more explicit—if and when science teachers recognise the contribution this can make to students' science education experiences.

Taking a slightly different focus, **Shirely Simon and Paul Davies** present examples of learning experiences outside the classroom to foster students' emotional, behavioural and cognitive engagement with science learning. Their chapter, "Initiatives to Prepare New Science Teachers for Promoting Student Engagement", outlines two initiatives that they use at the Institute of Education, London, to introduce pre-service teachers to creative possibilities for engaging students in science learning. Picking up on the theme of identity, introduced by Cowie and Khoo, Simon and Davies argue that "Designing learning experiences that are engaging for school students involves providing motivating experiences that support the development of a personal identity with science and that help them to recognise relevance in what they are learning". Throughout their chapter, they therefore promote the importance of paying attention to the affective agenda for science education, and their examples demonstrate an explicit focus on issues of student motivation, relevance and identity in their programme for pre-service science teachers.

In their first example, Simon and Davies outline the requirement for student teachers to plan a range of activities at Kew Gardens and the Science Museum, London, and then facilitate the activities at these sites with collaborating schools. Importantly, Simon and Davies note how the process changes the student teachers' perspectives on what is important in terms of the learning experience, and the special significance of the learning environments and the opportunities they afford. The second example highlights the importance of student teachers having opportunities to explore ways in which emerging digital technologies can be used to engage students in science learning, and the new opportunities for learning that such technologies offer. In particular, they point out the need for student teachers to think not only about the technology, but also to closely link this with their intentions for students' learning. Simon and Davies conclude their chapter by arguing for the value of ongoing teacher development through action research. Consistent with the theme of student engagement running through their chapter, they observe that the science teachers often choose to focus on an aspect of student engagement for their postgraduate investigations.

The theme of engagement is picked up again by **Cathy Buntting and Alister Jones** in chapter "Futures Thinking in the Future of Science Education". They draw on their previous work in the area of futures thinking in science education to demonstrate the use of a futures thinking framework to engage reluctant junior secondary students in thinking about science. This futures thinking framework includes five components—understanding the current situation, analysing relevant trends, identifying drivers, exploring possible and probable futures, and selecting preferable futures. In addition, a sixth component—underpinning science—was introduced to ground students' discourse in possible futures related to *scientific* developments. Using the framework with a class of mixed ability 13 year olds, they demonstrate the potential of the framework to engage these students in thinking and talking about science. The incorporation of futures thinking in science education continues to be relatively un-researched area, and this chapter contributes to the field by demonstrating the potential of the futures thinking framework to explore a range of different topics, and how it supports a pedagogy of transaction.

Amy Seakins also considers issues of engagement in chapter "Revealing Questions: What Are Learners Asking About?". Her premise is that asking questions shows curiosity and interest, and is an indicator of active learning. Building from this premise, Seakins argues that exploring the questions asked by learners can reveal much about the learner and the learner's understanding, attitudes and interests. An emphasis on learner questions, whether in school science or informal science learning, such as at museums or in online forums, also brings the learner to the forefront of the experience and has implications for the ways in which learners can shape and help develop their educational experiences. Reporting on a case study with A-level biology students (16–18 years of age) and adult visitors to the Natural History Museum, London, Seakins demonstrates how paying attention to participants' questions can shape the interactions that occur, and even support a more sustained, long-term interest in a particular aspect of science. She also raises the possibility that tracking learners' questions over a period of time could give valuable insights into learning progressions. From the learner's perspective, being supported to ask questions that relate to their own interests and motivations has the potential to widen the relevance and scope of their science learning, whether in the classroom or beyond.

Again picking up the theme of student engagement and pressure on science education to change in the face of the apparently changing nature, interests and needs of learners, **Neil Selwyn and Rebecca Cooper** explore the affordances of contemporary and possible future digital technologies in chapter "The Potential of Digital Technology for Science Learning and Teaching—The Learners' Perspective". Importantly, the chapter opens with a note of caution: despite the relentless hyperbole surrounding educational technology, there are few tangible indications that significant technological shifts are actually taking place on a substantial, system-wide basis. This does not deny that digital technology has much to offer. For example, digital technologies have potential to provide individual students with enhanced freedom from the physical constraints of the 'real world'. This includes overcoming barriers of place, space and time; offering access to experiences and data that would otherwise be inaccessible; and supporting socially-contextualised forms of learning and wider access to expertise and co-learners.

Caution lies in observations that students' actual uses of digital technologies remain rather more limited in scope than descriptions of the empowered 'digital native' suggest; students do not necessarily have an innate expectation or even desire to be constantly using digital technologies in their formal education experiences; and it is the science itself that needs to be motivating and engaging, rather than the mode of delivery. Even 'new', emerging technologies poised on the educational horizon—3-D printing, augmented reality, holographics, big data—will not in and of themselves revolutionise science education—although they could conceivably garner increased situational interest. Selwyn and Cooper conclude that while digital technologies will be an important part of science teaching and learning in the near future, more profound, system-wide shifts are needed to address deeper issues of learners' social and cultural disengagement in school science experiences.

In chapter "Facilitating Change in Science Teachers' Perceptions About Learning and Teaching", **John Loughran and Kathy Smith** explore the importance of ongoing professional learning opportunities for science teachers if they are to become initiators of change within their schools. The programme they outline, the Science Teaching and Learning (STaL) project, is an intensive course spaced across the school year, with 5 days of workshops and ongoing in-school support from a facilitator. The pedagogical purpose is to promote critical reflection and explicate personal understandings of effective school-based science education leadership. There is a specific emphasis on teachers beginning to notice what they say, what they value, and what they actually attend to in their practice. In the fifth of the workshop days, participants write a case study of their experiences, and all of the cases from each year's cohort are published as a book. The cases suggest that as a result of their learning experiences in the programme, participating teachers begin to think differently about their science teaching, they trial alternative approaches and they recognise the impacts of these approaches on students' science learning. As one teacher reported, "STaL … has enabled me to shift my focus from, 'What am I teaching?' to 'What are they learning?'" Through this programme, therefore, participating teachers begin to see their students' learning differently. This, in turn, encourages them to continue to refine their teaching—focusing on the students.

The chapter makes an important contribution to the book by highlighting the potential of intensive in-service professional learning for supporting teacher change in a changing educational context, referencing Goodridge-Kelly's (2010) salient observation that "[t]he demands of a changing society in many ways require very different approaches than the schooling we experienced as teachers, including the ways we were taught to teach" (p. 82). The chapter also points out the challenges that teacher change can pose for students (and indeed the wider community), who may for a range of reasons prefer the 'status quo'. However, as noted by Loughran and Smith, some changes—while initially uncomfortable and demanding—might actually lead not only to greater student engagement in and ownership of their learning, but open up science as being a more dynamic field of study, open to critique and further refinements.

A Final Comment

Léonie Rennie begins chapter "Making Science Beyond the Classroom Accessible to Students" of this volume with the premise that "the science students learn at school should enable them to become scientifically literate citizens, irrespective of what their future career ambitions may be". We could well have begun this introductory chapter with the same sentence—the essence of this book is our shared belief indeed that "the science students learn at school should enable them to become scientifically literate citizens, irrespective of what their future career ambitions may be".

A small number of themes that recur through the remaining fourteen chapters point to clear needs for science education if this view is to be realised. First, there is urgent need to reconsider both the fundamental forms of science that are the central pillars of the school curriculum so that these have some relationship to the foci and nature of science in this 21st Century, and the forms of learning of that science that are promoted and rewarded in school science. Second, school science needs to accept and embrace the powerful and multifaceted ways in which informal learning of science occurs. Third, curriculum and pedagogy need to accept that learning is both personal and social, and involves emotion. Fourth, students have much to teach us about the kinds of science learning that they find relevant and engaging, and their questions and interests are worthy of their teachers' attention.

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Learning for a Better World: Futures in Science Education

Michael J. Reiss

O, I am educated
For I have been told so –
You'd really be surprised, my dear,
At all the things I know.

When I was twelve years old, I learnt
How to add a to b,
And how the Romans say "I love"
And when the French say "thee".

And I learnt how the tundra
Behaves up in the North
And all about the prairies
And ships in the Firth of Forth.

And I was taught how Jesus
Had come to save my soul,
And all about the Pyramids,
And how to play in goal.

When I was a sweet fifteen
I learnt about the dead,
I learnt how when an acid's near
A litmus paper's red.
…
O yes my eyes are gentle;
And yet my mind is quicker,
For I read eleven hours a day
And my specs are getting thicker.

And though my smile is kindly
My teeth are rotting in my head,
And though my thoughts are up aloft
My lower half is dead.

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O what am I becoming
    Who is so brilliant?
Shall I become quite famous?
    Sometimes I think I shan't.

Sometimes I think that you, sir,
    Have killed your lovely duck,
And I shall lay no golden eggs
    For you to gloat and cluck;

I think your education
    Has maimed my better half
And has blown up my other side
    With cubic feet of gas. (Larkin untitled, in Burnett 2012, pp. 163–5)

I have argued for a number of years that science education, as currently undertaken in schools, is generally too narrow in its conceptualisation, its aims, its curriculum, its teaching and its assessment and that this is a major reason why it fails to engage many young (Reiss 1993, 2013). The aim of this chapter is to present a unified framework for understanding the scope, the purpose and the pedagogies of science education in the settings of school, out-of-school and lifelong learning. I attempt to show how science education can be reframed in a way that is true to science, true to education and engages with and takes seriously the interests and desires of learners, of whatever age.

It is increasingly evident that school science usually does not take enough account of student diversity, particularly with regard to how students learn science, where they learn it and what they find engaging about it. Gone are the days when it was quite exciting to do an experiment in a school science lab to see that plants make starch or that copper gains in mass when it burns. Nowadays, all of us are bombarded with science stories in the media. Indeed, the opportunities to access contemporary science are almost endless. I can look digitally through telescopes that give me live views of far-off galaxies and through web-cams that show me endangered birds of prey feeding their young in real time. How can schools compete? We need to acknowledge that much of where today's young people learn about science is already not in the classroom but via such as extra-school sources as the internet, in virtual reality, science museums, science centres, television, radio, magazines, films (fictional and non-fictional) and non-school books.

This is not, of course, to imply that there is not a central place for school science lessons in the learning of science. There is an urgent need for science education, both inside and outside of schools, to recapture a vision of how we can understand the physical world and how we should wisely and considerately make use of that knowledge. Schools have three great strengths in this regard: specialised teachers of science; specialised science equipment; and, other learners of science. None of these is restricted to schools but schools are distinctive in reaching the overwhelming majority of each cohort for substantial chunks of time. They therefore have the potential to enable all learners, including those with little science capital (Archer et al. 2012)—those who are never taken to science museums or centres, who have no adult relatives or friends with any connection to science and who are not encouraged to watch programmes or to read books about science—to benefit from science teaching.

I will begin by arguing that a rigorous science education needs to start with an examination of the purpose of education and then consider the place of school education for the learning of science, given that science learning also takes place before, outside of and after schooling. I will then exemplify these general considerations with specific reference to curricula and practices in science education at a range of ages. Admittedly, separate sections on pre-school science education, primary science education, secondary science education and lifelong science education—and I haven't even covered tertiary science education—can do no more than act as pointers. Hopefully, though, they help indicate that what I am proposing is feasible yet different from what happens nowadays in most sites of science learning.

What Should Be the Aim of School Education?

Before designing a school science curriculum, one needs to determine its aims (Reiss 2007). Immediately, one is faced with a choice—does one start with science or with education? Curricula exist in a wide range of forms and there are a number of ways in which they can be developed (cf. Kelly 2009). However, national curricula typically start with a list of subjects. They take for granted a dozen or so discrete school subjects and the knowledge they embody. It is subject requirements that get filled out. This approach has a number of consequences. For example, a subject-led curriculum, especially at secondary level, starts with, and so is necessarily constrained by, the availability of teachers capable of teaching certain subjects. More fundamentally, there is a general implicit presumption that agreement exists as to the purposes of school education without these purposes being critically examined anew.

An alternative to starting with subjects is to begin further back, with education and aims (Reiss and White 2013). To a certain extent this approach is closer to the continental European tradition of *didaktik* when it takes an approach to education based on *Bildung*—an education concerned with the formation of the whole learner through personal transformation. An aims-led curriculum has a fundamental advantage over the more usual, atomistic Anglo-Saxon approach to curriculum in that it can start with the needs and wants of students—both students as they live in schools and students once they have left their schooling behind. Another advantage of starting with aims is that if one doesn't, one finds that aims end up getting tagged on. For example, when the National Curriculum for England and Wales was first created in 1988, it had next to no aims to guide it. More recent versions have included lists of overall aims, but these have been tacked on to a structure already in place. Crucially, they do not generate that structure. John White and I have argued that that there are two fundamental aims of school education, namely to enable each learner to lead a life that is personally flourishing and to help others to do so too (Reiss and White 2013).

What Constitutes a Flourishing Life?

The notion that humans should lead flourishing lives is among the oldest of moral principles, one that is emphasised, for instance, by Aristotle in his ‘Nicomachean Ethics’. There are many accounts as to what precisely constitutes a flourishing life. A hedonist sees it in terms of maximising pleasurable feelings and minimising painful ones. More everyday perspectives may tie it to wealth, fame, consumption or, more generally, satisfying one’s major desires, whatever these may be. There are difficulties with all these accounts. Pleasure maximisation sounds great but provides a somewhat narrow conception of what it is to be human—cf. J.S. Mill’s famous “it is better to be a human being dissatisfied than a pig satisfied; better to be Socrates dissatisfied than a fool satisfied”. A problem with desire satisfaction as the sole arbiter is that it allows ways of life that most of us, for all that we value autonomy, would deny were flourishing, lives devoted to collecting milk bottles or viewing pornography, for instance.

A life filled with whole-hearted and successful involvement in a range of more worthwhile pursuits—such things as significant relationships, meaningful work, helping at a nature reserve, gardening, cooking, watching excellent films, being a member of an organisation that pursues worthwhile ends—is on a different plane. Most of us would consider that to be fulfilling. At the same time, nearly all of us in a modern society like our own presume it is largely up to each of us to choose the mix of relationships and activities that best suits us (certain family obligations are generally excepted from this generalisation, though less so than in the past).

A central aim of the school should therefore be to prepare students through their lessons and other activities for a life of autonomous, whole-hearted and successful engagement in worthwhile relationships, activities and experiences. With many of these—cooperative work activity, friendships and enjoying literature, for instance—it makes good sense to see that students gain first-hand experience. For others—things like mountaineering, composing symphonies, choosing to live an unmarried life, running a multinational company, walking on the Moon—imagined rather than direct involvement is likely to be more appropriate. This aim also involves acquainting students with a wide range of possible options from which to choose. With their development towards autonomous adulthood in mind, schools should provide students with increasing opportunities to choose among the pursuits that best suit them. Young children are likely to need greater guidance from their teachers, just as they do from their parents. Part of the function of schooling, and indeed parenting, is to prepare children for the time when they will need to, and be able to, make decisions more independently.

Equipping Every Student to Help Others to Lead Personally Fulfilling Lives

We want people to want other people, as well as themselves, to lead fulfilling lives. Such an aim is found in a range of moral philosophies, both religious and secular. Negatively, this means things like not hurting other people, not lying to them, not breaking one's word. Positively, it means helping others to reach their goals, respecting their autonomy and being fair, friendly and cooperative in one's dealings with them. Schools can reinforce and extend what parents and others in families do in developing morality in young people. Schools can widen students' moral sensitivity beyond the domestic circle to those in other communities, locally, nationally and globally. They can also help them to think about moral conflicts in their own lives and in those wider spheres. They can encourage students to reflect on the basis of morality, including whether this is religious or non-religious, rooted in human nature (Ridley 1996) or an invention of society (Mackie 1977). There can be a danger that this second aim can become nationalistic or be abused in a totalitarian state but good education can at least reduce the likelihood of this happening by encouraging students to develop the skills and disposition to be critical.

As future citizens, the great majority of students will contribute to the general wellbeing, as well as to their own, through work they undertake primarily after they have left full-time education. This activity will often be remunerated, though much of it, for example, caring for children or elderly relatives, may not be. As autonomous beings, students will eventually have to make choices about what kind of work to engage in. Schools should be helping them in this decision-making by developing their awareness of a wide range of vocational possibilities and routes into them, as well as their advantages and disadvantages.

Broad Background Understanding

There is an important link between the two major aims. Whatever we do in our lives that brings us personal benefit, or is intended to benefit others, takes place against a broad background of thoughts about the world we live in. Closest to home are thoughts about what sort of beings we are. We all grow up to believe, for instance, that our individual lives are finite, that we may or may not stay healthy, that the future has a considerable element of unpredictability (see Buntting and Jones, this volume). We all, bar sociopaths, come to see our lives as inextricably and positively bound up with the lives of other human beings. These perceptions cannot but influence the way we lead our lives.

Part of the task of education—at home and at school—is to help students to form this background that will colour everything they do. At a fundamental level, some of us will live by religious or other beliefs that give us answers to the deep questions, while others will live without such beliefs. But much of the background is less contested. Indeed, much of it will consist of well-founded scientific conclusions—about, for instance, the building blocks of life, our part in the ecology of nature and the social nature of humanity. This leads into the second part of this chapter, where I explore what an aims-based approach to curriculum design might mean for education about the sciences in school. I begin by reviewing current attempts to formulate aims for school science education.

Current Attempts to Formulate Aims for School Science Education

Many aims for school science education have been proposed (Reiss 2007, also see Fensham, this volume), though these are often implicit. A frequent aim of science courses has been to provide a preparatory education for the small proportion of individuals who will become future scientists (in the commonly understood sense as employed professionals). This aim has been widely critiqued on democratic grounds (e.g., Millar and Osborne 1998). After all, what of the great majority of school students who will not become such scientists?

Another aim is to enable ‘scientific literacy’. Although there has been a long-running debate as to the meaning of the term (e.g., Miller 1983), generally, scientific literacy is seen as a vehicle to help tomorrow’s adults to understand scientific issues (Gräber and Bolte 1997). The basic notion is that science education should aim to enhance understanding of key ideas about the nature and practice of science as well as some of the central conclusions reached by science. Perhaps to be included within this category is the argument that to be an educated person in the 21st Century is to understand something of science (e.g., Shamos 1995). This is the ‘science as culture’ argument; that science is as worth studying in itself, as are, for example, literature and the arts.

A further aim is that many science courses hope that as a result of what is learned, pupils both now and in the future, as adults, will be able to gain practical benefit from it. At its most straightforward this might be by entering paid employment that draws on what they have learned in science. Although, as noted above, most students do not enter such careers they too may still benefit individually from school science. For example, in most science courses, in countries round the world, it has long been accepted that one of the justifications for the inclusion of certain topics is that knowledge and understanding of them can promote human health. Such topics may include infectious diseases, diet, reproduction and contraception, exercise and the use of drugs (including smoking and alcohol).

Another, more mundane, way in which school science might help individual advancement is by providing what I have termed ‘science education for consumerism’ (Reiss 2007). This is the hope that school science education might, for example, help us choose the most appropriate technological goods (is it worth me paying x% more for a washing machine that uses y% less hot water?) or make broad decisions, for instance about climate change, on narrow criteria (where should I purchase my second home to minimise problems with rising sea levels or extreme weather events?). This is a sub-set of the more general and long-established argument that science education should be for public understanding (American Association for the Advancement of Science 1990; Millar 1996).

A further aim of school science education is that it should be for citizenship (Jenkins 1999). A ‘weak’ version of this approach consists of learning what a democracy is and the place that science plays in being an engaged citizen. A ‘strong’ version entails using such knowledge to bring about desirable change. This latter philosophy is closely allied to claims that the aim of school science education should be to effect social justice or socio-political action (e.g., Calabrese Barton 2001; Carter 2005; Hodson 2009). Calabrese Barton draws on feminist approaches to show that many of the students with whom she and her colleagues work, while seen in school as poor attainers in science, are actually perfectly capable of high quality science work provided they are given real choice in the science they work at.

It is evident that there are currently diverse aims for school science education. It is important, though, to emphasise that most teaching of school science proceeds on the assumption that such knowledge is good for students, without the precise aims having been thought through with any rigour and without the science curriculum beginning from such aims. Instead, science curricula generally begin with science. It might be thought that this is a sensible starting point but it leads all too often to disengagement as many students fail to understand the point of what they are learning (Reiss 2000; Schreiner 2006). I now outline how an aims-based approach to the curriculum that takes the notion of human flourishing as its core value might inform science education. Some might consider such an idea to be utopian; others that it is not sufficiently radical. As an evolutionary biologist I have a great belief in change but see change as most likely to result in sustained improvements when it is implemented incrementally. We can start with existing curricula and shift them appropriately. In any event, what is generally most important is how teachers teach. We want science teachers, whatever the ages of their students, to have a passion for science and a passion for education. Learners are often capable of more than their teachers presume.

Pre-School Science Education

Relatively little has been written about pre-school science education despite the importance this period clearly has for how each of us comes to understand the world. Nevertheless, there is growing interest in early years/emergent science, including a journal published since 2011: *Journal of Emergent Science*. A problem that bedevils many attempts to devise curricula for this age range (approximately 2–4 years) is that all too often such curricula are over-influenced by curricula for primary-aged children. Indeed, this is a common problem in education—that education for phase n is largely seen as preparation for phase n + 1. This approach results in a pernicious trickle-down effect where curricula for young children are partly determined by the needs of undergraduates.

So what might we want pre-school science education to seek to develop in young children? For one thing, we might want children to be encouraged to observe carefully and to explore what they see (Johnston 2011). The skill of observation is of value for a range of subjects beyond science, of course, but it is a key skill within science. Actually, the first time I can remember being encouraged to observe carefully in science was in a first year undergraduate practical session where we were undertaking a dissection of an unfamiliar fish (the head of a cod, from memory). The whole point of the exercise was that there was no textbook—unlike the drawings we did at school of histological specimens where our drawings were heavily influenced by the plates in such books as Bracegirdle and Miles (1971). For the first time in my life, so far as I can recall, I spent a sustained period of time observing carefully what was in front of me. While I have always considered myself 'bad at drawing', to my surprise, I found that my drawing of the bones of the head was rather better than my previous efforts at anatomical drawing.

Observation is closely aligned to listening, and at this age children can be encouraged to listen carefully and to develop (perhaps it is better to write 'retain') their ability to distinguish between sounds of similar pitch. The sorts of environmental education games where one closes one's eyes, or is blindfolded, and then attempts to locate the source of a sound without being heard oneself can make such learning enjoyable and personally challenging.

One would want children too to develop their scientific vocabulary. At this age, of course, such vocabulary is not specific to science and nouns like plant (to be distinguished from flower), water and ice, adjectives like heavy, light (in both its main senses) and dark, and prepositions like above, below, beside, near and far can all be learned or have their meaning refined or rehearsed.

At this age, above all, one would want learning about science to be closely connected to a child's family. One of the great problems with science, unlike, say, reading, is how high a proportion of parents, despite the efforts of occasional projects such as SHIPS (School Home Investigations in Primary Science) (Solomon and Lee 1993) presume that they can't undertake it with their children. Good pre-school science education can not only help young children in their learning but encourage parents to believe that they have a positive role to play.

Above all, one would want a child to begin to realise that s/he can playfully explore (interrogate) the material world. Objects differ in a whole range of observable features: their feel, their smell, the extent to which they keep their shape and so on. Such features can be investigated and begin to be related to the uses of the objects. Teachers should listen to the questions that pre-school children ask, whether such questions are asked in words or actions.

Primary Science Education

Until the 1960s, primary science in schools hardly existed other than as natural history or nature study. Since then, primary science has taken off across the world. Despite, though, the large amount that is written about primary science, insufficient theorisation has yet been undertaken as to what should be taught in primary science. This issue is particularly important as in practically every country only a very small minority of teachers of primary science have deep subject knowledge of science. There is therefore a real danger that certain topics (e.g., forces, the phases of the Moon) are taught when the teachers themselves have substantial misconceptions about them.

This is neither to denigrate primary science teachers nor to imply that teachers, whatever the age of their students, must have perfect knowledge. But we know, for instance, that quite a high proportion of physics graduates find it difficult consistently to apply Newton's first (If there is no net force on an object, then it continues in a straight line at constant speed) and third (When a first body exerts a force F1 on a second body, the second body simultaneously exerts a force F2 on the first body equal to −F1) laws of motion, let alone truly to have internalised them (diSessa 1993). Such teaching is surely better left to secondary school when: (a) students are more likely to be taught by specialist physics teachers; (b) students are more likely to be able to cope with the abstract reasoning that is either required for understanding such topics or, at the very least, greatly facilitates such understanding (cf. Shayer and Adey 1981).

Related to this issue is the problem of putting into the primary curriculum material that is better left to the secondary curriculum because of the availability there of more specialised equipment. In England and Wales, we have recently completed a rather bruising experience in which a new National Curriculum has been devised, in many ways the most substantial revision since the original National Curriculum was introduced in 1989. A pre-occupation of the government that England must have the best education system in the world led in the initial drafts, drawn up by civil servants with little or no experience of school teaching, to a principle in which any topic that featured in a world-leading jurisdiction (as defined by its position in PISA league tables) at age x had to appear in England at age x or earlier.

This resulted, for example, in an initial requirement that Year 6 pupils (10–11 year-olds, still at primary school) should know about sub-cellular components. The only way this knowledge could be learned in most primary schools, that generally lack classroom sets of high quality microscopes, would be from textbooks, computer simulations, videos or suchlike. Valuable as all these are for learning in science, there is little to beat being taught, as students routinely are early in secondary school, how to use a microscope with a range of objective lenses so that one can see for oneself such organelles as the nucleus and chloroplasts. Fortunately, the science and science education communities put on a relatively united front and the final version of the National Curriculum, while far from ideal, at least had such problems ironed out.

More positively, primary science can build on and challenge children's developing understandings of the scientific world, that is, it can help children develop their skills of enquiry (e.g., Rinke et al. 2013) and it can begin to help children understand some of the Big Ideas of science (Harlen 2010, 2011). Most primary schools do not have school laboratories and this can be a great asset. Rather than striving for a watered-down version of secondary science, teachers of primary science can help pupils connect what they are learning about science in the classroom with what goes on outside of school (see Rennie, this volume), whether in everyday situations, for instance in the home or a park, or in specialised settings such as a science centre or a nature reserve. An advantage primary teachers have is that they typically teach a wide range of subjects. They can therefore help children to see how science skills and knowledge can be of value in other school subjects, just as they can help children see how skills and knowledge learnt in other school subjects can be of value in science.

Secondary Science Education

The five or so years of secondary schooling (round about years 7 to 11 in many countries) are a crucial phase of school science education. How does a focus on flourishing shape the curriculum and pedagogy at this stage? I will concentrate here on two considerations: first, the world of work; secondly, diversity among people.

The World of Work

In many countries one of the arguments for according science a major place in the secondary school curriculum is its importance for modern society, including the world of work. STEM (science, technology, engineering and mathematics) graduates typically enjoy above average salaries and it seems to be the endless lament of Western governments that we aren't producing enough university STEM graduates (European Commission 2004; National Academy of Sciences 2007).

How, though, should one decide, for such possible employment purposes, how much and what sort of science students should experience when at school? The first principle, surely, should be to provide sufficient material for students to be reasonably well informed when deciding whether or not to continue with the subject for career reasons once it becomes optional. This principle does not point to a science curriculum providing comprehensive coverage; science teaching could include, among other things, what John White and I have referred to as 'taster-option' courses (Reiss and White 2013). Furthermore, a significant proportion of this material should be 'applied' so as to indicate the uses to which such knowledge is put. Indeed, not only should it be applied but courses should indicate how people make use of it in employment.

To give just one example, when teaching the topic of plant nutrition (sadly, not a topic that many students presently find that interesting), one might start by looking at how an arable farmer decides how much, if any, fertiliser to apply and when (which depends on such things as the stage of crop growth and the weather). This approach would soon get into issues about organic and small-scale as opposed to agrochemical farming, the economics of farming and the values people attach to their food as well as to more mainstream scientific matters such as the absorption of minerals by plants, the transport of such minerals in the xylem and their use in the synthesis of organic compounds.

However, despite attempts to introduce more applied material into a number of science courses, such material, and not only in science courses, is often considered of lower intellectual worth than ‘pure’ knowledge (Pring et al. 2009). Such an attitude, aside from being narrow-minded, is probably counterproductive; some students are attracted by learning material that they can see might lead to satisfying employment. In any event, the relationship between pure and applied science is not simply one-way, in that pure knowledge leads to applied knowledge. As historians and sociologists of science now accept, the relationship is more complicated than that. In some cases, advances in the applied sciences lead to advances in pure sciences (Gardner 1994).

Diversity Among People

People differ from one another greatly. And yet, from school science, one might think we are all the same bar our age, the fact that some of us are male and others female and some of us have medical conditions, such as cystic fibrosis or sickle-cell anaemia, or other natural variations, such as blue eyes or attached ear lobes, that result from single gene variants.

The reality, of course, is that humans of a given age vary greatly for reasons to do with inheritance, our upbringing, the environments in which we find or place ourselves, the interactions between our inheritance and these environments, our choices and chance. In ignoring most human variation and the reasons for it, school science curricula give the impression that such differences are uninteresting (which they aren’t), unimportant (which they aren’t) or too difficult for school study—which they generally aren’t and, anyway, school science education should serve as an introduction to interesting and important issues; as the next section of this chapter emphasises, science education doesn’t cease when students leave school.

In some cases, I suspect that school science curricula fail to deal with issues where diversity exists—for instance, human intelligence—because of a fear that raising such matters may cause problems. However, not raising them is likely to cause more problems. I suspect that students, for example, are more likely to believe that intelligence differs between men and women or between ‘races’ if they have not been taught critically to examine what is meant by intelligence and how it may be measured and used. One reason why teachers may be reluctant to include such material in the classroom is that the pedagogy required may be unfamiliar to them. However, teachers can learn to teach in ways that take serious account of socio-cultural issues, especially if they are convinced of the value of such teaching for their students. Another reason for teacher reluctance is that such teaching may require up-to-date content knowledge. There are many ways of dealing with this issue, including time for professional development and 'flipping' the science classroom so that the teacher is not seen as the reservoir of all knowledge—a change that makes all the more sense given the increasing use of digital technologies by students (see Selwyn and Cooper, this volume).

For a final example, consider how human sex is usually taught in school biology. It is dealt with as being entirely unproblematic: females are XX, males are XY, period. The reality is rather more complicated—and a lot more interesting. Sex cannot always be reduced to chromosomes. More and more students know about transgender issues and intersexuality is more common than generally supposed. Perhaps the simplest approach for biology teaching is to see maleness and femaleness as lying on a continuum (Reiss 2005; Scholer 2002). Done well, such teaching can provide students with a better scientific understanding of the roles of chromosomes, hormones and the environment in the determination (rather, under-determination) of ourselves. It can also help considerably to aid human flourishing.

Lifelong Science Education

In many ways the implicit assumption of school science curricula seems to be that once you have left school your science education ends unless you continue, for example at university, to take conventional courses in one or more of the sciences. And yet this is surely not an assumption made of curricula in English, in music, in the arts and in modern foreign languages. Here there seems to be more of a belief that the role of schooling is to prepare each of us for further study in these subjects. One studies *Jane Eyre*, *Lord of the Flies*, *The Rime of the Ancient Mariner* and *The Waste Land* at school in England in the hope that one will be inspired to read novels and poetry for the rest of one's life.

The reality, of course, is that out-of-school experiences have always been important for learning about science and they have never been more important than nowadays. There has been a veritable explosion in the media through which science can be learned (Fenichel and Schweingruber 2010, also see Shanahan's chapter, this volume). Interestingly too, disciplines, such as history, that once had rather distinct methods for establishing their knowledge claims are increasingly drawing on science to establish what happened. To give just one example, analysis of the teeth of the majority of the crew on board the *Mary Rose* reveals that they were not English, instead being of southern European origin, possibly Spanish prisoners of war or mercenaries (Ghosts of the Mary Rose 2008). This discovery raises the possibility that the distinctive failure to close the gun ports when the ship made a sharp turn in a battle with the French in July 1545 may have been because many of the crew did not understand orders given to them which might also explain the final words of the ship's commander, Admiral George Carew, that his men were "knaves I cannot rule". Archaeology is an example of a discipline that is being revolutionised by the application of science.

But there is more to lifelong learning than learning accepted science. More and more people are contributing to science. In some cases such contributions sit outside mainstream science. Creationist science is an obvious example but so too is what can be termed 'Outsider Science' (à la Outsider Art). Many people seek meaning in their lives and use science to help construct a world that makes sense to them and helps answer their questions, whether practical or existential. As I write this, there is a wonderful exhibition on in London at the Hayward Gallery called *The Alternative Guide to the Universe* (Rugoff 2013). Here, for example, we find Philip Blackmarr's drawings which communicate his theory that matter is made up from minute octahedrons that, when fitted together, model the properties of protons, neutrons and other subatomic particles. Here, too, we find James Carter's life work *The Other Theory of Physics* in which, *inter alia*, he argues that gravity does not exist. Instead, matter expands infinitely. Thus, an apple does not fall to the earth; the earth rises up to meet it. (For further examples of fringe physics, see examples on the internet or Wertheim 2011.)

However, many of the contributions made to science by adults and others outside of school accord with mainstream science. Actually, many disciplines—such as astronomy, botanical recording, entomology, ornithology and palaeontology—have long relied on amateur scientists to locate and identify objects. While it might be thought that the increasing professionalisation of science would have rendered such help obsolete, it has not been the case. Indeed, new technologies, not to mention the insatiable demands of science, far beyond the capacities of even the present expanding professional cadre, mean that today's amateurs are as important as ever. Hence the rise of 'citizen science', which enables members of the public to engage in real science, for example, by searching for astronomical objects, identifying organisms in local environments and tracking phonological responses to climate change. Hence, too, the increasing realisation by many funding bodies, for example medical charities, that the quality of the research undertaken by professional scientists can be markedly enhanced by taking seriously the interests and contributions of knowledgeable amateurs. As yet, though, school science seems to be taking virtually no notice of such developments.

Conclusion

Science never stands still. Its very nature is to question and advance. School science, though, too often appears as a living fossil. If we want today's and future generations of school learners to engage with science and retain a lifelong interest in it, we will need to reform school science so that it is true both to science and to education and so that school science is seen by learners to be relevant to who they want to be, to their developing identities. My contention is that a school science that takes flourishing and student diversity seriously can contribute to this change. If students are to wish to continue to choose to study science once it is no longer compulsory, they need to find a meaningful connection between the world of science and their own interests (Rodd et al. 2014).

School science education needs to be open to new ways of learning. For many, the promise that new technologies will transform learning in schools has proved to be hype (Selwyn 2011, also see Selwyn and Cooper, this volume). And yet we are still in the early days of these new technologies. New technologies will change how science is learned, and have the potential to enable greater student control over their learning (e.g., Hole-in-the-Wall 2009). Pedagogies, too, need to change. After all, it is well established in many countries that it is school science education, not science, that many learners are rejecting (Bøe et al. 2011).

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Connoisseurs of Science: A Next Goal for Science Education?

Peter J. Fensham

> *In a democracy, you have to assume that the people are capable of reasoning to a sound conclusion if they are adequately informed.*
>
> (John Dewey)

Introduction

In this chapter a case is argued for installing trust in science as an important central learning goal for school science education. Learning how and when to trust science will meet a major public need that 21st century citizens now have, since they are increasingly confronted by socio-scientific issues (SSIs) about which they have not, in their earlier science education, been prepared to make judgments. Furthermore, recent evidence from a number of countries has reflected public trust in science as subject to large ups and downs, indicative of a flimsy, rather than an informed basis.

Trust in science was raised as an issue in Inarticulate Science, the remarkable book by Layton et al. (1993) that reported some case studies of citizens in situations for which they had an urgent need to know some related science. Although the science in these cases was well-established, its acceptance on trust was not automatic, largely because of its arcane language of presentation. Irwin and Wynne (1996) also referred to trust in science as a factor in their further case studies of public involvement with science issues. Since then, researchers of the public understanding of science have continued to refer to trust in science, but the focus of their studies has moved to the risk and risk assessment associated with the scientific findings (Christensen 2009; Christensen and Fensham 2012). The concept of risk

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and its assessment has also been central in the deliberations among international science bodies since 1996 that led them to formulate as a principle of responsible science The Precautionary Principle: “When human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain, actions should be taken to avoid or diminish that harm” (UNESCO 2005, p. 14).

Norris (1995) was, I believe, the first science educator to raise trust in science as a learning outcome for school science. His case was based on Hardwig’s (1991) claim that trust is essential within the teams of multi-disciplinary scientists now needed for investigating today’s scientific problems. Indeed, Hardwig suggested that trust among scientists may now be more fundamental than evidence, since often “none of the team is personally able to vouch for the work of them all” (p. 695). When the evidence from others in the team cannot be trusted, the advancement of the science is disrupted.

Norris (1995) sets trust in science as an important learning outcome within a set of three broad goals he formulates for the science education of future citizens: learning science content, learning about science (its philosophical basis, its historical progression and its social processes) and learning to live with science as an important knowledge source for society. The new learnings for school science that are argued for in this chapter resonate well with these three goals for a science education that treats school students as the citizens of tomorrow. Norris goes further in characterising his successful science learners as acquiring the intriguing quality of intellectual dependence. The importance and appropriateness of this unexpected quality became ever clearer to me as I developed this chapter, and I return to argue for it later in the Discussion.

Norris’ (1995) paper inspired Kølsto (2001) to explicitly include trust in science as a variable in his study of 16-year-old Norwegian students dealing with the socio-scientific issue of power-line transmissions and the possible link with childhood leukemia. A number of aspects of trustworthiness were problematic for these students and they used several strategies to decide whom to trust that were mostly based on superficial contextual information. Kølsto recommended that the sources of scientific information need to be more emphasised in student learning, but little follow up research seems to have occurred.

The analysis of the realities about public trust in science that are discussed in this chapter led me to an awareness of how the emphases in current science curricula are failing to equip students (future citizens) with a firm background of knowledge for putting or not putting trust in science. From this analysis it became possible to suggest a number of new learnings for school science that could better equip the next generations of the public to be more assured about science.

Two phrases kept coming to mind. The first, the strengths and limitations of science, was common in much earlier lists of the learning aims and objectives for school science. Its use implied that students should learn which questions science can answer and which ones it cannot. It is rarely included in more recent curricula, despite the greater attention that is being given to the nature of science (NOS) in science education research, and in science curricula, to how science functions.

The second phrase is Connoisseurs of Science, a quite unexpected term to be applied to students emerging from school science. It was used by Isabel Stengers of Belgium in her plenary address to the ESERA Conference in Lyon, France, in 2011. This phrase was her aspiration for what the university students in her classes on Science and Citizenship might have learnt at school about science in relation to real world contexts, compared with the large quantity of context-free content knowledge they did acquire. The students, whether enrolled in science programmes or more general ones, perceived the "and" in her course title as an "either/or".

My attraction to the word "connoisseur" as a description of the student outcome goals for this chapter is because it suggests a person who has acquired the appropriate knowledge in a particular field to be discerning about aspects of it, and to make judgments about them. This is the type of science learning I am advocating in this chapter. Furthermore, I see this learning as being basic to the digital literacy Shanahan (this volume) discusses, and that its human and social features would contribute to Reiss' (this volume) better world futures, his educational goal for science education. It may also have some pertinence to the question about forms of science education that Lancaster et al. (this volume) raise.

A Science Education Responsibility

At this point, it may be helpful to explain my personal awakening to trust in science as a learning outcome for school. At the end of 2011 I was alerted to it as an issue in the annual letter from a long-term friend:

> I've been quite depressed for most of the year. I've been teaching science all my life in high schools, and now I find scientists not being trusted, and their findings being dismissed as alarmist or as just opinions. Where and how have I gone wrong?

This paragraph jolted me to take the issue seriously and to be reminded, for example, that in 2007 a comfortable majority of Australian citizens accepted the science finding that global warming is a human-induced phenomenon, but by 2011 this number had become a declining minority. Also I remembered that the first scientific report on the sustainable water needs of the Murray Darling river system was publicly burnt in the city of Griffith, NSW, with politicians and local authority officers silently looking on.

I found myself, as a science educator, also asking my friend's questions in the hope that answers to them might emerge that would lead to school science better preparing students in our science classrooms to regain trust in science or, better still, to be equipped to discriminate in a more informed manner between trust and distrust. To answer my friend's question of "Where and how have we gone wrong?" it was necessary to establish the extent and nature of the claim of distrust If it is real, its generating causes needed to be assessed and considered in relation to the current emphases in school science. The science education community could then move from the "where" and "how" of our "going wrong" to identify and suggest alternative practices of teaching and learning science for all students at school as future science-informed citizens, including those who become future science-based professionals.

Extent and Nature of Distrust—The Role of the Media

From early 2012 I began to collect and systematically read items in the public media that related to trust or distrust in science in the Australian context. Two very different types of reports were found. The first type (Type 1) were reports about socio-scientific issues and in Australia in that year global warming and the Murray Darling river system commanded the majority of the media's attention. Other issues about health, the environment and communications also received attention—vaccination of children, obesity, sugar and salt in diet, comparative speeds of internet response, endangered species, overfishing, etc. For each of these topics there were reports of both trust and mistrust of the science. A similar litany, I believe, could be found in the media of other developed countries, since some of these reports were about their issues.

The reports of the second type (Type 2) were of a different order and quite a surprise. These were periodical, short reports of science findings from both local and overseas sources that claimed to have quite explicit human and societal implications. These reports were, it seemed, feeding a public gullibility, or an unjustified trust in science. Type 1 reports are now discussed in detail with just a modest reference to those of Type 2 to identify the science issue they involve.

Type 1 Socio-Scientific Issues

Science's 21st Century Challenges to School Science

Elsewhere I have drawn the attention of science educators to the fact that, at the beginning of the 21st century, a number of national and international scientific bodies issued lists of what they saw as "Grand Challenges and Opportunities" (Fensham 2012). The issues in these lists challenge scientists because they are all ones that cannot be properly understood and resolved without the contributions of science. Like the Australian issues to which I have just referred, all are multifaceted in their scientific nature and so require inter-disciplinary scientific collaboration for their investigation. They are, furthermore, not solely scientific issues since responsive action on them involves social attitudes, economic consequences and political will.

Because of their consequences for the public, nationally and internationally, these socio-scientific issues need to be included (despite their complexity) in school science that takes seriously, as most curricula claim, the importance of science and the needs of students as future citizens. This inclusion will be no simple task since their inter-disciplinarity and multi-knowledge character contrasts starkly with the mono-disciplinary structure of most school science curricula, and the separation science teaching and learning in school has from other areas of the whole curriculum.

The *Grand Challenges* for 21st century science and technology, and their Australian counterparts, are interesting examples of the current stage of the historical sequence of relationships between technology, science and society that Gibbons et al. (1994) outlined. Initially and for a very long period, technology set society's agenda. Then from the later 17th century, science increasingly set both society's and technology's agenda, until now, in this century, there is much evidence that society is setting the agendas of both science and technology.

The political will for resolving these complex 21st century issues needs to be of such a hitherto uncommon kind that a number of prominent scientists view the future in a very gloomy way. Martin Rees (2003), while President of the Royal Society, suggested in *Our Last Century* only about a 50:50 probability for the conjunction of science, a supportive public climate, and the political will. Australia's scientific hero, Frank Fenner (2010), also predicted that, as a result of the population explosion, unbridled consumption and international failure to curb greenhouse gas emissions, *Homo sapiens* will become extinct, perhaps within 100 years.

These gloomy views are linked to another common aspect of the 21st century socio-scientific issues, namely, that the emerging science findings about them, if acted on, will lead some sectors of society to experience short to medium term negative social and economic consequences. The negativities associated with the issues to which I have referred above add an interesting engagement challenge for science teachers and their students, who hitherto in the second half of the 20th century could point to science offering all members of the public the potential, and many the actuality, of enjoying positive new technology-based life styles.

Media Reporting of Type 1 Science

A consequence of the shift to society determining the agenda of science is that the public media have become interested in the opportunities that emerge to influence the public about science matters. In Australia, our media's presentation of the above issues very commonly presents differences between scientists in a combative or adversarial manner—very different to the evidence-based arguments that occur within the science community before a conclusion is reached. The collegial procedures for intra-science arguments are not explained, nor is the practice of peer-reviewing publication. As a consequence, and because of the shortness of most of these media's reports, substantial scientific findings tend to be presented as opinions rather than evidence-based conclusions. For example, the uncertainty in "the Earth's temperature will rise between 1.5 and 4.5 °C from a doubling of carbon dioxide concentration in the atmosphere" is confused with the findings "not being known" and thus being inconsequential. The complexity of the factors involved in the scientific models and the possibility that different models lead to different conclusions are used to belittle the significance of the findings.

Interviews with a consensus scientist (a scientist who presents the view of the science community) are often reduced to zero worth because the time-scales in the science are outside the interviewer's expectations. Likely serious consequences that will only emerge over the rest of this century, are dismissed as of little importance for today's public. Likewise, they are gladly set aside by politicians elected for 3- or 4-year terms.

The single voice of a contrary scientist is given equal space by the media in order to provide what is described as "balance", as if such a single dissonant voice is a balance to the considered consensus findings of the body of scientific expertise behind the official reports. An apparently discrepant finding, or the use of a different starting point to determine a trend in a variable, are accepted without questioning their credibility or the rigour of their scientific establishment.

As if their opinions carry significant weight, public figures such as an Archbishop, an ex-Prime Minister, mining magnates and spokespersons from conservative social research institutes have also been given Australian media exposure to express doubts about science findings, at times quoting the contrary science findings. It has been rare, apart from *Letters to the Editor*, for corresponding lay-persons who are supportive of the consensus science position to be involved, since they would not serve the media's interest in controversy as news.

I am aware that my discussion of the media in reporting science has not expressly included the internet and its associated forms of social media. Shanahan's chapter (this volume) fortunately helps to fill this omission. The learnings about trust in science are obviously essential for the fruitful exchange of science findings via digital media and, in turn, would gain wider recognition among young people and the public through such sharing.

Sources of Doubt About Type 1 Reports—Fostering the Opposite of Trust

Scientific findings about SSIs like climate change and the Murray-Darling River Basin from the consensus scientific groups such as the IPCC (Intergovernmental Panel on Climate Change), the Australian Climate Commission and the Wentworth Group of water research experts are reported in précis form in the Australian media. Media journalist, editors and talk-back hosts have then commonly juxtaposed these reports with comments from a individual Australian or international scientist who has alternative and confusing interpretations of the same issue. This has the effect of raising doubt about the official reports. That the expertise of these alternative scientists is often in a different field of science, or that the scientists in question have an association with bodies in USA such as the Heartland Foundation is rarely made clear. Furthermore, the connection between this or similar foundations and some Australian politicians who express doubts about the scientific positions is also not commonly reported.

A check on the Heartland Foundation and its operations reveals that it provides funds for consulting scientists and that it and a number of similar organisations are financially supported by large donations from interested companies that view government regulation with respect to a number of science and technology issues as a threat to their continuing profit. For example, The Royal Society (2006) in Britain found that EXXON Mobil had distributed nearly $US43 m to 39 groups, which "misrepresented the science of climate change by outright denials of the evidence that greenhouse gases are driving climate change" (p. 2). The Lavoisier Society, an Australian group, has links to some of these US groups, and its influence in the Howard Government was strong enough to create a sense in Cabinet that "all this science is crap".

Pursuing the role of these doubt-generating institutions quickly opens a world of scientific intrigue that helps to explain the Australian media's reporting of the science of these issues. This intrigue is well-known to scientists in the affected fields of science, and it has also now been substantially documented and discussed by sociologists of science for a number of scientific issues. This literature describes how scientists investigating these sorts of scientific issues experience cut and thrust dimensions that go well beyond the way science's processes are presented in school science or the way nature of science (NOS) is being promoted by science educators.

Science as a Contact Sport by Schneider (2009) is a racy autobiographical account of the to and fro positions about climate change that occurred for him, other colleagues and between scientists as the evidence about the greenhouse effect and climate began accumulating from 1970 onwards. This book also includes details of the countering moves that were initiated by some scientists and government officials alarmed about an emerging science consensus and its consequences for business life and political response in the USA. The lengths to which these countermoves have gone is evident in Mark Bowen's (2008) book, *Censoring Science*, which documents the way the recommendations for the US put forward by James Hansen, NASA's climate expert, were systematically undermined and sidelined. The colourful metaphors would certainly add quite a new zest to the teaching of *Science as Human Endeavour*, a new strand in Australia's forthcoming national curriculum or to the meaning of NOS more generally.

The experiences of Schneider, Hansen and their other US colleagues with respect to global warming turned out to be just one case of a cut and thrust that has occurred within the US science community in relation to a number of other major socio-scientific issues. Covering the last 60 years, Naomie Oreskes and Conway (2010) have documented in detail in their book, *Merchants of Doubt*, how a group of prominent US scientists, including Fred Seitz, Robert Jastrow, Bill Nierenberg and later Fred Singer, have actively generated public doubt about the science of (a) smoking and its health problems, (b) acid rain, (c) ozone layer holes and (d) global warming. Distinguished for the work they had earlier done in quite different fields, these scientists then used their status to campaign against the science underlying these issues, even though it was outside their areas of expertise. These scientists also all had links to a conservative organisation, the George C Marshall Institute, and later to institutes such as the Heartland Foundation.

In the cases they analysed, Oreskes and Conway (2010) found these dissenting scientists using tactics, such as selective quotations from published papers, making reference to uncertainties in data and hence in findings, use of contra publications in pseudo-science journals, highlighting a contrary piece of data, cherry-picking of bits of graphs to give alternative predictions, accusing authors of ignoring others' findings, manipulating data, misrepresenting reports, using status to claim media attention, and accusing the scientific community of corruption, motivated by self interest and political ideology.

Collectively, these have become known as the "tobacco strategy" from the memo from a tobacco company executive in 1969 when the issue of smoking and lung cancer was under investigation: "Doubt is our product since it is the best means of competing with 'the body of fact' that exists in the minds of the general public" (Orestes and Conway 2010, p. 34). Many of these tactics for generating public doubt about science have been evident in the media discussion of the above Australian issues. Orestes and Conway concluded that what these scientists shared in common was the conservative attitude that living in a free world should mean living free of government intervention and regulation. This attitude is also characteristic of the politicians and prominent public figures whose views are reported in the media in association with doubt about socio-scientific issues.

From both main parties in Australian politics there have been expressions of trust and of distrust in the science of the key issues, for example, climate change believers and deniers. Some declared political believers contradict their own stance about climate science by then supporting fossil fuel development. Some deniers suddenly become believers when their party leader's position changes, or when the party caucus decides. Others claim to be neither believers nor deniers, but doubters, claiming an agnosticism or scepticism on the issue—a stance that properly belongs in science, but is now associated with the doubters.

This incoherence promotes doubt rather than trust. It is, however, consistent with the common stance of politicians in democracies to delay difficult decisions by treating all claims (including scientific findings) as exaggerated or ambit ones, that can be compromised to be more popular, or postponed in favour of shorter-term issues of immediate public concern and interest. In the short period between one election and the next, politicians are attracted by any seeming disagreement between scientists, as it delays difficult and perhaps unpopular long-term decisions being made. As a memo from Frank Lunz, an Adviser to President Bush, stated:

> Should the public come to believe that the scientific issues are settled, their views about global warming will change accordingly. Therefore, Mr President, you need to make the lack of scientific certainty a primary issue in the debate. (Burkeman 2003)

Type 2 Reports of Science

A different manifestation of the media's interest in science is the opportunity that is taken to report research findings that have an unexpected human aspect. In the following examples, two of the reports seem to be generated by journalists extending, in an opportunistic manner, what were originally cautiously published reports of scientific studies. The correlations are used to evoke the attention of a gullible public without pointing out the scientific limitations of the headline claims.

- Language skills linked to mother's time in the sun. *Sydney Morning Herald*, February 16, 2012
  This report précised an Australian study of vitamin D levels in 700 Caucasian mothers by Professor Andrew Whitehouse, who, it suggested, linked these data about time in the sun to a more general phenomenon of language impairment affecting 6% of primary students. There was no caveat that such a link would involve a large number of other variables.
- Eat more chocolates, win more Nobels? *The Age*, July 31, 2011
  This report was based on a study that reported a very high correlation between national chocolate consumption and the achievement of Nobel Prizes. The science used to suggest this link is a known association between cacoa intake and stimulation of intellectual activity. There was no indication that any measure of the Laureates' consumption of chocolate had been made, or of the multivariate nature of what was being proposed.
- Salt makes you smarter: Iodine deficiency could be why children lag behind at school. *The Age*, January 9 2013
  Apart from some editing, this report was written by an Australian scientist with considerable expertise in iodine deficiency and its biophysical consequences. The known link between severe iodine deficiency and cognitive impairment is used to suggest that a fall in the amount of iodised salt purchased by Australians may account for the reported decline in students' NAPLAN literacy and numeracy scores—another leap into a complex phenomenon that is well beyond what is scientifically established. (I contacted a colleague of the scientist, who apologised that the author had indeed gone well beyond the level of his findings. This scientific lapse was, I learnt, spurred by the frustrations researchers in this field have as they try to combat systematic doubt campaigns about salt in diet.)

In each of these cases, the media editor's headline is suggestive of a causal relation, whereas the body of the scientific report makes clear that these are merely correlational associations and would require much more investigation to shift this connection to a causal relationship. In Case 1 the time in the sun of the mothers in the study was not measured. In Case 2 the chocolate eating habits of the Nobel Prize winners were not measured, and in Case 3 there was no comparative measurement of the iodised salt consumption of successful students and less successful ones. These types of unwarranted suggestive scientific links are also commonly presented in advertising for all sorts of health issues.

Where and How Has Science Education Gone Wrong?

In this section I use the above analysis of the public reporting of science to identify eight learning gaps in the school science curriculum that are pertinent to the issue of developing an informed trust in science as a learning outcome of school science. Some of these gaps need more explanation than others, and it will be apparent that to an extent they overlap.

Establishment of Science

Taylor (2012) argued that the fundamental strength of science is that it forces its practitioners to confront their own fallibility. He set out a number of checks and balances that help individual scientists to check their own work, and these steps have not been shared with our students in school science. As a result a key element in the loss of trust in science is the public' response when science findings appear to be disputed within the scientific community itself. Accordingly, much more attention needs to be given in school curricula to the establishment of science's findings. One reason for this neglect is that school science in all its separate disciplinary areas has been, and is, almost totally concerned with the teaching and learning of well-established scientific knowledge. The manner of its establishment within the science community has seemed unnecessary and been kept a secret from students at all levels of school science. The reality that each bit of science in the students' school textbooks has both a human and an empirical establishment is a story that has not been commonly shared in school science, despite the persistent efforts of Matthews (1994) and others for the inclusion of the teaching of the history and philosophy of science.

Inter-disciplinarity of Science and Technology Issues

The real-world contexts that embody the socio-scientific issues under discussion mean that several of the traditional science disciplines are involved, and often in the inter-disciplinary way contemporary science is more commonly constructed. The continued mono-disciplinary structure of the school science curriculum fails to adequately prepare students for understanding and interacting with this complexity.

Assisting students to *make decisions* about these issues has been an explicit objective in many school science curricula for more than 25 years. Nevertheless, few mainstream curricula have taken this obligation seriously enough to adopt structures that would facilitate the learning of the required inter-disciplinary content or the scientific processes that could lead to such judgements.

Probabilistic Science

Despite the major differences between the disciplinary areas of science, in school we have tended to teach all the sciences as if they are physics. Physics does have a large number of relationships between concepts that are expressible in a simple quantitative way that applies in the "ideal conditions" (frictionless surfaces, vacuum-like space, conservation of energy, etc.) of school science. The power of these relationships is experienced by students in a sufficiently convincing way in contrived school laboratory conditions, and they are reinforced by reference to their underpinning of everyday physics-based technologies. The 20th century triumphs that launched the first satellites, put people on the moon, and now has the Curiosity Investigator collecting data on Mars, are brilliant examples of the quantitative power of this established physics. In the other school science areas of chemistry, earth science and biology, the established relationships are more often qualitative than quantitative, but the latter are given priority even when they hold only approximately and in ideal systems.

As school science has trickled down over the last century from the senior years of schooling to the primary and the compulsory years of secondary schooling, this "established exactness" has persisted, constraining the introduction of science topics that are inherently probabilistic. For example, the range of biological responses of human beings to changing bio-physical conditions is invariably statistical, but the inclusion of such topics of importance and interest to students is rare in school science.

Further, the emphasis on established relationships in school science has had the advantage of leading to the plethora of assessment questions, used locally and internationally, that have a single exact or correct answer that primarily evinces the students' careful recall of taught content knowledge. However, this common approach to assessing students' learning of science has had the indirect effect of poorly preparing students to appreciate and be confident about the many scientific phenomena that involve probabilistic relationships. When the science of everyday, real world situations in medicine, agriculture, resource exploration, communication, etc., is being investigated, or when predictions of socio-scientific consequences are involved, probabilistic relationships become ever more the norm.

Uncertainty in Science

The media discourse about the socio-scientific cases above has been much concerned with the uncertainties in the science findings and what they imply. School science has been taught as very certain knowledge. Such teaching of established science knowledge has left little or no room for the uncertainty that is endemic in many of science's findings. We have not prepared students for the uncertainties that are inherent in science at each of its stages of investigating phenomena. We have not helped them to distinguish between ‘uncertain’ (meaning don’t know) and ‘uncertain’ (meaning know, but not sure of the value). Interestingly, Kirch (2012) pointed out that in the same year as the scientific community launched the *Precautionary Principle* (see UNESCO 2005 and above), the National Research Council (1996) in USA included in its *Standards for Science Education* that students ought to be:

- expected to use data to construct reasonable explanations (“reasonable” means consistent with a larger body of evidence and testing, within a range of uncertainty);
- encouraged to model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and scepticism that characterises science; and
- to be involved in science activities so that these requirements are *consistent with the place that uncertainty plays in the discourse of science itself*. (pp. 121–122, emphasis added)

Nevertheless, the science curricula that have ensued in the USA since 1996, and in many other countries, have taken little notice of these intentions. Furthermore, the dominant instrument for assessing science learning over that period, Trends in Mathematics and Science Study (TIMSS), is US-based, but internationally influential. Its emphasis is on students’ recall of established content in the science disciplines. As a consequence, the inclusion of uncertainties languishes as a key feature in school science and they are seen by many science teachers as undermining the authority of scientific knowledge, and thus of their own authority in the school. For example, in a study of the cultural rules of reward in the science classroom, Rowland (2000) found that comprehension and conviction, not hesitation, was the expectation for both teachers and students. Pollack (2003) argued that because science is presented to students as an established body of knowledge, they will equate science with certainty.

Nature of Science

Since 2000 there has been a positive interest in school science in students acquiring a broader sense of the nature of science (NOS) than it had as simply *Working scientifically* in the curricula of the 1990s. A very substantial research base is also now available to expand the teaching of NOS in school science (Flick and Lederman 2004). In addition, the OECD’s Programme of International Student Assessment (PISA) project in its approach to assessing students’ science learning achievement has internationally encouraged these newer senses of NOS through its substantial use of items about *investigating science* and *using evidence* (OECD 2007).

Much of this research has been motivated by reviving in school science a recognition of inquiry as a process in science. Accordingly, there has been a greater concentration on the rationale and mechanics of inquiry and how they can be taught in school, both for their own sake and as an aid to the learning of science content. Another line of studies has focused on the role of argumentation in science as a chain of intellectual processes that can be learnt and practised by school science students. The basis for these studies is that the processes of argumentation are central to scientists working in a field, and that they are also needed by members of the public faced with making decisions about contradictory scientific claims (Driver et al. 2000; Sadler and Zeidler 2008).

Despite these welcome extensions for teaching NOS, the cultural and social aspects within the scientific community of gaining funding for scientific investigations and then of getting the research findings accepted for publication have not been seen as worth including. Hence, procedures for checking science findings and claims—peer reviewing, refereeing, and revision and rejection—have not been appreciated, although they are the very things the public needs to know about if they are to make judgements about the validity of the findings of scientific research.

Empiricism in Science

A strength of science compared with other fields of knowledge is its empirical way of establishing knowledge. Some simple aspects of this empiricism are regularly taught in school science, for example, terms such as ‘a fair test’, independent and dependent variables, and control of variables. Students are taught the difference between a question and hypothesis, the method or means of collecting relevant data, the recording of data, and the drawing on data to provide a conclusion of support or denial.

Unfortunately, this teaching in school science has implied, explicitly or implicitly, that science progresses in a simple Popperian manner that is consistent with Einstein’s oft-quoted statement: “No amount of experimentation can prove me right: a single experiment can prove me wrong”. This dictum, when applied to the topics of established science, means that contrary findings in a school laboratory are interpreted as experimenter error, and not an error in the science.

An inductive approach to empiricism in science, and to its progression, is not as simple or clear cut as school science implies. There are many instances in the history of science where a contrary finding did not automatically change science. My favourite, as a chemist, is the rejection for a number of years of Cronsted’s discovery in 1757 of nickel as a new metallic element. The prevailing theory for the existence of metals was the astrological one that restricted their number to the twelve already discovered! Rather than a new element it was *cupfernickel*—old Nick’s (the Devil’s) copper.

Popperian rejection does not apply well to scientific investigations in which new ideas are being explored and tested. The scientific examples described by Oreskes and Conway (2010) in *Merchants of Doubt* were cases of the testing of new ideas in science and intellectual tussling between competing research teams, that resulted in a progression that is more like two papers forward, one paper backwards.

Despite some rhetoric about the tentative nature of science, the school curriculum has not encouraged the sense of more realistic progressions in which theories and models are coexisting and competing with each other.

Models and Modelling

The fact that scientists use models to arrive at predictions about the future has come to the fore in media reports and so public appreciation of this type of modelling is needed. A prominent theme in science education research over the last two decades has been the use of models in science teaching. However, an examination of the learning focus of this research reveals that the features of futures modelling that are pertinent to the issue of trust have not been included.

Many papers were published about the use of models in teaching and learning science during the 1990s and Gilbert et al. (1998) discussed this research and the closely-linked studies of others into the use of analogies and metaphors in textbooks and in the discourse of science classrooms (Treagust et al. 1995). The declared genesis of this pedagogical interest in models and modelling was the fundamental role that models and modelling play in science itself, but the focus of almost all of these educational studies has been on the extent to which models can be helpful in the teaching and learning of science. It was surprising and disappointing to find that, apart from a significant study by Justi and Gilbert (2002) (see next section), so little of the research emphasis on models has been given to modelling itself, either as the process of scientists or for teachers and their students to learn. Models have been tools and objects for learning but not intellectual processes or skills to practice and appreciate.

Even the limited focus of the main body of this research on models in school science has not been very successful in becoming part of the pedagogy of science classrooms. A quick check on the index of a number of current textbooks for senior years chemistry, physics and biology found no mention of “models” or “modelling”, although they do list a few specific models that need to be learnt as knowledge content (the Bohr model, the kinetic molecular model, the Krebs model, the DNA model, etc.).

As an aside, I found both “models” and “modelling” in the corresponding texts for both basic and advanced mathematics, and students are given practice in both applying models and creating models for everyday practices. In basic mathematics, for example, models were applied for hiring a car and for mobile phone contracts, while in advanced mathematics, modelling of science processes as complex as damped harmonic processes in physical systems appeared, which could also be, but are not, taught in school physics.

Among science educators with an interest in history and philosophy there has been a lively second strand of research into how models have been historically used in science to explain particular phenomena, to constrain and inhibit alternative explanations, and to advance science’s understanding of them (e.g., Justi and

Gilbert 1999; Matthews 1994). Teaching the ups and downs of the progression of these models could be very helpful as background for placing trust in science, but the lack of a historical background in most current science teachers—and the curriculum's dismissal of the history of science—means that little of this toing and froing occurs in school science.

Causation or Correlation

As reported above, the relationships that dominate the school science curriculum are ones in which the causality requirement has been established, namely, variable Y always follows variable X in some way. Most school practical work uses either a guided discovery approach (heuristic) or a recipe approach to make these causal relationships manifest to students.

Another type of relationship that is important in science is that of correlation, and its role and difference from causation is not well dealt with in school science. It is rare to find practical exercises where students have to explore qualitatively a range of possible and improbable variables to find whether there is an indication of a relationship between any of them, or to quantitatively calculate the degree to which they are then linked by calculating their coefficient of correlation.

It is possible that, quite spuriously, one variable may be reasonably—or even strongly—statistically correlated with another. Discerning these cases needs tools of analysis that are also not being taught in school science, although they are essential for making sense of the second type of media reporting of science quoted earlier.

What Could Be Done in Science Education?

In this section some suggestions are made as to how these gaps in current student learning of science might be approached, so that a base for trust in science is established. The overlap among some of them is such that the suggestions for the fifth and sixth are treated together. These suggestions for new learnings are so preliminary that I give no attention to the level of schooling that is most appropriate, other than that students need to acquire these learnings during the compulsory years when science is studied by all. Considerable professional development for teachers would also be needed and the strategies described by Simon and Davies (this volume) and Loughran and Smith (this volume) for introducing teachers to new pedagogies have potential here. Science teachers' accommodation to teaching for these new learnings would be accelerated, as for previous innovations, by the provision of support materials for on-line and classroom use that are imaginative and of the high quality students now experience out of school. Above all, teachers would need to see this new pedagogy as valued by authentic new modes of, and foci for, assessment.

Establishment of Science

Before the curriculum reforms of the 1960s, it was common for students to learn historical examples of how the people and processes within science led to major changes. Such historical teaching is, alas, beyond many science teachers, and it would be considered quaintly unreasonable by many of today's students. As an alternative, dramatised versions of the more recent scientific intrigues in *Merchants of Doubt* (and their counterparts in other countries) could easily be prepared for teacher/student reading, discussion and debate. The ongoing topicality in public life of these dramas might interest students and would communicate well the human and procedural aspects supporting—and thwarting—scientific investigations. Dramatic presentation through video seems particularly suited to exemplifying how findings are debated before gaining support within the science community, and what is involved in finally publishing them.

The classroom analysis and discussion of these presentations would complement and extend the current interest in teaching and learning more about scientific argumentation and socio-scientific issues by explicitly highlighting the human and cultural dimensions of the intellectual arguments that occur within science. By being introduced to the rigorous processes within science's culture that lead to peer-reviewed publication, and endorsement by the scientific community, students would learn that science is required not to exaggerate or overstate its claims. This conservative aspect of the culture of science would be seen to contrast with the *modus operandi* of ambit claims and compromises that underpin political responses to the findings of science.

A study by Hart et al. (2000) provides encouraging evidence that students can, with creative use of laboratory tasks, gain some awareness of the multi-levelled processes in establishing scientific findings. Fifteen-year-old students were set some carefully designed tasks to carry out as a scientific investigation in the laboratory. The tasks had the purpose of getting them to appreciate how a scientific investigation is developed in stages. Students were then required to communicate these stages to another group and the procedures within them so that the latter could repeat them to provide verification or otherwise of the initial findings. Over the course of this extended exercise, the students gradually acquired a significant awareness of the way scientific findings are established.

Inter-disciplinarity of Science and Technology Issues

In the later 1980s the PLON project in the Netherlands introduced into physics education the idea of teaching *Concepts in Contexts* (Eijkelhof and Kortland 1988). A range of familiar and interesting contexts was used to introduce the power of physical science concepts and their relationships and, in the process, the students' knowledge is deepened. For example, in the unit *Ionising Radiation*, one of several consequences of using real-world contexts was that the concept of radiation damage with the *sievert* as its SI unit was added to the more familiar physics-only ones, which have the *rad* and *curie* as units. When this new approach to physics was evaluated, Dutch students responded more positively to the PLON materials than did their teachers, and it was more than a decade before the idea of using real-world contexts reappeared as context-based science teaching.

This resurrection of teaching science in context has been taken up quite widely in response to the growing evidence since 2000 of a lack of interest in science among students in more developed countries. It is, however, still constrained, as PLON was, to small inter-disciplinary additions to mono-disciplinary science teaching. The socio-scientific issues of the real world contexts being discussed, as has already been noted, are inter-disciplinary as far as their science is concerned, and often further complicated by interactions with other knowledge systems.

The continuing mono-disciplinary structure of school science curricula is known to develop in students a view of science that is characterised by abstractness (and hence, difficulty) and irrelevance to students' lives (Lyons 2006). The origin of this structure, mentioned above, is ascribed by Roberts (2007) to what he calls a *Vision I* view of scientific literacy, in which three or four traditional science disciplines are the sources of the content to be learnt in school science. This mono-disciplinary structure does not accommodate his alternative *Vision 2* view, in which the content for school science learning is drawn from relevant real-world science and technology contexts that will involve several of the science disciplines, or the newer interdisciplinary sciences that have not yet found a place in the school curriculum. These real-world science and technology contexts require the teaching of inter-disciplinary concepts, such as noise level, drug toxicity, 'use by date', available resource, etc. All these are at present excluded by the mono-disciplinary structure of school science, even though they are well defined, measurable, and central to students knowing and being confident about their use in everyday science and technology contexts.

In 1998, the designers of the PISA Science project took a radical decision, against conservative advice, to design its test items as responses to presenting real-world contexts that involved science and technology. That these contexts were unfamiliar and so, from the formal science curriculum viewpoint, were unfair to students was outweighed by the interest and novelty they held for the 15-year-old students (the target population of future citizens). Performance on these tests, while by no means perfect, has been much better than the doubters had expected (OECD 2007).

Altogether, the weight of evidence in favour of teaching and learning the science of real world contexts (*Vision 2,* Roberts 2007), is now encouraging enough for it to become much more mainstream, (Aikenhead 2007a). If students are to learn to make decisions about science and technology issues, an explicit rhetoric for school science for more than 25 years, mainstream curricula must be restructured to take this obligation seriously, and to allow the learning of the required inter-disciplinary content and the scientific processes that could make such judgments more possible.

Probabilistic Science

The standard medical approach to the testing of the effectiveness of a treatment, via treatment and placebo matched groups, and the counterpart design, Latin Squares, in agricultural science, are common examples of probabilistic science that could be included in the science curriculum. Indeed, experiments using the latter design could be simulated in school grounds and laboratories. Comparing the human response to the performance of comparable technologies, as occurs in product testing, would also extend probabilistic science to the more physical sciences.

The scientific procedures involved are an extension of the ‘fair test’ design that is already commonly taught and learned. Students, through experiencing them, would be assisted to appreciate that in both medical science and in agriculture the findings are usually probabilistic, since the matching of the samples and the variability in human subjects, soil qualities, and technical products, is more complicated than is usual in school fair tests. The statistical difference between the trial samples and objects leads to a *probability of effect* that can be calculated for statistical significance.

Uncertain Science

I remember observing a lesson in Sweden which was an interesting variation of the usually mundane practical tasks that are used to teach junior secondary students to use a thermometer to measure temperature occurred The teacher asked her class of 12-year-olds to find out why water does not boil at 100 °C, as their textbook stated. The uncertainties in a scientific investigation were quickly apparent as different water samples, different observers and various laboratory thermometers became involved.

Kirch (2012) has argued for scientific uncertainty as a basic teaching and learning goal for science education as it is exemplified in: (a) planning investigations, (b) communications about peers’ investigations, (c) whether a cause-effect relation looks likely, (d) the merits of the data and (e) the ways this information is used for explanations and solving real-world problems. She starts with the actual scientific case of the disappearing honey bees—a problem for which, when it was first observed, science’s answer was simply ‘Don’t know’. No plausible suggestions could be made to further its investigation. This example of a “Don’t Know” problem in science can then be contrasted very clearly with “Know” problems, for each of which there is a solution, but with a degree of uncertainty or a percentage likelihood, such as the example given earlier of the magnitude of future global temperatures if carbon dioxide emissions continue at the current level or rise further.

Kirch (2012) presents a two-pronged model for uncertainty in science based on its empirical aspects and on its more psychological origins. She then uses it to mount a strong case for the teaching and learning of uncertainty in science that resonates well with what I am advocating in this chapter.

Empiricism in Science, and Models and Modelling

The empirical nature of science is integral to teaching about particular models for scientific phenomena because it is empirical evidence that, in the end, establishes their strengths and limitations. Likewise, in designing a scientific model, the availability of empirical measurements provides the grounds for choosing the model's variables, and also for changing the model when it fails an empirical test.

There is, however, a difference in the modelling of phenomena that are amenable to direct experimental measurements and the modelling phenomena that involve predicting the future: "We cannot perform experiments on the future before it happens" (Schneider 2009, p. 48). Modelling of this latter kind is critical to many of the issues that are associated with the lack of trust in science. Indeed, some of the hesitation within the ranks of scientists themselves about issues such as global warming is related to this futuristic nature of their modelling.

Justi and Gilbert (2002), in their study of teachers' views of modelling, do list predictive purposes as one use of modelling in science although it is not an aspect that was discussed in their interviews. They asked groups of teachers at different levels of schooling and university about their sense of what is involved in modelling in science: to inform an investigation, to advance a sense of explanation and, in the face of contradictory evidence, to modify or discard the current model. From the responses, a model of the modelling processes was developed that has two stages—a mental stage and an empirical stage—and their paper concludes with some discussion of how the rather complicated processes in their model could be learnt by students.

The learning about modelling I am proposing is less ambitious and difficult, although two stages are still involved. Students need to gain an appreciation of what futures modelling by scientists involves, not to acquire the skills themselves. A way to start would be to get students to plot long-term available data for variables that may be related to a familiar phenomenon. Comparison of the projection of these data into the future from a relatively short time span with a longer time span is likely to set the scene nicely. Maritja Bogataj, Slovenia's IPPC representative, in her introductory address to the IOSTE Symposium in 2010, urged as an example, learning to distinguish between "weather" (what is likely to happen tomorrow) and "climate" (the long term trends in weather variables).

A next step would be to discuss a phenomenon such as global warming, the health of the Murray-Darling basin, the impact of fishing on the ocean, the decline in an animal or plant species, etc., for which there are a number of plausibly connected factors and for which data of the corresponding variable have been collected over a longish time period. Students would then be required to develop a hypothesis in which they choose to associate two of these long-period, measured variables—the mental stage in Justi and Gilbert's (2002) model of modelling. The way to assess the hypothesis would then be related to how the future extrapolations of the measured variables' measurements might affect this relationship—the empirical stage. In this exercise the students would be formulating a model that is capable, in due course, of being tested as the trend extrapolations become empirically measured. The chosen variables, their data and data trends do not themselves separately predict. Rather, the prediction is that something will happen in the future, depending on whether the chosen variables change sufficiently in the direction of greater connectedness and hence more likely causality. If they do not show this convergence, other variables need to be considered and a new model developed.

This checking for convergence is why the IPPC redoes its predictions every 6 years, its member scientists adding new relevant factors and their trending data so that the future predictions are always subject to the degree of confidence about this or that part of the model. The process is one of consensus, not in any one scientist's conclusions, and this consensus offers to society the range of potential outcomes and the probability or confidence about each of them. This type of scientific modelling has the subjective and objective aspects that correspond to Justi and Gilbert's (2002) stages, but these authors' goal of individualistic learning of modelling misses the communal nature of scientific futures modelling. The teams of scientists working with different contributions to the model provide both its scientific strength and the source of the public's confidence in their claims. These are the overall aspects that science students need to learn to appreciate.

Causation or Correlation

The three cases of Type 2 reports quoted earlier, or any other example of this type of correlational reporting, offer readily available contexts for teachers and students to critically discuss to identify the warranted (evidence established) and unwarranted claims (evidence lacking). Alternatively, the suggested claim in these case studies, or for claims advertising household and health products, could be given as a design investigation, with students choosing the variables for which data needs to be collected, drawing on reference literature as to the methods that would generate these data, deciding on designing the sequence of the investigation, and indicating criteria (qualitative or quantitative) that would be sufficient for them to conclude that a causal relationship was probable.

Cases of correlational claims are good ones for students to learn the lesson that science, as a cultural enterprise, has inbuilt processes that protect it from the human frailty of claiming more than its current state can justify. Taylor (2012) provides a useful popular description of how these processes force scientists to confront the possibility of their own fallibility.

Discussion

For these new directions for school science education to become a reality, it will first require pressure from society for these new learnings. This pressure is already building up as the number of these issues become ever more urgent, and as politicians begin to recognise that science-informed citizens are an asset for support in the difficult decisions they need to make.

Next, it will require reforms of the science curriculum and an assessment of learning openness that is permissive of such changes. This will, in turn, encourage education researchers and innovative teachers to explore teaching strategies that are aimed at developing these new learnings. When these are successful, the momentum for change in the priorities for mainstream science learning will follow, together with professional development programmes to support science teachers.

The new national curriculum for Science in Australia (ACARA 2014) gives some encouragement that, at least, some of the suggested changes are beginning to be mainstreamed. For the P-10 (the compulsory science years):

- the Science Understanding strand includes learning about models along with facts, concepts, principles, laws, and theories
- both the Science as Inquiry and the Science as Human Endeavour strands, while not specifically referring to modelling, do include several associated processes, and there are strong words about evidence-based decisions about current and future applications of science.

The reform of current science curricula, and hence what students learn in school science, is contingent, I believe, on establishing a new image of the person school science primarily intends to produce. For far too long, the image that has dominated our curriculum structure, that has coloured our thinking about science teaching and our sense of science learning and its assessment, has been the *mini-scientist*.

Historically, the natural sciences were introduced into schooling for the tiny minority of students then continuing for a full secondary education as preparation for their university science-based studies. Thus, in the senior school years, they were introduced to the rudimentary knowledge and experimental procedures of the science disciplines as an induction process for future work as a scientist. This image persisted during the first 60 years of the 20th century and was evident in the priority given by the curriculum reforms of the 1960s to the traditional disciplinary sciences for this student outcome target. In the 1970s, alternative science education materials began to be developed for students in the earlier secondary years and even for those in primary schooling, but their essence was nevertheless a watered-down version of the disciplinary content that still only seriously began in the upper years. Some words and phrases about learning science in the early 20th century such as 'heuristic learning', and 'discovery learning' continue to be used erroneously in research and in curricular documents, as if they have a scientific as well as educational meaning in schooling.

The image of the mini-scientist persisted even when, in the 1980s, there were repeated national calls for *Science for All*, and for scientific literacy in the 1990s. These slogans embodied widespread recognition that school science should be catering for the totality of students, all of whom will be future citizens in societies influenced by science and technology (Aikenhead 1990; Bybee 1997; Fensham 1985). Despite the seismic magnitude of this officially-endorsed shift of student target from the minority of students aspiring to work in the science field to the whole population of schooling, educational systems have had great difficulty in redefining the science curriculum so that it adequately serves both these populations. Indeed, producing mini-scientists has persisted as the underlying influence on school science so that the curriculum content in most countries still consists of introductory knowledge in the chosen science disciplines.

One obvious answer to this dilemma is to give priority for all or most of the years of school science to a science curriculum that sets out to meet the science needs of all students as future citizens along the lines proposed by Millar and Osborne (1998). Such a curriculum does not exclude more specialised science studies for optional study by aspiring 'mini-scientists' who might in this way gain advance placement in university science-based courses.

A key step towards this reorienting of the science curriculum would be a new image for the outcome learner of school science. 'Science-informed citizens' is beginning to be used for this new image (Allchin 2011). It acknowledges all students—tomorrow's citizens—as the target population, and suggests their learning is to inform them with knowledge of, and about, science as knowledge-for-action, not to build a store of isolated pieces of elementary science content knowledge. Under his three broad goals for the science education of citizens, Norris (1995) has them learning science knowledge, how such knowledge is established, and a frame of mind that recognizes science is required if we are to solve some of the world's critical issues. The new learnings discussed in this chapter contribute detail to the second and third of these intentions.

In the 1980s, when the new target of all students was first broached, the science education reformers saw as their goal that students would become intellectually independent in their science knowledge. Munby (1980) hoped each would have "the capacity to make judgements about knowledge claims for oneself" (p. 19). He was echoed in the following decade by the many science educators, including myself, who were attracted to constructivist-inspired pedagogies. Likewise, scientific literacy when it came into vogue was described in individualistic learning terms (Aikenhead 2007b; Bybee 1997).

It could be argued, though rather doubtfully, that such intellectual independence may have been appropriate when science education was conceived as learning the isolated concepts of established science, and even for learning to mechanically replicate experimental procedures. It is, however, quite an impossible goal in schools, that students individually can be given the range of experiences that embrace the nuances in the science community about investigating complex socio-scientific issues, share in the debates about their uncertain science, and experience the cultural norms whereby these issues are investigated and reported.

The reality that the culture of school science is fundamentally different from the culture of science brings us to Norris' (1995) quality of *intellectual dependence* to which I referred in my Introduction, and promised to return to in this section.

The stance of intellectual dependence that Norris (1995) associates with students' science learning in preparing them for citizenship, is not, he argues, a passive one. Rather, it requires the science student to learn an attitude of reflective scepticism about science, who can be trusted regarding scientists' claims to knowledge, and how to make judgements about their credibility. Furthermore, he points out that when it comes to putting scientific consensus claims into effect in society, the nature of this dependence on the scientific community, as authority, changes sharply. The public's knowledge of the implications for society exceeds that of the scientific community and scientists and non-scientists become interdependent—an *intellectual communalism.*

There are studies in many fields that remind us of the fundamental role that trust plays in social life as human beings' means of overcoming ignorance (Smithson 2008). In this spirit I concur with Norris (1995) that students in school science cannot achieve a stature in which they have all the resources for judging the truth of a science knowledge claim independently of other people. It should, however, be possible for them to gain in their science education the learnings of the processes behind a scientific claim backed by the scientific community, rather than claims just by individual scientists, regardless of their apparent individual status.

As, and if, these new learnings are achieved in school science, students will, indeed, be developing a basis for deciding how, and when, to place trust in science. They will become, not experts in science, but *connoisseurs of science*.

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When Science Changes: The Impact of ICTs on Preparing Students for Science Outside of School

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It was no ordinary science news story. Beginning with the original press release (NASA 2010), the announcement of results suggesting that a bacterium could incorporate arsenic into its DNA caused a frenzy of media discussion. And while the wild speculation about its implications for extraterrestrial life and the ensuing public feud between two iconoclast scientists make for an exciting case study, they are not the real story. More pressingly, the saga highlights a chasm in approaches to scientific literacy that continues to grow as both the practice and communication of science increasingly happen in digital spaces. Typical conceptions of scientific literacy, which often give little specific attention to science media or focus such attention only on traditional newspaper media, are insufficient to prepare students to make sense of science as it will play out in the public sphere of their lives outside of school. This chapter will examine the arsenic story to draw out the missing elements of contemporary approaches to science media in school science, in particular ways in which legitimate conflict and disagreement need a more prominent place (see also Fensham, this volume).

Information and communications technologies (ICTs) are here understood not just as they apply in the classroom but as a broad term that includes devices, interfaces, hardware and software that are used to access, share, store and communicate information both by individuals and institutions. This conception includes not only technical communications but also all forms of broadcast media and textual media (such as newspapers) that are distributed and accessed in digital form. ICTs have, over several decades, connected scientists to each other in new and unexpected ways, encouraging large global collaborations between individuals who may have never met. Increasing public and consumer access to these technologies, though, have brought those collaborations and connections out into the open. Examples like the polymath project (Nielsen 2011) place problems in the open on websites where hundreds of experienced and expert members of the scientific community can contribute and anyone can observe. Collaborative spaces such as

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the website and community at Openwetware.org allow researchers and graduate students to share lab procedures in a Wiki style so that they can learn from the experiences of other research groups. Fold-it, a game that challenges players of all ages to find the lowest energy configurations of complex protein structures, brings individuals from outside of the scientific community into the process while solving problems that could not be tackled by individual researchers. Social media platforms such as Facebook and Twitter facilitate almost instant access to scientific findings, press releases, media reports and often researchers themselves.

In this environment, one of the most pressing impacts of ICTs on school science is not how they change the pedagogical possibilities of the classroom but how profoundly they have changed the public scientific landscape students find themselves in currently and will find themselves in as adults. While words such as citizenship and everyday life are not without their challenges, a consistent recognition has grown among science educators that science education must prepare students for the interactions they will have with science after leaving school, both as youths and adults. Those needs cannot be adequately conceived any longer without taking serious notice of the way that ICTs are changing scientific communities and what it means to engage with science in the media and public sphere.

The Case of #Arseniclife

One of the most prominent recent examples of this shift began with a press release from NASA dated November 29, 2010. The contents of the release were brief: “NASA will hold a news conference at 2 p.m. EST on Thursday, December 2, to discuss an astrobiology finding that will impact the search for evidence of extraterrestrial life. Astrobiology is the study of the origin, evolution, distribution and future of life in the universe”. All of NASA’s press releases are posted publically and anyone with an interest in space science can access them, but most receive little attention. With a mention of extraterrestrial life, however, this one caused a quick and excited reaction from institutional news outlets, opinion writers and bloggers (see, for example, Plait 2010). The technology website Gizmodo even ran the provocative headline “Did NASA discover life on one of Saturn’s moons?” (Read 2010). The live press conference was widely anticipated and broadcast openly online. Websites for space enthusiasts and amateurs, such as space.com, promoted it to their members and encouraged them to watch. And while the press conference did not announce finding alien life on Saturn’s moons, it detailed experimental findings of a bacterium retrieved in California that appeared to be able to substitute arsenic for phosphorus in its DNA, seemingly opening up possibilities for new forms of life. The news was quickly reported, with outlets such as the New York Times (Overbye 2010) and New Scientist (Dessibourg 2010) posting news stories online within hours of the press conference.

If the coverage was breathless and quick, as is typical of "breakthrough" stories, the criticism this time was equally rapid and equally public. On December 4, only 2 days after the press conference, University of British Columbia biologist Rosie Redfield posted a detailed critique of the accompanying paper published online by the journal *Science*. The commentary is over 2,000 words and lays out for any interested reader the basic method and findings of the paper while identifying possible errors that may have been made at each step. For example:

> The Methods describes a standard ethanol precipitation with no washing (and no column purification which would have included washing), so I think some arsenate could easily have been carried over with the DNA, especially if it is not very soluble in 70 % ethanol. Would this arsenate have left the DNA during the gel purification? Maybe not—the methods don't say that the DNA was purified away from the agarose gel matrix before being analysed. This step is certainly standard, but if it was omitted then any contaminating arsenic might have been carried over into the elemental analysis. (Redfield 2010)

She sums up her opinion on the study unequivocally:

> Lots of flim-flam, but very little reliable information. The mass spec measurements may be very well done (I lack expertise here), but their value is severely compromised by the poor quality of the inputs. If this data was presented by a PhD student at their committee meeting, I'd send them back to the bench to do more cleanup and controls. (Redfield 2010)

She describes the post as being written mostly for herself, to clarify her thinking, and for others in the field but the language of the critique was not overly technical and would have been accessible to many interested people, including high school teachers and students, and the concluding paragraph quoted above requires no specialised knowledge to understand. Furthermore, there are 275 comments and questions from readers, including other biologists working back and forth to make sense of each other's critical comments. This comment from a research pharmacologist exemplifies the level of detail and scientific language present in the comments.

> I couldn't understand the basis for the calculation of the As:P ratio in Table 1 where the ten-fold difference in the As +/P- medium was represented as 7.3 - based on % dry weight but I can't get 7.3 to come out if I expressed the difference in molar units. One quick correction (prob a html glitch): the arsenate concentration of Mono Lake should be 200 micromolar, not mM.
> It's really valuable to have a microbiologist take this paper apart. Yet another example of why science blogs are so important and why scientists should blog. Thanks so much. (Kroll 2010)

More than just being available, however, critical commentary like Redfield's quickly spawned mass media coverage of its own, bringing readers outside the research community and interested public an ongoing story of unsettled science before the first announcements could have even fully been explored. On December 7, still less than a week after the press conference, Carl Zimmer published an article in the online magazine *Slate* summarising email responses he had received from researchers under the title 'This paper should not have been published: scientists see fatal flaws in the NASA study of arsenic-based life' (Zimmer 2010a). The next day he made public the text of all of the responses he received, sharing thirteen researchers' critical views in their own words (Zimmer 2010b). Coverage of the critique became almost as big a story as the original study, receiving extended discussion from the Canadian Broadcasting Corporation (CBC), the *New York Times*, the *Washington Post* and more. For ease of sharing updates, the hashtag code #arseniclife, used for searching Twitter updates, was taken up by anyone interested in sharing information about the story including journalists, scientists, teachers and all manner of other science curious individuals.

This case exemplifies a major shift both in practice (scientists connecting quickly with each other to engage in cross-disciplinary collaborative critique) and accessibility (the entire process of scientific debate about the validity of the findings took place in the open). Zimmer (2011), in a piece entitled 'The Discovery of Arsenic-Based Twitter: How #arseniclife changed science', makes a strong comparison between this case and a typical cycle of scientific critique:

> In earlier times, such critics didn't have many options. They could write to *Science* and hope that their letter would be published long after the public's attention had turned to other things. They could write to their local newspaper and try to sum up their objections in 50 words. They could grouse over a beer with likeminded colleagues. Now, however, they can form an online community. Blogging scientists read the #arseniclife paper and aired their complaints. On Twitter, they kept each other up to date on new developments in the story. Within a couple weeks the New York Times and the Washington Post were reporting not on the Science paper, but on the online debate. The center of gravity had shifted.

This does not mean that the usual processes of science were circumvented. The paper was peer reviewed by the journal in the usual fashion, and in June 2011 *Science* published the complete original paper (Wolfe-Simon et al. 2011) along with eight technical commentaries that were also subject to peer review. The difference was again in accessibility and the processes that led up to the submission of the letters. Redfield, after receiving several comments on her original post urging her to submit a letter to *Science*, posted a public draft of the letter to her blog and sought comments from colleagues. Any interested adult or student could have now have witnessed: a scientific press conference, the harsh critiques that controversial findings receive usually behind closed doors, the processes of writing and submitting comments to a journal, and the norms associated with published findings and commentary.

Harsh informal commentary is not new to science. The difference, however, is that it all happened in private fora, either in private in-person conversations or through the drawn out formal processes of scientific journals. ICTsbegan to change that even in 1989 with the frenzy surrounding the cold fusion press conferences (Taylor 1994). While the media continued to report on the exciting new findings and the US government even debated providing urgent funding to support the work, people such as CERN physicist Douglas Morrison were setting up electronic newsletters sent by email and posted to newsgroups such as sci.physics.fusion (Taylor 1994). Similarly, supporting and contradictory findings were quickly distributed to interested research groups by fax. The Princeton Plasma Physics laboratory, for example, received news of Japanese findings through a short handwritten

English translation of a Japanese newspaper article faxed to their lab: “4/1/89. Yomiuri Shimbun (Japanese biggest news paper). Tokyo Agriculture & Engineering University announced ‘The [Koganoi-shi] re-produced the Utah experiments’. They measured heat, gamma and tritium. Prof. Koyama” (Lewenstein 1995, p. 413). These informal ICT-facilitated networks were essential to the quick scientific consensus that built up in opposition to cold fusion claims. The arsenic story represents the next step in the impact of ICTs on science and science communication: taking those informal networks public for all to see.

Furthermore, the arsenic story, like any true examples of unsettled science (as opposed to scientific frauds), does not end with the critique. Redfield continued to post updates of her lab’s attempts to grow the bacterium and replicate the results, detailing modifications of the procedures and other setbacks. As those results came together, she posted draft results and even copies of the peer reviews that their replication study received when they it submitted to *Science* (Redfield 2012). Other researchers pursued studies to explain how the bacterium could survive in such arsenic-rich environments in ways other than incorporating arsenic into its DNA (Basturea et al. 2012). This led to interesting new findings such as Elias et al. (2012) evidence of a specialised mechanism for discriminating between arsenic and phosphate, suggesting that the bacterium, instead of incorporating arsenic, is able to survive because it is so good at removing it. Because of the profile that the earlier critiques received though, these follow-ups were widely reported in popular science outlets and network media, which is very unusual for replication and follow-up studies. In contrast, for example, provocative findings related to the connection between autism and vaccines (Wakefield 1999) remained largely unchallenged publically for many years (though retracted more than a decade later), a situation that seems to have contributed to wide misunderstanding about the relationship.

The way that the arsenic story played out in public challenges how we define the necessary knowledge and skills associated with scientific literacy. The story requires much more than reading and understanding the scientific content of news reports—those reports were largely contradictory and embedded with all of the hallmarks of the complicated social processes of science-in-the-making (e.g., Kelly et al. 1998). ICTs, in this case specifically blogging and social media platforms, changed the way that these findings were communicated and especially what was communicated. And this should not be treated as an isolated case but more likely as an example of the direction of things to come. An important question to ask then is: how should this direction influence the media elements of scientific literacy?

Preparing Students for Their Lives Outside of School

The media elements of scientific literacy have always been defined in relation to preparing students for their adult lives and their lives outside of school. The abilities, background and agency to engage with scientific issues that impact one’s life and community have had a prominent place in the goals for science education for several decades. Calls of "Science for all" underline the importance of scientific knowledge beyond preparation for scientific careers. As DeBoer (2000) highlights in his review of definitions of scientific literacy, the empowerment of citizens to act in their world with greater autonomy has been a driving force of science education even as far back as the 1893 report of the Committee of Ten in the United States. More recently, related desires have been expressed through emphases on scientific literacy, Science-Technology-Society (STS) approaches to science education, and socio-scientific issues in the classroom (e.g., DeBoer 2000; Kolsto 2001; Walker and Zeidler 2007).

Considering students' lives outside of the school has always necessitated paying attention to the venues of scientific discussion encountered by adults. DeBoer (2000) rightly identifies the ability to make sense of this source of information as one of the key goals of science education:

> Science education should develop citizens who are able to critically follow reports and discussions about science that appear in the media and who can take part in conversations about science and science-related issues that are part of their daily experience. Individuals should be able to read and understand accounts of scientific discoveries, follow discussions having to do with the ethics of science, and communicate with each other about what has been read or heard. (pp. 592–593)

Even though there are significant conflicts in the various definitions of scientific literacy (e.g., DeBoer 2000; Hurd 1998; Roberts 2010), the relationship to functionally and expertly engaging with media transcends most versions. As Hazen and Trefil (1991), cited in McClune and Jarman (2012) bluntly propose, "If you can understand the news of the day as it relates to science … then, as far as we are concerned you are scientifically literate" (p. 3). And most of those arguments rest on the assumption that engaging with science media is important because of the impact it has for the adults whom our students will become. Phillips and Norris (1999) go so far as to describe a parallel between the centrality of textbooks to students' learning and the media as a source for adults. In the same way that textbooks become curriculum, science media may act as an un-ignorable lived science curriculum for adults. They are sometimes described as a key source of ongoing science education for adults (Falk et al. 2007; Hansen 2009). Learning experiences in science therefore must promote skills and attitudes for critically engaging with the media (Jarman and McClune 2007), something that Wellington (1991) pioneered in exploring, because while adults will continue to learn science throughout their lives, school science plays a key role in their early development, providing a baseline for their later interactions with science.

The focus on application in adulthood is also not, of course, without complications. McClune and Jarman (2012), for example, argue that criticality is something that develops in the long term and perhaps is only truly visible after a student has left school. But without at least consideration of the adult worlds that students will encounter, there can be little hope of reaching the goals outlined in most conceptions of scientific literacy.

Media in Science Curricula and Classrooms

If media importance in science education is defined by preparing students for their adult lives and lives outside of school, what is the media environment that they are currently preparing for? What does it look like in curricula?

The appearance of statements and specific outcomes that prioritise meaningful engagement with science media or the development of skills in critically assessing public reports is mixed and somewhat idiosyncratic, likely influenced by a wide variety of factors including local priorities. Across Canada, where curricula are developed at the provincial level, there are wide gaps. The provinces of Alberta and Ontario are often held up as examples of science education excellence because of their performance in international tests. In Alberta though, there are almost no references to critical literacy or media. The program for Grades 7–9 encourages students to show interest in science. by seeking out media reports on environmental issues (Alberta Education 2014a). There is no indication of what they should do with those that they find. The only reference to reading in that program and the program for Grade 10 (the final mandatory science course) is to the importance of reading chemical labels carefully (Alberta Education 2014b). Reading or media of any type do not appear in any other mandatory science courses. In Ontario, on the other hand, the definition of scientific literacy that guides the documents for mandatory science courses (such as Grade 9–10 Science) is similar to those reports described above that identify critically reading media reports about science as a key indicator of scientific literacy. Only one of the specific curricular outcomes that guide classroom practice, however, is specified in relation to this goal and again only in relation to an environmental issue: “compare different perspectives and/or biases evident in discussions of climate change in scientific and non-scientific media (e.g., with reference to knowledge, beliefs, and values) [AI, C]” (Ministry of Education, Ontario 2008, pp. 79, 91).

In the United States, the National Science Education Standards (National Research Council 1996) encourage students to be “able to read with understanding articles about science in the popular press” and “engage in conversation about the validity of the conclusions” (p. 22). The newer Next Generation Science Standards, created by state representatives, describe the importance of criticality in relation to all types of science media, but in the specific standards require only that students “Read grade-appropriate texts and/or use media to obtain scientific and/or technical information to determine patterns in and/or evidence about the natural and designed world(s)” (NGSS Lead States 2013, p. 15). No attention is given to preparing students to manage controversy, disagreement or science-in-the-making, such as the #arseniclife story.

Similarly, surveys of teacher practices in relation to science media suggest that these materials are part of regular classroom practice but that they are mostly used in simple ways. Jarman and McClune (2003) found that 92 % of the UK teachers in their sample group used materials drawn from newspapers. Kachan et al. (2006) similarly found that 93 % of the Canadian biology teachers they surveyed used news stories as part of their teaching. But like the curricula, while there is a presence of science news, the depth is limited. News stories in both of these studies were used primarily as a way to illustrate the relevance of science to the world outside of school but not in ways that would prepare students to engage in that world. Salleh (2001) found that only rarely did teachers indicate media awareness or criticality as important learning goals in their use of science in the media.

Whatever attention science media receive in classrooms and curricula seems to focus almost exclusively on reading comprehension and seeing broader applications of science, an approach that emphasises students as passive recipients of settled science. The approach of a science news display board is common, which acts only to make students aware of new “discoveries”. McClune and Jarman (2012) claim that even in the science education literature, most studies explore only students’ cognitive responses, for example, do students understand the concepts they are reading about? There is little attention paid to how to make sense of and participate in public discussions, controversies and policy debates. Christensen (2011) similarly comments that few science education studies look beyond developing or examining abilities to read and understand newspaper articles as media literacy. This is a very impoverished view and one that would not prepare students well to engage as adults, even in a newspaper-dominated media environment. Christensen (2011) goes on to argue that even choosing slightly broader media pieces, such as TV reports, would constitute an improved vision of science media as it applies to developing scientific literacy.

Developing a greater understanding of the media environment in which students will find themselves outside of school becomes even more important when patterns in student and young adult engagement with science media are explored. While students may enjoy reading news stories in school, several studies illustrate major gaps between a desired scientifically literate approach and the actual practices that students engage in when they read.

Surveys of student perceptions of news reports illustrate a largely positive attitude to reading science media both in and out of school. Halkia and Mantzourdis (2005) report that high school students in their sample enjoy the way that science is presented in media articles and, in particular, prefer it to the modes of presentation common in science textbooks. Many students indicated that they choose to read science news items even outside of school, though they say they are most drawn to those that are presented in ways not typical of scientific writing, such as with emotional and poetic language and strong narrative features. The students seem to indicate that they access science media not in the process of information seeking but in attempts to identify enjoyable and interesting reading material. The teachers in Kachan et al. (2006) also largely report that students responded well to their attempts to incorporate science news items and that the activities encouraged student interest and participation. Students were described as being interested in science news for its relevance and importance.

Digging further into students’ responses, however, illustrates a more complicated relationship with the texts. Phillips and Norris (1999), for example, began by asking students for their prior views on a variety of scientific propositions and then provided texts for them that reported new findings that might support or contradict their prior beliefs. Regardless of the substance of those prior beliefs, Phillips and Norris found that upon follow up, students reported views consistent with those in the texts, typically without strong or detailed reasons for those views: “Students who expressed either less or more certainty about their background beliefs [after reading] tended to do so, not on the basis of critical evaluation of the text but on the basis of mere deference” (p. 325). They argued that students were too willing to accept the authority of the text rather than engage with it more deeply. Similarly, Norris et al. (2003) found that university students over-reported the certainty of media reports that they read, reading tentative findings as fact. Further, the students in both studies seemed to reason almost exclusively from the claims made in the texts. They did not go further to weigh claims or evidence critically against their prior knowledge or any pre-established criteria. This would have led to particular challenges in making sense of #arseniclife. The initial reports came from sources that students and adults would easily defer to (NASA and the journal *Science*) and the critique began in non-traditional online venues. Where would a student or interested adult turn once those critiques began appearing in other publications that would also normally receive their deference (e.g., *The New York Times*)? Should they believe the initial reports or the critiques?

Where students do engage more critically, their efforts seem to rest on their personal understanding of science processes. This approach leads them to (a) focus almost exclusively on issues of methods and procedure, the major orientations of practical work in school science or (b) rely on reasoning better suited to everyday and social disagreements. McClune and Jarman (2012) describe a study presented by Korpan et al. (1999) that identifies readers’ priorities by tracking the questions that they ask and the additional information that they seek when they read science news reports. McClune and Jarman highlight the ways in which students’ views of scientific processes dominate their assessments, with most seeking factual details related to methods and observations. Dominating their responses are questions about sample size, controls and experimental design. These are important questions, but they leave out much of the larger context of scientific study, such as the relationships to theory and to prior research, the status of the findings within the scientific community, and implications of peer review and funding processes. This focus on methods is perhaps unsurprising given Norris et al. (2003) finding that university students were best at assessing the validity of particular statements when those statements related to methods and procedures. It is perhaps the area of scientific practice in which students feel most confident and have the most developed discrimination ability. Unfortunately, these questions seem guided by limited views of scientific research, with students overlooking information that is not explicitly experimental.

When issues of experimental procedures cannot account for disagreement among experts, students tend to turn to resources from everyday thinking. In one of the earlier science education studies of media engagement, Driver et al. (1996) examined students’ nature of science understandings in relation to two scientific disagreements. When they encountered disagreements among experts, the students tended to first blame the amount of experimental evidence (i.e., not enough leads to disagreements). Failing that, however, they turned to everyday motivations for disagreement: individual bias and self-interest. They tended to ignore the internal and external social construction processes essential to scientific knowledge creation. Building on that work, Christenson (2011) examined students' responses to scientific disagreement directly by showing students a short television segment related to possible dangers of mobile phone use. The segment shows a scientist discussing his finding that mice exposed to mobile phones showed no greater increase in tumour risk. Both the scientist and the reporter highlight that this contradicts an earlier study showing increased tumour risk related to mobile phone exposure. A second scientist is introduced and argues that the new study may not erase the risks identified in the previous one. There is no specific point of disagreement but s/he suggests that the matter is far from settled and that there are many other possible dangers beyond tumour risk. As Christensen notes, there are therefore two levels of unsettled science here: a new study that contradicts a prior one and two scientists who disagree in their interpretation of the current study. When students discussed the disagreement, however, they rarely addressed how disagreements like this are fundamental to the processes of science. They concluded that one or the other of the studies must be flawed or that the scientists are primarily acting out of personal interest. Both of these explanations are possible but they miss the importance of debate and disagreement. They also miss the reality of scientific practice that contradictory results are typical in emerging areas of research, not atypical or necessarily indicative of misconduct or incompetence. Christensen concludes that while students may have resisted or outgrown the problematic ideology that science is purely objective and value free, this process has interfered with their ability to make sense of the social and theoretical interactions inherent in science.

Kolsto (2001) is also ambivalent about students' critical engagement, finding that most students recognise the importance of carefully weighing opinions and facts presented by various parties in a public scientific controversy but that they have only shallow resources on which to draw, making controversial science very difficult to navigate. Students want scientists to be neutral and disinterested and they know that scientists are not always, but they are unable to express the means for identifying those who best fit the criteria. They are similarly unsure of how two scientists could disagree in the absence of inappropriate personal bias. Kolsto is clear that this finding casts doubt on Norris's (1995) claim that, lacking in the specialised epistemological knowledge necessary to assess scientific claims, students should instead be guided to carefully weigh the believability of experts. Students do seem to keep this idea in the foreground of their engagement with controversies already. However, they do not know what information to seek or how to weigh the information that they do have to make such a decision, and they do not understand how to make sense of legitimate scientific disagreement between experts. This weakness sits at the heart of making sense of #arseniclife. All of the players have a strong surface level of credibility and would pass any efforts to establish their believability. There is also no obvious commercial or financial bias, and yet there is vehement disagreement. Does this mean that one side or the other is necessarily fraudulent or relying on a blatantly flawed experiment? Or are there elements of such disagreement that are merely typical for legitimate science-in-the-making?

Findings from a wide variety of investigations with students and young adults suggest that school science does not adequately prepare students to deal with science in the news, whether as part of fully blown public controversies or even just in the reporting of new findings that may contradict previous ones (as almost every cancer or dietary study that makes the news seems to do) (Christensen 2011; Driver et al. 1996; Kolsto 2001; McClune and Jarman 2012; Norris and Phillips 2003; Phillips and Norris 1999). Students seem to struggle with the epistemological expertise necessary to discriminate on elements of scientific work beyond technical details related to experimental methods and they turn to everyday reasoning that could be applied to any dispute, citing personal bias, self-interest or sometimes incompetence as explanations for disagreements. Science news items, however, are dominated by scientific controversies and unsettled science-in-the-making that is almost always characterised by contradictory results and differing interpretations. This gap between the science that students are prepared to assess (settled science where experimental results are clear and unequivocal) and what is presented in science media is only widening as ICTs come to dominate the way that science is communicated and shared. Much more so than in traditional newspaper and magazine reporting, students and adults live in a media environment where the social processes of science play out in public, where the disagreements and contradictions of science-in-the-making are inescapable and where those processes play out differently through large collaborations and inter-disciplinary teams (even scientist-citizen partnerships) that highlight the social processes of science. These changes make a reconsideration of the importance of this kind of scientific literacy essential.

What's Missing?

While phrases such as science for citizenship and everyday life are not without difficult challenges, a consistent recognition has grown among science educators that a very important element of science education is the need to prepare students for the interactions they will have with science after leaving school, both as youths and adults. As discussed earlier, such competence is often conceptualised as the defining characteristic of scientific literacy. And Christensen (2011) cogently argues that as science and technology continue to change rapidly and impact on public lives, skills, aptitudes and strategies to navigate a science media environment become ever more pressing. Without consideration of the actual media and policy environment in which students will find themselves, school science cannot hope to prepare students to navigate that environment with with confidence.

As discussed, despite appearing in the definitions of scientific literacy that guide many international curricula, intentional goals and practices are missing. Specific curriculum outcomes tend to focus on reading and understanding media reports, if they appear at all. Any mentions of criticality and social processes are minimal. When teachers do engage with science news (which they appear to do quite frequently, e.g., Kachan et al. 2006) these elements are lost in favour of using news to excite student interest or pursue content learning goals. Examples like #arsenic life illustrate that these motivations are not enough.

Recognition is not new that the guidelines for working with science news in the classroom are weak (e.g., Kolsto 2001; McClune and Jarman 2012; Norris and Phillips 2003). The #arseniclife case, however, illustrates that a further issue looms that exacerbates the weaknesses already identified: the science media environment is changing as it increasingly happens through ICTs. A recent Gallup poll (Saad 2013) reported that American adults primarily encounter news items of all types (including science) through television and the internet (including through social media). The only age group that prioritised print over online sources was those over 65. And even when those online sources are still news agencies, ICTs are transforming the work of science journalism, the role of reporters and the forms in which journalism and science news are encountered (Allan 2011; Fahy and Nisbet 2011; Shanahan 2011). Fahy and Nisbet (2011) interviewed science journalists from prominent publications in the US and the UK, finding that they identify their roles and jobs as constantly shifting within this new environment. For example, "online science journalists have a more collaborative relationship with their audiences and sources and are generally adopting a more critical and interpretative stance towards the scientific community, industry, and policy-oriented organizations" (Fahy and Nisbet 2011, p. 778). John Rennie, former Editor in Chief of *Scientific American*, argued in an online question and answer session for Health Care Social Media Canada that health care providers and organisations need to pay much more attention to ICTs in science communication because they have effected a profound shift in people's relationship to health information. For example, "News isn't where people first hear about new stuff anymore… More likely to hear about items of interest via social media before the formal news story. Editors/reporters take this to heart" (Rennie 2013).

ICTs have shifted the way people access and interact with science news and reporting. They have also created new forms beyond conventional science news reports (e.g., written for newspapers and in inverted pyramid form) and secondary literature (e.g., science magazine articles written to present a summary account of scientific findings for more public audiences). Blogs, in particular, highlight the contributory power of ICTs, giving a space for first-hand contributions from scientists, graduate students, parents, patients, amateurs and journalists writing with a different voice. Rosie Redfield's blog took a prominent place in the #arseniclife story and represents first-hand information directly from her lab, including her own voice and that of her students. In a print-only media environment, these voices would have been absent from the conversation that was available to those outside of the scientific community. Even when these blogs are written by science journalists who may have been responsible for the newspaper items already used in classrooms, the online forum creates an entirely different genre. The tone is usually personal and the posts are written with emotion and excitement not usually found in newspaper reports. This tone is largely a result of the first person style that is favoured in blogs and the editorial freedom that allows journalists to pursue topics of personal interest rather than those prioritised by their editors (M. McKenna, personal communication, March 5, 2011; C. Zimmer, personal communication, February 24, 2011; see also Shanahan 2011). Interpretation and analysis moves to the forefront over descriptive reporting of scientific news (M. McKenna, personal communication, March 5, 2011). The online medium also offers mechanisms for directing readers to additional and supporting information. Links can be provided to journal articles, critical essays and contradictory posts written by other researchers. Science journalist, Carl Zimmer, for example, tries to eschew speaking for scientists and prioritises including them and their own words in the discussions on his blog. This approach was clear in his coverage of the arsenic story, which consisted both of reported stories and blog posts that shared first person responses from scientists critical of the NASA report (Zimmer 2010a, b). In print media, there is rarely room for including the full text of their responses.

Of course, this contributory openness has darker elements. It can also include corporate sources that use these online fora as direct marketing, attempting to pass for scientific coverage. Bubela et al. (2009) in particular note the prevalence of information from the nutraceutical industry communicated through digital media environments such as blogs and Facebook. In other instances, science communication spaces such as blogs hosted by individuals, including scientists, can provide a confusing mix of scientific information and ideologically driven statements about politics or religion (Bubela et al. 2009). All media content has implied values and a particular orientation but the openness of online technologies provides room for much greater range without necessarily any editorial guidelines or oversight.

All of these possibilities present a challenge for even the most scientifically literate. How does one best manage immersion in this environment? How does one get involved and what is the best way to do so? School science, if it is ever to address the future needs of students outside of school, needs to consider how the activities of the classroom contribute to answering these questions. This point is especially pressing because high school students already recognise that navigating conflicting information from putative experts is the greatest challenge of engaging with science media (Kolsto 2001).

The Missing Social Elements of Epistemology

The challenge is in identifying exactly how school science can make that contribution. How can students be better prepared for a public science environment that is characterised by shifting genres and constantly new forms? Even if the online media of today were thoroughly prioritised and students engaged through blogs, Twitter and Facebook (which many teachers do, e.g., Luehmann and Frink 2009; MacBride and Luehmann 2008), the media environment of their adult lives is unlikely to look like that which they would encounter in schools. The direction of efforts to take into account the impacts of ICTs must go beyond the particular platforms and devices common at the current moment.

Not surprisingly, as a starting point, recommendations for including science media in school science have focused on developing a better understanding of science journalism as a genre. McClune and Jarman (2012) and Ryder (2002) argue that attention to the practices, forms and language of journalism, is essential and yet is often overlooked in science education. But, of course, knowledge about the practices of science is also essential for engagement with science media. While many different terms are used to describe the experiences and understanding about science (nature of science, scientific processes, scientific attitudes, socio-scientific issues), they are often the common ground in arguments about what essential elements will help prepare students for science outside of school. Studies such as Christensen (2011) illustrate that it is this second element, knowledge of relevant practices of science, where the largest gap exists with respect to issues such as #arseniclife. Several of the groups she observed mentioned issues related to media bias, addressing practices such as “possible omission of information, misinformation (inaccurate reporting of facts), or the deliberate manipulation of content for the media’s own purposes” (p. 128). Absent from their explanations, however, was an understanding of the processes of science that lead to legitimately different interpretations and conflicting information. Results like hers suggest that students are engaging in some critical literate practices such as questioning bias and interests (as advocated by Bingle and Gaskell 1994; Jarman and McClune 2007; Lemke 2001; Norris et al. 2003) but they are often unable to tell the difference between disagreements that are based on those issues and those that are legitimate to scientific practice.

Discussions about epistemology in school science, including those under the banner of the nature of science, often acknowledge that science is done by people and is a social activity. Those recognitions, however, rarely go further to examine what that really means for how science happens (Christensen 2011). The behaviour and actions of all involved in the arsenic story, from the enthusiastic press release, the first hints of condemnation, the wide collaboration on critical commentary, the disagreements found within that commentary to the novel results that followed cannot be fully explained or understood with the key elements that typically appear in NoS guidelines. Lederman et al. (2002), for example, outline six keys understandings, including those that hint at social process, but they are insufficient for the public science-in-the-making that characterises ICT-facilitated science media and communications. For example, they identify “The Imaginative and Creative Nature of Science … Science involves the invention of explanations and theoretical entities, which requires a great deal of creativity on the part of scientists (p. 499). But how do those creative leaps happen? The description implies the creative genius of an individual scientist, creating new ways of thinking about things from their own experiences and ingenuity. The “Theory-Laden Nature of Scientific Knowledge” addresses the subjective nature of observations and interpretation, also noting that it can apply to groups of scientists: “This (sometimes collective) individuality or mindset accounts for the role of theory in the production of scientific knowledge. Contrary to common belief, science never starts with neutral observations” (p. 501).

But this point is without acknowledgement of what it means for scientific conflict or for the constant back and forth that sometimes culminates in consensus or rapid scientific change. How might theoretical differences in understanding DNA lead one group (the NASA team) to interpret the results as indicative of arsenic uptake in place of phosphorus, while others see it as indicative of the ability to carefully discriminate between arsenic and phosphorus? The elements Lederman et al. and others lay out are very important scientific practices, but they cannot fully account for the type of science that is beginning to play out in public as a result of ICT-mediated communications.

One of the pioneers in examining the practices of science, from which NoS guidelines are partly drawn, was Hungarian chemist Michael Polanyi. His efforts to understand the culture of science offer an important suggestion for what may be missing from curricula and that could support students, and the adults they become, to make sense of science as it plays out in public through ICTs. His writings, a combination of political theory, economics and his own personal experiences as a scientist, frequently used everyday metaphors to explore scientific processes. In examining the political theory of scientific work (Polanyi 1962), he asked how science could be possible if it were merely the shared work of individuals, like a group of people sitting around a table shelling peas. If science were merely a group that pooled their efforts, but for which the work of each individual were separable, scientific movement would soon grind to a halt. The creative processes are impossible when working in isolation. He likened it instead to a group working on jigsaw puzzle. It is inefficient to set each individual to separate tasks at opposite corners as they quickly can become stuck when left to their own devices:

> The only way the assistants can effectively co-operate, and surpass by far what any single one of them could do, is to let them work on putting the puzzle together in sight of the others so that every time a piece of it is fitted in by one helper, all the others will immediately watch out for the next step that becomes possible in consequence. (Polanyi 1962, p. 55)

These results are only possible when the group is self-regulating as well, deciding together when solutions are feasible and fruitful. A group with a pyramidal structure, leading to a single authority would never solve the puzzle. That individual would become mired in the same difficulties as each of the team members if they worked in isolation. The same applies to science. It cannot be understood as individuals working in isolation or under the supervision of a guiding authority.

> Admittedly, scientific authority is not distributed evenly throughout the body of scientists; some distinguished members of the profession predominate over others of a more junior standing. But the authority of scientific opinion remains essentially mutual; it is established between scientists, not above them. Scientists exercise their authority over each other. Admittedly, the body of scientists, as a whole, does uphold the authority of science over the lay public. It controls thereby also the process by which young men [sic] are trained to become members of the scientific profession. But once the novice has reached the grade of an independent scientist, there is no longer any superior above him. His submission to scientific opinion is entailed now in his joining a chain of mutual appreciations, within which he is called upon to bear his equal share of responsibility for the authority to which he submits. (Polanyi 1962, p. 60)

The defining characteristic of science here is that of mutual authority. It is not the individual creativity of scientists or the interaction of science with culture. While these are necessary to acknowledge, none are sufficient to understand how science happens and this point is clearly on display in the arsenic case. Aiming to provide activities that prepare students for science outside of school (a science environment that is increasing dominated by scientific information accessed through ICTs) must include support and experience in evaluating both reports of settled science and science-in-the-making in ways that make clear this essential feature of science. School science must not only address epistemology as it pertains to methodological issues, it must also address the essential social elements of that epistemology, such as mutual authority.

Arguing for greater attention to knowledge about science, Ryder (2002) distinguishes between two main areas: epistemology ("the ways in which knowledge claims in science are developed and justified" p. 639) and sociology of science ("interaction among scientists" p. 639). He argued at the time that the epistemological elements are underrepresented in school science, but the literature and curricula that have built up around ideas related to the nature of science typically engage both of these elements well. Lederman et al. (2002) explicitly describe these two elements as the central content of NoS programs. In laying out their key elements of NoS teaching, they identify a balance of perspectives that can be classified as epistemological (e.g., 'The Empirical Nature of Scientific Knowledge') and sociological (e.g., 'The Creative and Imaginative Nature of Science'). Ryder (2002), however, gives passing mention to some degree of overlap (issues that are both epistemological and sociological) identifying peer review processes as an example. This overlap though is likely much larger and more important than Ryder or NoS approaches such as Lederman et al. acknowledge. This is the element that is needed to understand #arseniclife and other examples of science-in-the-making that play out as a result of the shift towards ICT-mediated science: a socially focused epistemology of science, one that acknowledges the centrality of mutual authority, conflict and differing interpretations. Knowing the importance of argument, disagreement, theoretical perspective and differences in frontier science may contribute to offsetting students' tendency to attribute disagreement to incompetence or bias. This is essential if they are to live in a world surrounded by constant reporting and access to all pieces of the scientific process, including those that were previously conducted behind closed doors.

#Arseniclife as a Case Study

#Arseniclife not only highlights the social epistemological gap, it provides an excellent case study for high school students to begin to examine these issues. A preliminary discussion on how to assess the validity of sources can provide a place to begin.[1] Are students already somewhat thoughtful about sources and bias such as those in Christenson's (2011) study? Asking them to rank sources (including those online) such as journal articles, textbooks, blogs, Facebook posts and online news articles can allow them to reflect on their own perceptions, such as the high priority they likely place on journal articles. The case study can then be examined chronologically, beginning with the press release and press conference and continuing through the blogged critique and the coverage of the findings that the bacterium is adept at selecting phosphorous. At each stage, questions can guide students towards a discussion of what information is credible and whether disagreements are due to everyday issues such as bias or whether they are part of the legitimate processes of science. The happy ending (so far) of the controversy leading to interesting and novel findings about the mechanisms bacteria use in extreme environments can help illustrate the importance of controversy and disagreement. These studies may never have been conducted without the motivation provided by the ongoing dispute. The mutual authority that Polanyi (1962) describes is also easy to identify and highlighted in the words of the scientists critiquing the arsenic paper. Questions about who decides what scientific information is correct can provide important insight for students.

It is important to note that this case study idea and the potential guiding questions are not entirely unlike the many activities built around socio-scientific issues that also deal with unsettled science. Those are very important and valuable approaches. The difference is one of orientation. The imperative here is to inject necessary attention on the social elements of epistemology, to offer students experiences that can better prepare them to understand how and why scientists can legitimately disagree and do so in public.

Conclusion

There has been consistent recognition that making meaning from science media such as newspapers and television is a crucial element of encouraging scientific literacy (e.g., Oliveras et al. 2013). But even the most recent iterations (e.g., McClune and Jarman 2012) miss that a world of isolated science news reports is no longer the media landscape in which students live. There is a serious shift brought on by the impact of ICTs on communication both within scientific communities and science media.

This is a separate argument from those that address ICT and changing media availability through a lens of changing the nature of learners (Anderman et al. 2012) or changing the pedagogical opportunities available in the science classroom.

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[1] These case study ideas are based on a 2-hour activity session developed in partnership with Dr. Catherine Anderson of ScienceWorld in Vancouver for 16- and 17-year-old students participating in an afterschool science program.

Pressing changes are needed in how school science treats science communication and science media from the perspective of students' changing experiences and the media landscape in which they are embedded. For example, when teachers and curricula focus on high school students' reading in science, one or two approaches dominate: either learning to read about difficult concepts, or learning about the different types of scientific writing, for example, primary sources (e.g., journal articles) and secondary sources (e.g., science magazines and newspapers). These are important and valuable scientific skills. There is little guidance, however, on how to navigate and make sense of a genuine controversy such as #arseniclife. Despite strong and important efforts to incorporate understanding about science (such as NoS and scientific processes) in school science, the social elements of epistemology are often overlooked. And yet it is those understandings that are needed to make sense of the unsettled science that students will encounter outside of school.

Cases like #arseniclife make it clear that current trends in ICT dominated communications in science necessitate a change in the way science media is conceived of as part of scientific literacy. The social epistemological elements of scientific practice, including mutual authority and legitimate conflict, are more important than ever because they are coming to the forefront as ICTs change both the practices of science and how those practices are visible to those outside of the community. Students need opportunities to make sense of those elements if they are to have any preparation for the science-in-the-making that they will encounter in their lives outside of school.

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Forms of Learning in Senior Secondary Science as Represented Through an Integrated Curriculum

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Introduction

This chapter considers the forms of learning in science that are represented in an integrated approach to the curriculum in the final year of schooling in Hong Kong. An integrated approach to the curriculum has been advocated by a number of curriculum scholars (e.g., Beane 1995, 1997; Hargreaves et al. 2001) as it is seen to be beneficial for student learning, by making learning applicable, meaningful for students, relevant and thus more motivating. In some countries there have been attempts to integrate science with mathematics (Berlin and Lee 2005) and/or other learning areas such as technology (American Association for the Advancement of Science 1993, 1998; National Science Teacher Association 1997). In Hong Kong, a new core subject called Liberal Studies (LS), introduced at the senior secondary level (age 15–17) in 2009, integrates multiple discipline areas including science. The subject is intended to provide opportunities for students to do "cross-disciplinary studies, pertaining in particular to critical thinking, life education, values education and civic education, with due consideration given to their relevance in the Hong Kong context" (CDC/HKEAA 2007, p. 2). As such, it provides an important example of quite different forms of intended student learning at a level of schooling where the genuine complexities of real situations and contexts and phenomena can be explored, including, obviously, quite different forms of science-related learning.

In this subject, Liberal Studies, learning and teaching take on a thematic or issue-based approach with each of its six modules based on a specific theme. Of the six modules, two have a science focus: Public Health and Energy Technology and the Environment. Both are grouped under an area named 'Science, Technology and the Environment'. The LS curriculum intends to be situated towards the 'more integrated' end of the curriculum continuum proposed by Fogarty (1991). The

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integration involves multiple subject disciplines such as social science, citizenship education, geography, personal or self-development, science, technology and public health. Disciplinary-based knowledge is almost unidentifiable in curriculum documents, and subject boundaries are non-existent.

Based on an intention to promote citizenship education, the design of the LS curriculum is consistent with Beane's (1995) suggestion that students be engaged in a search for "self and social meaning", and the curriculum focus on "problems, issues and concerns" (p. 616). According to Venville et al. (2008), the integration of different subject domains in a curriculum should "encompass a holistic view of knowledge…disciplines, including science, …[should] be considered a source of explanation and inquiry to answer and explore real life issues relevant to learners" (p. 860). With this, disciplines including science are seen to be important and contribute to a holistic view of knowledge. However, given the fact that (a) the LS curriculum is written with a thematic approach, with disciplinary-based content kept to a minimum or even non-existent, and (b) LS is taught by teachers regardless of whether they have a science background, it is doubtful whether "a holistic view of knowledge" is in fact maintained. It is likely that science content or science disciplinary-based knowledge can be considered when answering real life issues or themes being examined in the curriculum. However, without a science background, teachers will likely avoid or have no choice but to ignore scientific perspectives in the discussion. The subsequent discussion can hardly be expected to lead to balanced views or generate holistic understanding.

At the senior secondary level in Hong Kong, students are currently required to take four core subjects: Chinese, English, Mathematics and LS. In addition, they may take one to three elective subjects although it is common to have students taking two. With the limited number of elective subjects, it is possible for students to avoid taking any science subjects, and even if they take two elective subjects in the science domain, it is unlikely that they will cover all three main areas, namely physics, chemistry and biology, as was the case in the former Hong Kong Advanced Level Examination.

As LS is a core subject that has to be taken by all senior secondary level students in Hong Kong, it provides an excellent opportunity for all students to establish fundamental understandings of science. This chapter aims to portray the different forms of science learning that are represented in an integrated curriculum, and provides comments and suggestions for enhancing such a curriculum.

This chapter sets out to analyse the forms of learning in science that are represented in LS as an integrated curriculum, and does so by considering the following questions:

- what is the nature of science knowledge learned through this subject?
- what purposes are served by the science content, for the students and for the society in which the students live?
- when such a subject is presented as the integration of different or totally separate subject areas, is the resultant science learning coherent such that students' science understanding is built up and accumulated?

The Context

The Hong Kong senior secondary school education system has undergone a structural change that began in 2009. Instead of 5 years of secondary plus 2 years of senior secondary education, a 6-year secondary school structure was adopted. The last 3 years of secondary school are now named the New Senior Secondary (NSS). The NSS curriculum was implemented to provide students with a flexible, coherent and diversified learning experience (CDC/HKEAA 2007). LS is a new core subject[1] in the framework of the NSS curriculum that was developed based on the student-centered learning approach, and that employs inquiry learning as its approach to teaching and learning.

At the primary level in the current structure in Hong Kong, science is learned through a General Studies curriculum integrating six domains of study (Healthy living, People and environment, Science and technology in daily life, Community and citizenship, National identity and Chinese culture, Global understanding and the Information age) (Curriculum Development Council 2011). At the junior secondary level, this integration is built on the three domains of science, namely physics, chemistry and biology. At the senior secondary level, there is a choice of taking science as elective subjects. Alternatively, science and environmental studies topics are covered in the curriculum of the new core subject Liberal Studies, which in itself is also an integrated curriculum. The focus of this chapter is on the final years of the senior secondary level when Liberal Studies is taken as a compulsory core subject.

The Liberal Studies Curriculum

The emphasis of the LS curriculum is different from that of other subjects set for public examination at the Senior Secondary level. The emphasis is not on subject content but on the development of thinking skills, citizenship education and a positive attitude towards life. This section aims to provide some background about the subject and will introduce its aims, the evolution of its development, and the preparation for implementing the subject before it was launched in 2009.

The Curriculum Aims for Liberal Studies

The curriculum aims for the LS subject as provided in the 2007 curriculum document are as follows:

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[1] LS was one of the elective subjects at the Advanced Supplementary (AS) level in the secondary curriculum before the NSS. The curriculum for AS level LS is different from the newly proposed LS in NSS.

(a) to enhance students' understanding of themselves, their society, their nation, the human world and the physical environment;
(b) to enable students to develop multiple perspectives on perennial and contemporary issues in different contexts (e.g., cultural, social, economic, political and technological contexts);
(c) to help students become independent thinkers so that they can construct knowledge appropriate to changing personal and social circumstances;
(d) to develop in students a range of skills for life-long learning, including critical thinking, creative problem solving, communication, and information technology skills;
(e) to help students appreciate and respect diversity in cultures in a pluralistic society and handle conflicting values; and
(f) to help students develop positive values and attitudes towards life, so that they can become informed and responsible citizens of society, the country and the world. (CDC/HKEAA 2007, p. 5)

Unlike other NSS level subjects, the emphasis is not on facts, concepts or skills specific to certain academic disciplines, e.g., mathematical skills. The curriculum document becomes a resource providing a framework for teachers to select content which allows issue-based inquiry and is consistent with a cross-curricular focus. The issues selected will be controversial so as to promote thinking from multiple perspectives, thus enhancing the development of critical thinking skills.

The curriculum consists of three areas of study, with modules under each area as follows:

Area: Self and personal development

Module 1: Personal development and interpersonal relationships

Area: Society and Culture

Module 2: Hong Kong today
Module 3: Modern China
Module 4: Globalization

Area: Science, technology and the environment

Module 5: Public health
Module 6: Energy, technology and the environment

The Development of the Subject and Its Evolving Purposes

LS was first introduced in 1991 as an elective subject at the Advanced Supplementary (AS) Level (F[Form or Grade].6 and F.7, aged 18–19) in the old curriculum. Since 1984, secondary school subjects in Hong Kong have had a greater focus on the local context and on political issues. This innovation was due to the anticipated change of sovereignty in 1997. The introduction of Liberal Studies was also related to a number of changes in curriculum directions from the 1970s to the 1990s. These changes include the introduction of interdisciplinary or cross-curricular subjects to meet the political, social and diverse education needs of pupils in Hong Kong in the 1970s. The introduction of cross-curricular subjects is consistent with the international literature on curriculum integration (Beane 1997; Drake 1998; Jacobs 1989, 1997). These researchers advocate cross-curricular subjects, arguing that they facilitate students' holistic understanding as reflected in real life contexts instead of compartmentalisation or separation of knowledge into academic subjects. Moreover, cross-curricular subjects provide opportunities for teacher and student collaboration while facilitating students' learning through making connections. In the 1990s, there were cross-curricular subjects to introduce civic education, moral education, sex education, and environmental education (Morris and Chan 1997a, b). The LS subject was introduced to provide students with opportunities to examine contemporary issues of social and personal significance from multiple perspectives, and to develop problem solving and critical thinking skills (Curriculum Development Council [CDC] 2000).

The introduction of LS in the 1990s was seen as an attempt to strengthen citizenship education with the resumption of sovereignty by the PRC in 1997 (Fok 1997). Fung and Yip (2010) interpret the introduction of the module 'Modern China' in LS as an attempt to develop a sense of citizenship, and compared this with the Basic Education Curriculum (Makabayan) in the Philippines with an emphasis on patriotic values.

The subject did not relate to any traditional school subject, nor was it a required subject for entrance to university disciplines. There was a lack of understanding among students about LS as a subject unlike traditional subjects such as Biology, Chemistry, etc. The subject was not very popular among AS level students. By 1996–1997, only 10 % of schools had adopted LS. Now that it is a compulsory subject for NSS students, there has of course been a significant increase in the number of students taking it since 2009.

The fundamental characteristics of the LS subject at the AS and NSS level were similar. It is a subject that aims to overcome the boundaries of traditional advanced-level academic subjects. Instead of focusing on abstract decontextualised knowledge at pre-university level, it challenges students to examine a wide range of real issues related to their everyday experiences. The theme of nurturing students to develop their critical thinking ability is maintained as the subject becomes compulsory at the NSS. According to Morris and Chan (1997a), the development of students' critical thinking ability is related to a social reconstructionist ideology which also promotes social and political awareness.

Preparation for the Implementation of the Subject

Many teachers new to the subject would be expected to share the teaching workload incurred by the introduction of this new core subject, and these teachers would have to cope with new subject content and a new teaching approach. Despite the fact that the subject LS had been launched at the AS level, Leung (2010) maintains that teacher professional development is essential in informing teachers the differences between the AS and NSS level subjects. He suggests that teachers' understanding related to curriculum integration has to be enhanced, and discussions on obstacles and issues related to implementation are important. Although the Education Bureau has provided workshops, and teacher-training institutes have organized training programmes for those who were intending to teach LS before the implementation of the NSS curriculum, many teachers were still concerned about their inexperience in teaching the subject.

The LS curriculum has been developed to fulfill many educational purposes including nurturing critical thinking skills and citizenship education. It is a subject that involves three years of senior secondary level study and occupies at least one-sixth of the total curriculum time in NSS. While the LS curriculum, being a core subject, offers immense opportunities to provide all senior secondary students with an understanding of science, further analysis is needed in order to ascertain the quality of the science learning, for example, whether the learning coheres with previous science learning experiences, whether conceptual development is considered across years, and if science learning is integrated or applicable to everyday situations as intended.

Forms of Learning in Science

Despite the different ways in which science is represented in different curricular settings, it is important that students can make sense of their learning. Will a curriculum which introduces science as integrated with other subject domains, as LS does, make better sense to students? What is the role of science conceptual understanding in an integrated curriculum, or is it essential? On the issue of whether conceptual understanding is essential, Vosniadou et al. (2008) maintain that certain activities can occur without conceptual grounds. Building on this argument, Aufschnaiter and Rogge (2012) suggest that everyday functioning, for example, turning on a switch, does not require a coherent 'explanatory' framework such as explaining how an electric circuit functions. They propose three different conceptual qualities or levels based on a discussion of examples. The first level describes students who adopt an 'exploratory approach'. The students describe their observations or explore an experimental set-up without making reference to any conceptual framework. The second level is an 'intuitive rule-based approach' in which students predict events purposefully, demonstrating that they have a basic understanding of science rules even though they may not be referring to them explicitly. The third level is an 'explicit rule-based approach' whereby students apply scientific concepts or rules to generalise events or phenomena. With this framework, students may not need to draw on science conceptual understandings if the teaching is targeted only at lower levels of understanding. However, in order that students can apply scientific rules or for generalization, science conceptual understanding is essential.

Many researchers share the view that science teaching covers more than science concepts and principles; it should include science processes, the nature of science and the relevance or application of science in everyday situations (Lederman 2008; McComas 1998; Osborne et al. 2003). More recently, to allow efficient learning and teaching of issues about science, Duit et al. (2012) argue that students need to learn about science processes and views of the nature of science.

The Nature of Science (NOS) has been an objective in science education in the USA (American Association for the Advancement of Science 1990, 1993; Klopfer 1964; National Research Council 1996; National Science Teachers Association 1982) for almost 100 years (Central Association of Science and Mathematics Teachers 1907; Kimball 1967; Lederman 1992). Abd-El-Khalick (2005) provides an assessment of experts' understanding of the general notions of NOS appropriate at school which suggests that:

1. Science is a human enterprise, practiced within a community of scientists.
2. Scientists ask and answer questions about the natural world in an attempt to understand it.
3. Scientific knowledge is generated by a range of methods, often involving the creation of hypotheses, theories, laws and models. These have different but related roles.
4. Scientific knowledge demands evidence (is empirical), and is testable through rigorous processes.
5. Creativity, imagination and curiosity also play a key role in knowledge generation.
6. As a social activity, science is influenced by cultural, societal and personal factors, including economic and political considerations.
7. Scientific knowledge is provisional and developmental.

Moreover, Driver et al. (1996) provided five arguments that help us to understand the importance of understanding NOS:

1. to make sense of science and manage the technological objects and processes in everyday life;
2. for informed decision-making on scientific issues;
3. to appreciate the value of science as part of contemporary culture;
4. to help develop an understanding of the norms of the scientific community that embody moral commitments that are of general value to society; and
5. to facilitate the learning of science subject matter.

As for how NOS understanding may facilitate the learning of science, Bell et al. (2000) report that NOS understanding is necessary for critical thinking and problem solving, it provides a more authentic context for understanding scientific knowledge and its progression, and it is linked to scientific literacy. The understanding of NOS forms part of science learning and emphasizes the learning of science in relation to social and everyday contexts.

In discussing whether practical skills are essential for science learning, there are views that it is not only a 'mechanical' aspect (Gott and Duggan 1995); students may draw on practical experiences to predict, explain, and transfer to new contexts (Wellington 1998). Practical scientific inquiry is seen as a subset of practical work that demands the application of both scientific conceptual understanding and procedural understanding including design, measurement and evaluation of the inquiry (Gott and Duggan 1995). Toplis (2012) argues for a link between conceptual and procedural understanding of science. He draws on PISA (2006) data, suggesting that motivation and attitudes are relevant to science, and investigates the relationship between practical work and science learning attitudes. He calls for a reappraisal of scientific inquiry such that it achieves a number of learning outcomes, namely: enhancing conceptual understanding, development of inquiry skills, promoting student initiated inquiries, and encouraging group work and discussions among students.

Despite the fact that the learning of science is thus not confined to science conceptual understandings, science conceptual understandings are still essential for more advanced levels of learning in which students need to apply scientific rules and/or make generalizations. Science inquiry, NOS and science processes are taken as different forms of science learning. The learning of NOS has to take place with reference to social or everyday contexts.

Forms of Science Learning in the Liberal Studies Curriculum

This chapter analyses the nature of science knowledge learned through the LS curriculum: the purposes of the science content for the students and for the society in which the students live; and, as LS is presented as the integration of multiple disciplinary or subject areas, whether the resultant science learning is coherent such that students' science understanding is built up and accumulated. To answer these questions, the curriculum document (CDC/HKEAA 2007) and the Hong Kong Curriculum Development Council (CDC 2012) teachers' manual were analysed. The latter provides teaching materials and suggestions addressing science, technology and environment issues. These two documents thus form the sources of data to answer these questions.

Drawing on the two official curriculum documents mentioned above, the analysis provided in this chapter is at an 'institutional' level according to Deng (2009) who examines the curriculum content of liberal studies with the framework proposed by Doyle (1992a, b). The framework consists of three levels of curriculum structure—the institutional, the programmatic, and the classroom. He argues that a school subject is a socio-technical construct in the form of design (e.g., curriculum frameworks, syllabi, and textbooks). Being driven by curricular policy, the institutional curriculum is based on values and the demands of the society or country. The programmatic curriculum consists of a description of the content in the school subject, materials for use at the classroom level, and learning and teaching activities. The classroom curriculum comprises instructional events and connects with the experience, interests and the capacities of students (Westbury 2000).

The Nature of Science Knowledge and the Purpose of the Science Content Learned Through This Subject

Starting from an institutional perspective, an examination of the official curriculum document suggests that it has explained linkages among the three areas of study in the subject, namely, self and personal development; society and culture; and science, technology and environment. While these are presented as areas of study, they are not found as separate school subjects at lower levels of education. The relationship between science, technology and environment with the other two areas is explained as follows:

> Self & Personal Development < > Science, Technology & the Environment
> Knowledge in science and technology helps individuals to understand many problems that they encounter, so that they can make informed decisions and appreciate their responsibilities to society, to the world and to the environment. On the one hand, the development of science and technology facilitates human exploration of the material world, and improves our lives. On the other, it affects our way of life, our mode of communication and even our ways of thinking. To make better use of science and technology in our lives has become a critical modern concern.
>
> Society & Culture < > Science, Technology & the Environment
> The development of science and technology has helped to hasten social development, reduced the distance between regions, and brought a new impulse to cultural encounters and growth. For today's society, sustainable development requires a simultaneous consideration of factors related to science, technology and the environment. Given that social problems have become increasingly complex, the progress of science and technology needs to catch up with the speed of change in society—but any new technology will also *bring new challenges and problems to society and the environment*. (CDC/HKEAA 2007, p. 12, emphasis added)

From the above descriptions, the purpose of the science content is explicit. Students need to 'make informed decisions', understand how 'to make use of science and technology in our lives' and how science and technology 'bring new challenges and problems to society and the environment'. In terms of science knowledge, these understandings will involve the adoption of an 'explanatory framework' (Aufschnaiter and Rogge 2012) within which the students do not necessarily need to make reference to any conceptual framework, or if so, a minimal understanding or an 'intuitive rule-based approach' will be sufficient.

The curriculum document also provides 'key questions for enquiry' for the two STE modules (Public health and Energy, technology and the environment) in the area of science, technology and environment. These questions are presented in Table 1.

Within each module, there are two themes. In the module 'Public health', theme 1 is 'Understanding of public health', and theme 2 is 'Science, technology and public health'. In the module 'Energy, technology and the environment, theme 1 is 'Influences of technology', and theme 2 is the 'Environment and sustainable development'. Under each theme, the curriculum document provides a few questions for enquiry and some explanatory notes. A summary of the questions for enquiry is provided in Table 2.

Table 1 Key questions for enquiry in the area of study: science, technology and the environment (CDC/HKEAA 2007, p. 15)

Public health	
Understanding of public health	How is people's understanding of disease and public health affected by different factors?
Science, technology and public health	To what extent does science and technology enhance the development of public health?
Energy, technology and the environment	
The influences of energy technology	How do energy, technology and environmental problems relate to each other?
The environment and sustainable development	Why has sustainable development become an important contemporary issue? What is the relationship between its occurrence and the development of science and technology?

Table 2 Questions for enquiry in the modules 'public health' and 'energy, technology and the environment'

Public health
How is people's understanding of disease and public health affected by different factors?
How did people understand the causes of disease in the past? *Was their understanding scientific?*
How is people's understanding of health affected by economic, social and other factors?
How is people's understanding of public health affected by the development of science and technology?
In what ways is people's understanding of public health affected by health information, social expectations, personal values and beliefs in different cultures?
To what extent does science and technology enhance the development of public health?
Can science and technology provide new solutions in the prevention and control of diseases?
In the area of public health, how is the development of science and technology affected by various factors, and what issues are triggered by this development? *How can the fruits of scientific and technological research be respected and protected?*
What challenges do different sectors of society, the government and international organizations have in maintaining and promoting public health?
Energy, technology and the environment
How do energy technology and environmental problems relate to each other?
How does the development of energy technology affect the exploitation and use of energy?
To what extent does the development of energy technology create or solve environmental problems?
What are the implications of environmental change on the development of energy technology?
How do energy problems affect international relationships, and the development of countries and societies?
Why has sustainable development become an important contemporary issue? What is the relationship between its occurrence and the development of science and technology?
How do science and technology match with sustainable development? What are the constraints?
How do the living styles of people and social development affect the environment and the use of energy?
What responses could be made by the public, different sectors, and governments regarding the future of sustainable development?

CDC/HKEAA (2007), pp. 47–55—emphasis added

In considering whether the understanding is scientific, students will certainly need to have some understanding of science concepts and the views of the nature of science. For the other question about 'the development of science and technology', students will need to learn about the history of science. For many of the questions, students need to analyse and work out the relationship between science and other dimensions of understanding, such as the cultural, social and economic perspectives. As a result, the demand on students is beyond a basic understanding of scientific concepts; it requires students to assimilate, apply and integrate their understanding from cultural, social and economic perspectives.

The questions 'Can science and technology provide new solutions in the prevention and control of diseases?' and 'How does the development of energy technology affect the exploitation and use of energy?' require students to apply an 'intuitive rule-based approach' (Aufschnaiter and Rogge 2012). The application of updated scientific understanding is needed if substantive answers are to be provided. If not, for students with superficial scientific understandings, they may not be able to judge if the so-called 'new solutions' or 'development' are in fact novel or if such solutions or developments are effective, and hence be unable to make 'informed decisions', as expected by the curriculum developers. Similarly, in answering the questions 'What are the implications of environmental change on the development of energy technology?' and 'How do science and technology match with sustainable development? What are the constraints?' substantive answers will require an 'intuitive rule-based approach' (Aufschnaiter and Rogge 2012).

In answering the question 'How can the fruits of scientific and technological research be respected and protected?' some understanding of the nature of science is again essential. Students will need to understand how scientific discoveries are shared among researchers as well as with other members of the society. For the question 'How do the living styles of people and social development affect the environment and the use of energy?' students will need to be able to apply their scientific understanding to everyday situations or, as Abd-El-Khalick (2005) puts it, to make sense of science and manage the technological objects and processes in everyday life.

The LS curriculum demands that students apply an 'intuitive rule-based approach' (Aufschnaiter and Rogge 2012) at the minimum. They need to develop a good understanding of scientific concepts, views of the Nature of Science and the History of Science and further apply such understanding in everyday life situations. Further, they need to relate, if not integrate, science understandings with social, cultural and economic perspectives.

If the learning of practical skills and practical scientific inquiry are seen as essential components of science learning, then LS does not offer students learning opportunities to develop these skills. The issue-based approach is built around the discussion of contemporary social issues, in this case, ones that are related to science, technology and the environment. There is no explicit requirement in the LS curriculum for practical science activities, nor does it remind teachers to provide students with opportunities for practical scientific inquiry.

Coherence and Accumulation of Science Learning

In an attempt to answer the question of how and whether the resultant science learning is coherent such that students' science understanding is built up and accumulated as a result of studying Liberal Studies, detail is drawn from both the teachers' manual published by the Curriculum Development Institute (CDC 2012) and the curriculum guide (CDC/HKEAA 2007). Science learning is defined to include knowledge or content, the method of inquiry, as well as views of the nature of science.

First, some background information or basic understanding may serve as a basis for students to build up their scientific understanding. For example, understanding of concepts or understandings such as 'what are food additives', 'types of food additives', and 'the functions of food additives' may be further developed, building on basic understanding, as students study LS.

Second, the inquiry method as advocated by the LS curriculum may be used to gain further understanding of the science concepts. For example, the teachers' manual states that teachers should "engage students in information collection to enhance their understanding related to the topic" (CDC 2012, p. 94).

Third, science understanding is established in LS with reference to its application to life in modern society; basic understanding may support the students in further explorations. For example, the use and impact of renewable and non-renewable energy is an on-going debate, and whether the use of new sources of energy may reduce pollution and the related social concerns (CDC 2012, p. 96) can be further explored when students possess initial understandings. As suggested by the teachers' manual, during the process of inquiry, students are expected to:

- build on personal experience to reflect on personal lifestyles in assessing the impact on the environment;
- adopt different roles such as personal, retailers, environmental protection agencies, government, plastic manufacturers, etc. to understand the debate of plastic bag tax;
- work out ways to balance the quality of personal lifestyle, economy, social development and protecting the environment;
- analyse present and past situations and work out possible solutions;
- evaluate the effectiveness of the plastic bag tax and prepare for the future. (CDC 2012, p. 94)

These processes are related to the study of the nature of science. Students' understanding of science and technological objects may explain processes in everyday life, inform their decision-making, and help them appreciate the value of science in society and culture, while the implications of scientific advancement for moral commitments are to be accumulated and built up through their study of these two modules.

Conclusion

The analysis of the LS curriculum guide and the related teachers' manual presented above suggests that students are likely to apply an 'exploratory approach' or 'intuitive-based approach' in order to inform their decision-making as citizens. However, in order to provide comprehensive answers to questions related to the impact of new advancements in science and technology, students will need to apply an 'explicit rule-based approach'. As for the purpose of science learning, scientific understanding is to help students to 'make informed decisions' and understand how 'to make use of science and technology in our lives' and how science and technology 'bring new challenges and problems to society and the environment'. Further, students are required to work out the relationship between science and other dimensions of understanding, such as the cultural, social and economic perspectives. However, the LS curriculum does not offer opportunities to develop either science process skills or practical skills.

As for whether students' understanding is coherent and accumulated, continual effort will be needed by students to apply the methods of inquiry they learn from the subject. In order to address questions related to the impact of scientific advancement as listed in the curriculum, sound understanding of the nature of science is crucial. In order to meet these demands of the curriculum, either students have to start their LS in Secondary 4 with a relatively strong science background, or the LS curriculum needs to provide time and opportunities for them to enhance their science learning. For example, students need to have experience with scientific inquiry projects, and to have learned about the Nature of Science and/or the History of Science. This latter suggestion, to enhance the science component in the curriculum, would require revisions of the aims and content of the LS curriculum would need to be put forward.

In recent attempts to review the New Senior Secondary Subjects, initiated by the government, there were suggestions to make the LS curriculum less challenging for both the students and teachers, with proposals to reduce the curriculum content. This could involve a reduction in the content of each module or a reduction in the number of modules. For example, suggestions include the deletion of both modules related to science or the integration of the content of these two modules into the rest of the curriculum. It is suggested that the assessment component, which takes the form of student-led inquiry (Independent Enquiry Studies, IES), be revised to involve a secondary analysis of information or data or a documentary analysis. These suggestions confirm a perception among teachers that the curriculum is overcrowded. As teachers without a science background will be teaching the subject, it is not surprising to see the suggestion of deleting or integrating the two science modules. Student workload is seen to be heavy and hence teachers urge clarification that in the IES component, the collection of first-hand data is not required.

If the suggestion of deleting the science modules is accepted, science educators will likely regard this development as a loss of a good opportunity to integrate science learning with other subject domains, making it meaningful and accessible to all senior secondary students. In considering revisions of the curriculum, I strongly recommend a holistic consideration of students' science learning experience. Curriculum developers should consider different forms of science learning, i.e., understanding of scientific concepts, scientific inquiry, nature of science and history of science. At the same time, the current emphasis on integration and application in everyday situations, as well as with cultural, social and economic perspectives, is retained.

In addition to considering ways to enhance the curriculum content to strengthen students' science learning, curriculum developers should seriously consider teachers' understanding of science. The science education literature suggests that teachers retain their subject-specific responsibility and tend to focus on science discipline-based knowledge. Attempts at integration, providing opportunities for application or adopting a holistic view of knowledge, need to be encouraged (Lear 1993; Venville et al. 2008). The LS curriculum is situated near an extreme end of the curriculum integration continuum proposed by Fogarty (1991), where science disciplinary-based knowledge is almost non-existent. The revision of the curriculum will need to address the balance between both ends of the continuum. In addition, learning and teaching can be designed to be beneficial from both a disciplinary-based perspective and an integrated perspective of the curriculum.

The next issue to be investigated would be the relationship between teachers' understanding of the LS subject and whether and how this influences student learning. As the subject is in its early years of implementation, there is still much discomfort among teachers in teaching the subject. Wilson and Kittleson (2012) propose developing a theoretical framework to describe and explain teacher discomfort. In fact, Frykholm (2004) describes 'debilitating' and 'educative' discomfort for teachers. The former relates to teachers who are concerned about the appropriateness of the curriculum and the adequateness of their own conceptual understanding to implement the curriculum reform. The latter refers to teachers who are able to "tolerate discomfort" and use it as a "pedagogical tool" (p. 146). Moreover, differences in pedagogical methods in teaching a discipline-based subject and an interdisciplinary subject need to be considered by curriculum developers.

Beyer and Davis (2009) call for an investigation into Pedagogical Content Knowledge (PCK) for science teachers and their curricular planning decisions in analysing the adoption of curriculum reform initiatives. In fact, the two science modules in the LS curriculum would be best taught by science teachers as they are more aware of enhancing students' science learning. It may be too much to require that teachers without science backgrounds achieve the integration and application of science understanding in social, cultural and economic perspectives. This tension is evident in the suggestions to delete the two science modules in the recent curriculum review.

Critics have also raised issues related to high-stakes assessment and the subject being assessed in a public examination. Educators and teachers have warned that this move would deter teacher professional freedom, instructional imagination and creativity (Luke et al. 2008). Although the aims and the learning outcomes for students are explicit in the curriculum document and teachers' manual, the impact of public examination on the achievement of the planned learning outcomes remains to be seen. Finally, the analysis in this chapter is based on an 'institutional' curriculum plan (Doyle 1992a, b); study at the 'programmatic' and 'classroom' levels will provide further information on whether the different forms of student learning have in reality taken place.

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Pursuing Different Forms of Science Learning Through Innovative Curriculum Implementation

Greg Lancaster, Debra Panizzon and Deborah Corrigan

> *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)

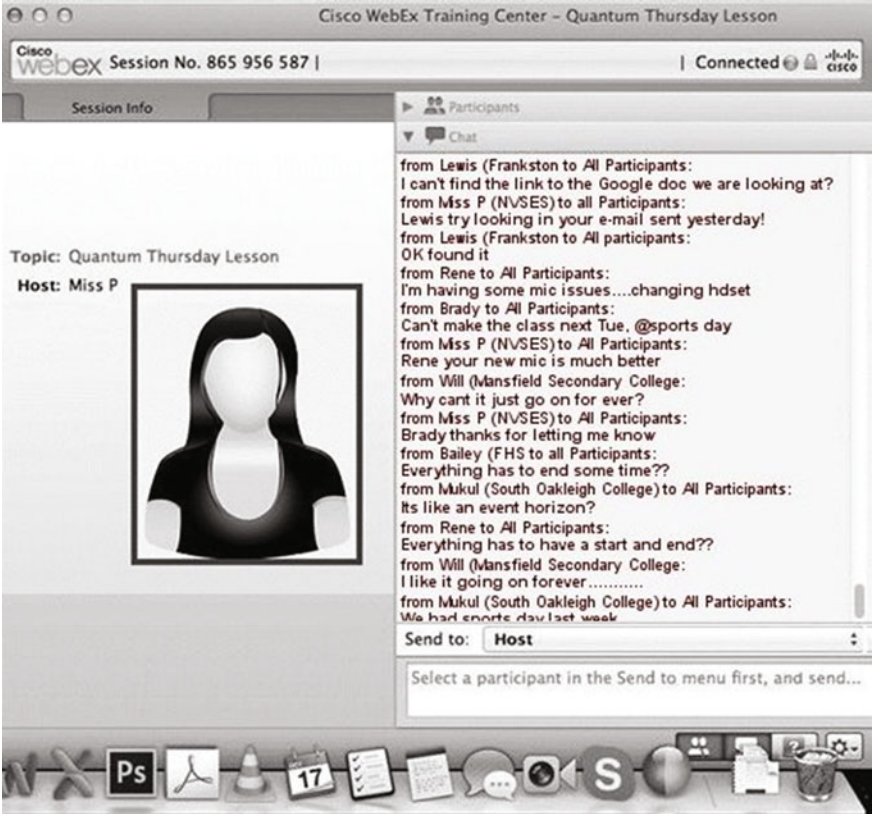
Clearly, the focus for most students in these responses is about how their understanding of science has changed. However, the last two quotes demonstrate wider acknowledgement. The first response indicates that the activities and discussions included during NVSES classes have encouraged students to explore 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



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

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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Reconceptualising the Learning and Teaching of Scientific Concepts

Colette Murphy

Introduction

In a recent discussion with physicist colleagues about ways to address high attrition rates for first year undergraduate science courses (see, for example, Matz et al. 2012) the subject of difficult science 'concepts' arose. We argued about the nature of concepts and whether they actually existed or whether they were human constructs, developed in attempts to explain natural phenomena. One physics colleague, Jack (pseudonym), found this disturbing: "What about *magnetic flux density* then, are you saying it's not real?" We discussed assertions that scientific concepts could be theorized as *tools*, constructed using scientific investigation and that some are better than others for use in explaining specific phenomena and that all can be refined. Jack was disturbed, and said he needed to go away and think hard about this.

This chapter explores the use/misuse of scientific concepts in teaching. It attempts to provide an action-oriented view of concepts as dynamic, changeable, contextualized and usable *tools* that have been developed over time to help explain the world around us and how it 'works'. Learners and teachers can critique these tools: Are they all 'good'? Which ones are fit-for-purpose? Have all been demonstrated definitively to exist, or are some still models (the atom?)? It considers the work of Vygotsky and his followers, among others, and suggests ways in which students and teachers can think differently about learning and teaching science concepts in school and undergraduate science classes. Vygotsky's work helps to address many questions relating to scientific concepts and their development.

Vygotsky (1896/1934) lived until he was just 37 years of age, yet his legacy continues to affect learning and teaching 80 years after his death. Science education researchers recognised the significance of Vygotsky's work for transforming the

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learning and teaching of science around 20 years ago (Driver et al. 1994; Howe 1996; Lemke 2001; Wells 1994). More recently, citations of Vygotsky in science education journals have increased significantly, although there is little evidence of researchers reading Vygotsky deeply and applying his constructs systematically in research and practice. For instance, Lima et al. (2014) cite a handful of studies in which "meta-theoretical commitments to dialectical materialism have been put to work as tools for original theorization in various sensible different situations" (p. 562). These four studies include those of Wells (2008) and Murphy and Carlisle (2008). This chapter is based on a close reading of Vygotsky and other scholars' work on concepts and how such ideas can help science learning and teaching.

Currently, many scientific concepts are presented as 'entities' to be 'learned' and are difficult to transfer to everyday and current science research and practice contexts. In this chapter I revisit learning science via a sociocultural perspective, in which science learning and teaching is not organized for a 'generic' learner, but is structured to support the learning and contributions from diverse learners (see also Reiss, this volume). Learners and teachers use scientific concepts collaboratively in meaningful contexts, promoting science as asking questions and searching for explanations of phenomena, which is not always straightforward. Firestein (2013) describes the process of scientific endeavour as akin to looking for a black cat in a dark room, and there may not even be a cat in the room. His advice for getting the feel of how scientists think is:

> Next time you meet a scientist — at a dinner party, at your child's school, just by chance — don't ask her to explain what she does. Ask her what she's trying to figure out. (p. 82)

The notion of *using*, as opposed to *learning* scientific concepts, underpins much of the argument in the chapter. This idea arises from writings of Vygotsky and Wittgenstein; the latter suggested in his later corpus that the meaning of concepts lies in their *use* in particular contexts. The idea was also key to the discussions of the 'ordinary language' philosophers of the mid-20th century, who suggested that it is more fruitful to *use* high-level concepts (e.g., time) than to try to define them. We can then define lower-level concepts (e.g., watch) only because we are able to use the higher level concept on which it depends. It is common, however, in science classrooms for teachers to expect students to learn specific definitions of concepts (e.g., energy) outside of a context, instead of considering the different ways the *idea of energy* is used both within and outside science. I will be advocating ways that we can engage students in their learning more positively if we loosen our reliance on considering concepts as universal, permanent entities.

An outline of the ideas in the chapter is presented in Table 1. The chapter is constructed in three main sections: the nature of scientific concepts, how they develop, and classroom research into scientific concept development.

Table 1 Moving towards a sociocultural view of scientific concepts

Traditional	Sociocultural
Nature of scientific concepts (SC)	
SC exist as entities	SC are created as **tools**
SC represent ‘truth’	SC created in scientific endeavour
SC are independent of culture	SC are culture-dependent
SC are universal	SC are context-bound
SC are permanent	SC are subject to change
Ideas and theories of scientific concept development	
Maturation is the driving force of development of SC—abstract concepts develop later	The social world is central to and mediates the development of SC—toddlers use abstract conceptualisation in play
Development leads learning of SC	Learning leads development of SC
SC develop linearly	SC development is dialectic and occurs via the ZPD (see Fig. 1)
The development of SC is progressive	Development of SC comprises zigzags, gaps, regression, and conflicts
Students’ SC are either correct or ‘misconceptions’	Students’ SC represent their best try at explaining phenomena
SC development occurs when misconceptions are challenged via cognitive conflict	SC development occurs via thinking in complexes and pseudoconcepts
SC development is independent of emotion	Development of SC requires emotion
Classroom research on scientific concept development	
Teachers create science content for children to learn SC, based on curricular guidelines	Children learn meaningful science oriented within four major concepts: place, time, materials and conscious reflection
Verbalization of SC is assessed as learning	***Use*** of SC is assessed as learning
Logical SC ‘grow’ from experience	Learning of SC requires bridging into scientific convention
SC are learned independently, e.g., via IBSE	Learning of SC is mediated via cultural tools, including language, signs and symbols
Children learn SC individually	Children learn SC socially
Learning SC does not require student dialogue	Learning SC requires forms of dialogue
Learning of SC is reactive to the teacher	Learning SC occurs via dialogue and problem-solving
SC are ‘created’ by the teacher for students to learn	SC are co-constructed by students and teachers
Primary science requires children to learn basic SC	Primary science provides opportunities to derive scientific explanation from close observation
SC taught over a short period	SC are developed over a long time
The direction of learning SC is bottom-up	The direction of learning of SC is top-down

The Nature of Scientific Concepts

Most definitions of a scientific concept refer to it as an idea, or law, which helps to explain a phenomenon under investigation. Taxonomies have been developed, but none of these have generated wide acceptance—it is difficult to reduce the levels of complexity into a single framework. Definitions can limit the scope of scientific concepts in that they exclude the entire *process* of scientific endeavor. What about the concept of *inference*, or indeed *investigation*? Voelker (1975) suggested that such concepts are themselves major scientific concepts that need to be included within a broader definition. But how so?

For educational purposes, Vygotsky proposed a 'super-concept' framework that defines all human activity within the environment. There are four major concepts in this framework (Kravtsova 2010):

- *Time*—all human activity in the world occurs in a certain time;
- *Space*—all human activity takes place within a space, or place;
- *Substance*—all human activity uses substance, or materials;
- *Conscious reflection*—human activity differs from other animals because of the element of reflection on what, how and how to improve the action or activity.

It could be argued that this framework provides a structure in which every scientific concept can be subsumed. We can find a place for the 'process' concepts within Vygotsky's framework under 'conscious reflection'.

Theoretical Considerations of the Nature of Scientific Concepts

In his theoretical consideration of concepts, Vygotsky used a model from classical mathematics that suggests that ultimately concepts are all subsumed into one logical system, which he refers to as a system of equivalences:

> The higher levels in the development of word meaning are governed by the law of equivalence of concepts, according to which *any concept can be formulated in terms of other concepts in a countless number of ways.* (Vygotsky 1934/1986, p. 199, emphasis in original)

His broad grid for concepts is based on the surface of a globe, onto which every concept can be placed using a system of coordinates, corresponding to latitude and longitude in geography. A concept's 'longitude' relates to its degree of abstraction, and thus characteristic of thought processes, while its 'latitude' represents its objective reference, for example: plant or animal.

The geographic analogy is only useful at a surface level, however. Vygotsky himself emphasised the limitation of the geographic analogy as being neither complete nor accurate, although it has been used since, particularly in philosophical considerations of concepts, such as in the work of the 'ordinary language' philosopher, Gilbert Ryle. Vygotsky contended that in a *true scientific concept*, the bonds between the parts of an idea and between different ideas are logical; thus the ideas form part of a socially constructed and accepted system of hierarchical knowledge (Berger 2005).

Science Concepts as 'Tools'

More recently, as the field of science education has embraced sociocultural theory, the idea of scientific concepts as 'tools' for use in helping to explain and understand phenomena has become much more accepted. Wells (2008) argues that scientific concepts are not possessed by individuals; rather they provide cultural resources, which are used for a variety of purposes. Thus, scientific concepts can be considered as 'cultural tools' developed by scientists, to help describe and explain the world around us. Mastering their use, Wells suggests, is best developed when students are engaged in scientific problem solving, which requires these 'tools'.

Vygotsky first developed the notion of *cultural tools* via a dialectical synthesis of the thesis that human cognition developed through the use of physical tools (made, for example, from stone, iron and bronze) and the antithesis that human cognition developed via the use of communication. His synthesis of these two arguments was to suggest that human cognition developed from a combination of tools and communication: the development and use of *cultural tools*, the main one of which is language. Cultural tools are the signs and symbols that comprise the mechanism for the development of higher cognitive skills, or, in today's parlance, *thinking skills* (Gredler and Clayton-Shields 2008). They include graphs, charts, symbol systems and language. When humans first made use of physical tools, they communicated with each other ways that the tools could be best used for various purposes (gestures, etc.). Thousands of years later, speech evolved and 'knowledge' became stabilised as 'cultural tools' (for instance, descriptions of tool use in different contexts) within oral tradition, which was passed to subsequent generations. Vygotsky argued that human cognitive development is different from animals in that it is largely, although not entirely, based on language (van der Veer 1994). This collective memory, or knowledge, was externalised with the invention of writing. Knowledge was more permanent and thus independent of who produced it, and became written 'objects' used for education in different cultures (Wells 2008). Knowledge was thus passed on via collaborative activity using cultural tools, such as pictures, diagrams and writing. As science developed, concepts were created, based on empirical observation and thorough scientific investigation, to help explain phenomena.

Here we have a much more *active* description of scientific concepts. They are constantly being tested for their ability to function as tools in different contexts. Some tools are better than others at doing a specific job. It could be the case that some scientific concepts serve the science context well, but not the science education context—for example, respiration. The term ‘respiration’ is confused with breathing by younger learners, and the biochemistry of respiration is far too difficult for most senior school biology students to understand, unless they have a good knowledge of chemistry. Some concepts are very tricky to use, especially if there is complex mathematics involved, such as relativity theory. Are the scientific concepts we use in schools for science learning fit for purpose? Or is the question: is the *way we teach* science concepts fit for purpose? It can be useful for students to be made aware that each scientific concept has been generated during the investigation of specific contexts and then replicated to test its generalisability. Science concepts are not permanent, however; they change with time and new technologies. Fensham’s chapter (this volume) argues for learners to become connoisseurs of science. His ideal can be developed in school science with increased attention to discussions of how, where and when various scientific concepts came about, including the associated difficulties, political and technological barriers and enablers, as well as other human factors, to engender a deeper appreciation of the scientific endeavour.

Development of Scientific Concepts

The way(s) learners develop scientific concepts has been debated for many years. Conceptual change. Has become very popular in recent years; it was believed that students suffered ‘misconceptions’ about phenomena and in the process of cognitive conflict when they were challenged with the scientific explanation, they went through a process of conceptual change, drawing on their growing science knowledge and that of teachers and peers (Hewson et al. 1998).

Conceptual change, however, has not delivered the learning gains needed, for example, university physics students still misunderstand very basic concepts as evidenced by consistent poor performance on the force concept inventory test (Miller et al. 2013). Miller et al. look to different explanations as to why some scientifically wrong ideas persist at university. They suggest that unless learners are *using* scientific concepts in, for example, problem-solving, it is unlikely that they will retain the scientific explanations they are presented with after they have learned them for a test or examination. It could be that such scientific concepts are not good for learning out of context and that we need to apply different pedagogical approaches to affect the understanding of specific concepts.

Another factor that is becoming increasingly important in science conceptual learning is the role emotion plays. Vygotsky proposed the importance of the *unity of affect and intellect* in the zone of proximal development ZPD—that emotion and learning are interdependent. It is impossible to learn without emotive engagement (Reid 1788/1969) and other higher mental functions (Mahn and John-Steiner 2002). Matthews’ chapter (this volume) provides more discussion of the crucial role of emotion for science learning.

The rest of this section summarises research into scientific concept development in children over the past century. Perhaps the strongest idea to come from this work for today's science classrooms is the prevalence of pseudoconcepts in science learning—students can repeat the scientifically correct concept to gain examination credit without understanding its nature or being able to apply it.

Very Young Children Use Abstract Thought

Children are capable of abstract thought from a very young age. Vygotsky suggested that children's imaginary play is key to their ability to abstract. For example: a child playing with a cardboard box and using it as a 'shop' for play purposes—the child affords the box certain characteristics of 'shopness' during the game. Imaginary play is not often seen in the classroom science in many schools; most 3–5-year-old children are playing like toddlers, just manipulating objects, such as sand and water, and not engaging significantly with other children (Murphy 2012).

Vygotsky maintained that creating an imaginary situation in play provides a means by which a child can develop abstract thought. Children develop abstract thinking via the use of objects—for example, toys, props, clothes—in make-believe play. Such a use of objects for pretend rather than real-life purposes serves as a bridge between the sensory-motor manipulation of objects and fully developed logical thinking, when the child can manipulate ideas in their heads. Using various props to separate the 'meaning' of the object from the object itself. For example, to drive a block on a carpet as is it were a truck (giving the block 'truckness') acts as a precursor to abstract thought. The best kind of play to develop abstract thought is where children use unstructured and multifunctional props, as opposed to those which are realistic. Non-realistic props strongly promote language development to describe their use. For example, a cardboard box may serve first as a shop, then as a school, then as home. Vygotsky suggested that this repeated naming and renaming in play helps children to master the symbolic nature of words, which leads to the realisation of the relationship between words and objects and then of knowledge and the way knowledge operates.

Vygotsky's perspective on play also connects it to the social context in which a child is brought up. He maintained that adults and older children should also be involved to enable the younger children to model both roles and the use of props. Vygotsky promoted the notion that play, as learning, should lead development, as opposed to the more accepted one of development leading learning or play. Veresov (2004) discussed learning that takes place in or within children's play. He used the Vygotskian example of a child playing with a stick by using it as a horse. The child will learn about the object (stick) and its objective physical properties, but she/he will also decide whether such properties allow or prevent the stick from becoming a horse. If the object does not suit the play task, the child will stop playing with it.

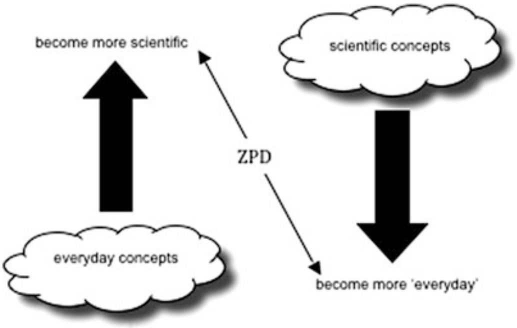
In primary school science, a Vygotskian perspective would presuppose that teachers promote role-plays and imaginary play in science learning for children throughout the primary school to further the development of abstract, conceptual thought. There would be a lot less focus on individual play with objects and more on collective play, preferably involving older children who can model both roles and the use of props for the younger ones.

Concept Development Is Dialectical, Not Linear

Vygotsky (1934/1986) proposed a dialectical, as opposed to a linear, model for the development of scientific concepts: "the child's scientific and [her or] his spontaneous [everyday] concepts… *develop in reverse directions* …they move to meet each other" (p. 192, emphasis in the original). Using the example above, the students' everyday concept of a *puddle* develops more scientifically when they learn about evaporation; at the same time, their concept of *evaporation* will become more everyday to them when applied to familiar contexts, such as puddles and perspiration.

Vygotsky proposed that teachers create a *zone of proximal development* (ZPD) between the scientific and everyday concepts by illustrating and emphasising the *relationships* between them and showing how the scientific concept can be utilised to explain the everyday concept, while simultaneously raising the everyday concept towards its scientific conceptualisation (see Fig. 1). For instance, a child may have a rich understanding of the everyday concept *brother* but not be able to define it in the more logical, conceptual way as *male sibling* (Panofsky et al. 1990). The task of the teacher, for Vygotsky, is not to evaluate individual conceptions as correct or as 'misconceptions', but rather to help the child, through instruction with respect to the *relationship* between concepts within a system of concepts, and to develop conscious awareness and voluntary control of her/his own thinking (Wells 2008).

Fig. 1 Dialectical model of concept development



The Process of Forming Scientific Concepts

Most of the science education research literature regarding scientific concept formation relies on the work of Piaget (1955, 2001) and Vygotsky (1934/1986) and their followers. The general argument is whether (a) it occurs via replacement of child (egocentric) concepts by adult ones as children get older (Piaget) or that (b) scientific concepts are formed from learned experiences in which children first exhibit 'pre-conceptual thinking', which shows evidence of organising thoughts and some abstraction, but not of systematic thinking or sophisticated abstraction.

Over two decades ago, I argued that both of these explanations underestimated young children's thought in terms of coherence and systematic thinking (Murphy 1987). The study involved 280 children (5–7-year-olds) who were recorded during a game in which a child described the meaning of a scientific word (concept) without using it for the rest of the class to guess the word. Despite a large proportion of the responses being context-bound, children's descriptions evidenced definite, coherent ideas about most of the concepts. Many 7-year-olds demonstrated a level of abstraction beyond that predicted by Piaget or Vygotsky. For example: the description of *amount* as *degrees*; *weather* as a *sort of condition*; *transport* as *types of vehicles*, and *idea* as *a plan*. I argued that the limiting factors in the development of scientific concepts could be largely related to lack of vocabulary, experience and specific conceptual frameworks, as opposed to the lack of systematic thinking.

The Vygotsky Blocks Experiment

Vygotsky and his co-workers explored the process of concept formation using a series of *double-stimulation* experiments. Double stimulation is a principle according to which a subject, when in a problematic situation, turns to external means for support in order to be able to act (Vygotsky 1997). The problem is the first stimulus and the external means is the second stimulus. Vygotsky's double stimulation method placed learners in problem-solving situations that were different from any learning they would have experienced. The experiments thus investigated the formation of *new* concepts via problem-solving tasks requiring the use of non-verbal *signs*. The signs provided a way to solve the problem (Sakharov 1928). Vygotsky and his co-workers studied the ways that learners of different ages struggled or successfully used these aids, documenting changes in learner activity and accompanying changes in cognitive functioning. The task was to sort a set of wooden blocks of different colours, shapes and sizes into four groups. The experiment was repeated more recently by Towsey (2007), who described the blocks as follows:

> The material comprises 22 wooden blocks of five colours (orange, blue, white, yellow, and green); six geometric shapes (isosceles triangles, squares, circles, hexagons, semi-circles, and trapezoids); two heights; two sizes (diameters); with the labels **cev**, **bik**, **mur**, and **lag** written underneath them (**lag** and **mur** having five blocks each, and **cev** and **bik** having six). (p. 3)

The labels in Towsey's description represent the signs that provide a way to solve the problem. There are four labels and four groups. At certain points while working on the task, the participant is invited to look at a label and see if the clue aids its solution. The solution is that the *lag* blocks are all tall and big; the *mur* are tall and small; *bik* are flat and big; and *cev* are flat and small.

The blocks experiment formed part of a series carried out by Vygotsky and co-workers, which led to the proposal of the stages that are passed through in the formation of concepts by children. The stages comprise *random grouping*, *thinking in complexes, pseudoconcepts* and *true concepts* (see Fig. 2).

The youngest children grouped objects 'randomly', according to chance or some other subjective impressions. Older children demonstrated that they were thinking in complexes, in which they began to abstract or isolate different features, or attributes. These were related to the child's experience, not using logical thinking. At this stage the child is showing evidence of organising thoughts, which lays the foundation for more sophisticated generalisations. Such pre-conceptual thinking is deemed necessary for successful mathematics (Berger 2005) and scientific concept construction. The next stage is the development of pseudoconcepts, which can be confused with true concepts because the learner might be using the right words to describe the concept, but lacking the logical connections between its parts. The learner is able to use the pseudoconcept in communication and activities, such as exams, as if it were a true concept. For example, the learner may use the definition of an ionic bond to describe how it differs from a covalent bond without understanding the nature of chemical bonding. The words of the learner and teacher may refer to the same idea, but their meanings may not be the same (Gredler and Clayton-Shields 2008). Berger (2005) suggests that true concepts are formed from pseudoconcepts via the *appropriate* use of signs and social (frequently teacher) interventions, thereby forming a bridge between the individual and social meanings.

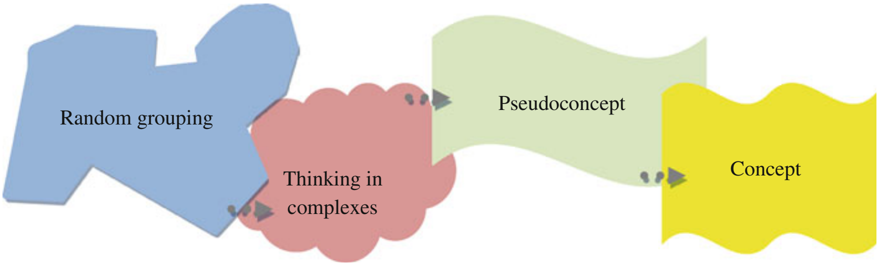


Fig. 2 Scientific concept formation stages

A true concept is bound by *logical* bonds within parts and between different concepts.

The Prevalence of Pseudoconcepts in Science Learning

Many students pass science exams using pseudoconcepts, and only develop the full meaning much later, if at all. The teacher or exam marker may wrongly assume that there is no need for further development.

This confusion between identification of pseudoconcepts and concepts accounts for the common experience of pre-service science teachers that they only begin to understand science when they start to teach it. They might have used personally meaningful pseudoconcepts to communicate knowledge successfully using the written form, including appropriate use of signs, symbols and scientific terminology. But this may not have been as useful when trying to explain a similar idea without the 'props' of the signs and symbols. It could also explain the experience of tertiary students who find that many professors who are experts in their field can give excellent lectures in language they can all understand, whilst less expert academics frequently hide behind terminology and complexity. True concepts are learned with conscious awareness (Gredler and Clayton-Shields 2008) and promote the development of everyday concepts into the accepted scientific framework, where they can be used, further developed and critiqued.

A major problem in concept development is recognition of when true conceptual thinking is being demonstrated. Unless this process involves evidence that learners are *using* the concept(s) appropriately, it could be argued that it is a pseudoconcept, not a true concept. Another issue is the case that learners can be thrust into problem-solving with new concepts before they have developed them sufficiently for the task, resulting in incomplete concept formation. The eventual formation of true concepts indicates that the learner is now able to master their own thinking. One of the most difficult tasks for learners, according to Gredler and Clayton-Shields (2008), is to learn the connections and relationships between concepts. Their advice is for students to construct a large visual diagram of the concepts in the topic, and between topics, as the term progresses. This activity requires pre-planning by the teacher to identify the required concepts for learning in advance.

The ZPD in Scientific Concept Development

The ZPD represents the total interactions between the learner and others and with their environment, which need to take place between subsequent stages of development in, for instance, the learning of particular scientific concepts. The 'zone' therefore represents the 'buds' or 'flowers' of learning, leading to the 'fruits' of the next stage. Vygotsky first described the creation of ZPDs in terms of levels of assistance given to learners of the same 'actual' cognitive level (for example, same IQ scores) in solving more difficult tasks. Despite being measured at the same level, one child might solve the task with very little help (the support is thus within her/his ZPD for the task), while another may not solve it even after several different interventions designed to support the learning (the support is outside the learner's ZPD for this task). Such interventions may include: demonstration of the problem solution to see if the child can begin to solve it; beginning to solve it and asking the child to complete it; asking the child to solve the problem with the help of a child who is deemed more able; explaining the principle of the needed solution, asking leading questions, analysing the problem with the child, etc. (Gredler and Clayton Sheilds 2008). Vygotsky considered performance on summative tests as an indication of the child's past knowledge and argued "instruction must be orientated towards the future, not the past" (Vygotsky 1934/1962, p. 104).

Vygotsky's later work, as well as that of his followers and other scholars, has extended ZPD creation to include a much broader range of interventions, including changes in the learning environment, selecting tasks to promote scientific thinking, and enabling meaningful scientific dialogue between peers and teachers. All of the examples of classroom research in the next section focus on ZPD creation to facilitate the learning of scientific concepts as tools, as opposed to entities.

Classroom Research in Scientific Concept Development

In teaching scientific concepts, we aim to: develop student understanding of the concept(s), make the learning meaningful in relation to school and out-of-school experiences, and enable students to appreciate and *interact* with the world of science, which uses concepts in codified and regulated contexts. The third aim is most neglected and yet, it could be argued is the most vital for engaging students to think and learn about the world as it is and its future. Below I provide some classroom research examples of how scientific concepts can be used in more interesting, dynamic and active ways in learning and teaching science.

ZPD Creation to Enhance Children's Meaningful Science Learning

There are a number of experimental schools in Russia, designed on Vygotskian principles, called *Golden Key* schools (for details, see Kamen and Murphy 2011). In these schools, experiments, hands-on experiences, readings and discussions about science during the ages of 3–10 are considered foundational to true scientific thought, especially when children are encouraged to *theorise on their experience of* *observed phenomena*. In the *Golden Key* schools, ZPD creation to enhance children's meaningful learning is facilitated by mixed-age teaching, paired pedagogy and situating children's learning in a context that is meaningful, interesting and that motivates them to learn.

To facilitate children's experiences with and development in their thinking about science (as well as the other academic areas) the *Golden Key* Curriculum has a 4-year cycle of themes, based on Vygotsky's four super-concepts:

- Space (or place)
- Time
- Substance (or Material or Matter)
- Reflection

Place

When children start school at the age of 3, 'place' is the first concept focus. They are 'oriented' first in a group 'place' within the room, then in their own place within that group. They begin their exploration of place by working with the teachers to 'set up' the room. They bring in artifacts from home, including photographs, small ornaments, etc., which are placed on each child's table area and thus link the school place with the home place. Older children then take the younger ones around the school and gradually introduce them to the whole school and all who work there, including the other teachers and catering and cleaning colleagues. Early work with maps includes showing how to find other rooms in the school. When children are totally familiarised with the school, they reflect on this learning by inviting parents and relatives to the school, and children give them a tour of the school and its community. The 'place' orientation continues as children develop by orienting themselves between home and school, then in the local area, etc. Each classroom has a set of large wall maps, superimposed upon each other, so that children can orientate all of their learning in the 'place'; behind a map of the town (in the school I visited) was one of the province, behind this a map of Russia, then Europe and so on until the maps at the back were of the cosmos.

Teachers support children's ongoing exploration of place by creating imaginary journeys connected to the event that serves as the core of the lesson. These multi-age imaginary expeditions provide opportunities for children to engage in science learning. Teachers provide a context for older and younger children to explore life, earth, and physical science concepts. They set up imaginary interactions with science phenomena during the children's "travel". As they go on their "journey" they may look, for example, at which side of the rocks the moss grows or where the sun is—developing a connection between the moss and the sun, helping them develop a powerful understanding of scale. Older children may discuss these connections with the younger children. Children are introduced to, for example, the three states of matter by "encountering" water as steam, water, and ice or snow in their adventure.

Time

Similarly, children are oriented within the concepts of time, materials and reflection. Figure 3 shows a timeline, which children constructed as a 'time-based' activity for their own classroom. Their timelines start with the beginning of life on earth, and children can orient their science learning in time using them. For instance, they can mark the times when dinosaurs roamed the earth, the discoveries of fire, the wheel, electricity, the Moon landings, etc. They can use the timeline to visualise life spans of large trees, humans and elephants and to consider themselves in relation to older members of their family, ascendants and younger members. During the study of time the school creates a "time machine" and during their "time travel" they become aware of great scientific discoveries. They realise there was a time before electricity was harnessed and explore a time with no cars and where horses and candles were used instead of cars and electric lights. The goal is to help children to experience, in imaginary play situations, life before these discoveries. The time machine also "takes" children to the future—allowing children to use their spacecraft to travel to planets, solar systems, and galaxies. They explore flora and fauna. Through their imaginary travel, they investigate the cosmos and compare it to Earth. For example, children may compare the atmospheric pressure, surface temperature, and length of day on Venus to Earth.

The placement of the present day in terms of their cultural historical context is viewed as important to allow and facilitate the children's mediation with their world and in turn promote development. As with the children's interaction with space, the imaginary and real interaction with time by a multi-age group, and with the support of teachers, provokes development and foundational (both real and imaginary) encounters with science concepts.

Fig. 3 Timeline to help children orient their science learning in 'time'

Substance

In relation to the ‘substance’ concept, children use materials in different ways depending on their age. Early exploration of materials is important for speech development. As children get older they focus on manipulating a wide variety of materials and theorise on these experiences to arrive at logical explanations of phenomena. Vygotsky maintained that children at elementary level need to be encouraged in such activities for science learning, which are vital for the later development of conceptual thought within the concepts constructed by generations of scientists. This world of science has its own ‘culture’ based on specific scientific tools such as signs and symbols, into which children will be encultured mainly at a later stage of their development (post-11) when they are taught by scientists or by teachers who have a good knowledge of science. The early theorising about children’s observations of phenomena is also how children become oriented within a framework of ‘reflection’. They are invited to present their ideas to other children and their teachers and to listen to and incorporate other ideas into their own reflections.

Reflection

During the 4th year, the year of reflection, these scientific methods and concepts switch from becoming the focus of science to the method of understanding and comparing and understanding different cultures. All the children have partially formed scientific understandings: emerging concepts that become more complex as they get older. The science study becomes more focused as an academic subject. An experiment is typically conducted with the whole (multi-aged) group at a *Golden Key* school. The older children also discuss experiments in their separate class period. Then they come back to the whole group, and with the teachers’ help, discuss the experiment with the younger children. Science becomes more formalised, with experiments providing the context for the older students’ science ‘reflections’. This formalisation through the students’ theorising at multiple developmental levels prepares them for more abstract and generalised understanding in middle school.

Creating ZPDs to Bridge IBSE with Scientific Convention

Inquiry-based science education (IBSE) needs to connect the task explicitly with the scientific context to ensure that the learning is meaningful. Rubtsov (2007) describes such a setting involving seven to 9 year-old children:

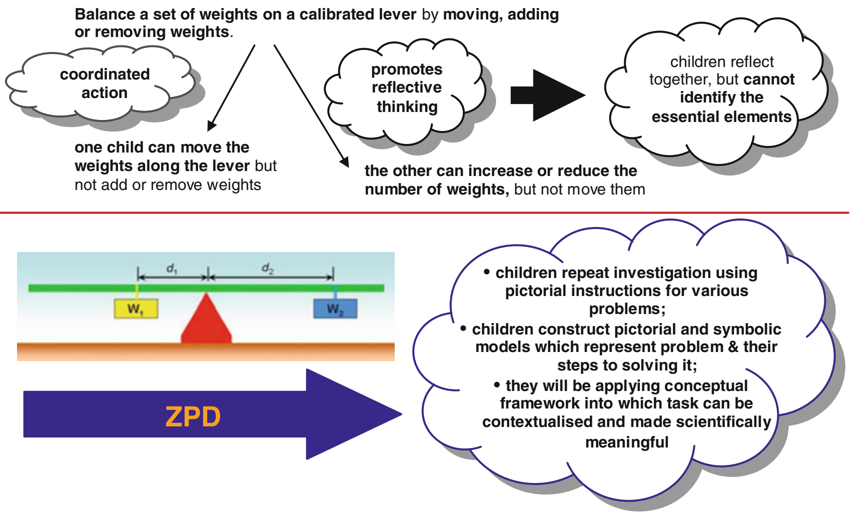


Fig. 4 ZPD to bridge IBSE with scientific conventions

> Two children must work together to balance a set of weights on a calibrated arm by moving, adding or removing weights. To solve this problem, they must take into account the relationship between each weight and its distance from the arm's centre of gravity. One participant is allowed to move the weights along the arm but not to add or remove weights; the other may increase or reduce the number of weights, but not move them. This division of activities, therefore, requires the two participants to work together, coordinating their activities in order to solve the task successfully. As the children move to the next problem, they switch roles. (p. 10)

Rubtsov (2007) cautions that such activities, while promoting reflective thinking, do *not* guarantee that each child will be able to identify the essential elements of the task. He suggests that to increase the effectiveness of the activity, children should be provided with *pictorial and symbolic models* to represent the problems they are solving and the steps they use to solve them. Hence they will be applying a conceptual framework into which their activity can be made scientifically meaningful. The pictorial and symbolic models, together with the discussion generated between learners as they complete the task, will become more meaningful to the children (and more so again with continued use with new, similar activities) (see Fig. 4).

This type of work will help to promote thinking and stimulate children to reflect and explain in order to understand how their experiences and their context-bound knowledge fit into a larger scientific system (Howe 1996). The teacher is essential here to guide the work and provide the conceptual framework. Howe argues that a contrasting, Piagetian approach would prefer that the children worked on their activity without teacher intervention. Howe maintained that:

> decontextualized tasks, chosen to represent a process but unrelated to children's everyday knowledge or interests, would not have a place in a science curriculum informed by a Vygotskian perspective. (p. 46)

Bereiter (1994) argued that school science exists predominantly in a context of mere learning, and that we should aim to move it towards one that constitutes knowledge building. He suggested that this situation could be achieved by activities aimed at collaborative creation in the classroom. Knowledge-building also requires that students use the scientific 'tools', including signs and symbols, so that their ideas can translate easily into scientific contexts.

Creating ZPDs to Enhance Science Communication in the Primary Classroom

Language is crucial to the development of scientific concepts. Scientific concepts have been developed by communicating, chiefly through language, ways to explain and manipulate the world around us. Of necessity, a scientific language has developed alongside such concepts, which communicates the ideas more efficiently. Thus learners need this language both to learn and to use scientific concepts. The language of scientific concepts is non-intuitive, and sometimes assigns scientific meanings to words used commonly in everyday speech (for example: force, energy). Learners ascribing the everyday context to these words are frequently described as having 'misconceptions' whereas, more likely, it is the case that the scientific use of the term has not been made explicit and the learner is expected to make a 'quantum leap' by using words differently in science without such differences being emphasised to them. Learners' contradictory statements about the world are not 'misconceptions'; they result from the lack of a scientific conceptual system in which to situate their ideas in their everyday concepts (Gredler and Clayton-Shields 2008).

Too much science learning in school and undergraduate science classes is aimed at individuals without engaging the importance of generating a shared language in the classroom to which all can contribute. Learners who are given opportunities to talk through their understanding of scientific learning and ideas, by group work and/or presentation, can be prompted in the use of scientifically appropriate language in the context of their own words. Teachers can listen out for and learn which terms are problematic and discuss ways of using such terms that are more meaningful for the learners. For example, in my observation of a pre-service teacher's lesson on the particulate nature of matter, 'Paul' was walking around the class checking children's work and asked an 11-year-old girl at the back of the class, close to where I (his supervisor) was sitting, which of gases, liquids or solids had the most energy. She answered 'solids'. Paul asked why she thought solids and she laughed, saying that it was because they were the strongest, "of course"! Paul tried to explain to her that the particles in the solid didn't move much, whereas those in the gas moved really fast, so they had more energy. However, she wasn't convinced—she raised her eyebrows and Paul moved on to another group. No 'bridge' was being made for the child's everyday linkage of strength to energy to particles in her experience to the scientific consideration of particle energy as totally separate from strength.

An example of a bridging activity that is designed to aid children in developing their own theories about phenomena using close observation is described by Murphy et al. (2013). Children (aged seven to eight) were introduced to the phenomenon of miscibility via a teacher demonstration of pouring syrup, then oil and then water into a glass jar. They observed that the water formed a layer between the syrup and oil, a phenomenon that they might not have expected. They then *repeated* the experiment in groups a few times (to introduce them to scientific replication) to observe very closely and see if they can come up with an explanation, based on their observations, for water displacing the oil. Following the experiment, children *presented* their theories to explain the phenomenon, using diagrams, writing and, if appropriate, presentation tools. This aspect constituted the ZPD created by the teacher to enable the children to work as scientists in this activity. An extract from one of the children's group presentations to explain the reason why water formed a layer between syrup and oil was:

> …the cooking oil is at the top and the liquid … there was bubbles in the cooking oil and it is free, like, it can move around and then it, amm, lifted up and then the water went underneath it. [8 year old]

This explanation prompted the researcher to go home and check for air bubbles in the oil—it was exactly as the child had described! This level of close observation and generating explanation consistent with the observations is rare, even at higher levels. Recently, Murphy (unpublished) carried out this same investigation with post-primary science student teachers, asking for explanations based solely on observation, not inference. They found the task extremely challenging and were absorbed totally in the activity. Indeed, they commented that this approach to science learning and teaching was one that they had almost never been exposed to. Primary school teachers can be encouraged to promote this method of teaching science, as opposed to asking children to learn facts. Such an approach would require assessment that focused on scientific reasoning, which might provide an excellent foundation for post-primary/tertiary level science learning about conceptual frameworks that have been developed by scientists to explain phenomena.

Other examples of activities of ZPD creation to promote dialogue and presentation came from giving children opportunities to express their ideas of how things might 'work' (Murphy et al. 2013). A 'black box' activity introduced by Hans Persson (now available on *YouTube*) called '*The Bucket*' was extended by teachers with a class of 6/7-year-old children. The teaching sequence started with a sorting toys activity followed by observation of the movement of a battery-powered toy car.

Children were invited to draw the inside of this car and to present their drawing to the class. The school principal overheard some children and created a ZPD for them to present at a higher level by offering his office for the presentations to a video camera. Each child sat in the principal's chair and spoke to the camera (see Fig. 5a). Their descriptions were recorded and transcribed. A typical one was:

> My name's … and I'm going to show you how this car works. The power of the pump goes into the batteries and makes more power in the batteries. And then it goes into the wheels. Then you push the button, and it goes zoom and fast. And then this here is the engine and these are the wires that are connected on to the engine… (boy, aged 6)

This description revealed the way that children were thinking, and bringing their experiences into the science classroom. The child above seemed to highlight his concept of 'power' in describing how the car moved. Amongst others, descriptions and pictures focused on the central function of cogs in turning wheels (see Fig. 5b) and on electricity. Video footage evidenced children's engagement with the task and their clear enjoyment of being given the opportunity to express their ideas in words as well as pictures.

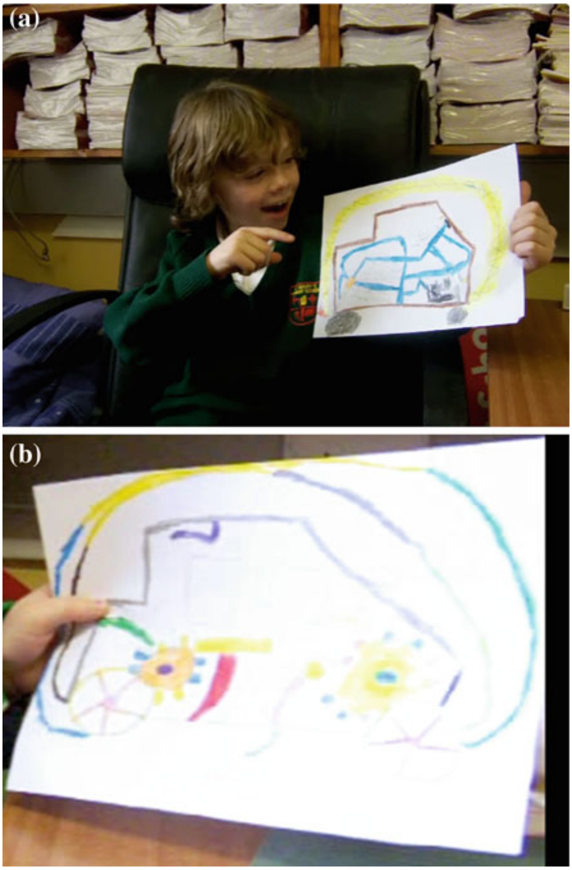


Fig. 5 **a** Child describing his drawing of the *inside* of a toy car. **b** Child's diagram of cogs *inside* the toy car

The teaching sequence continued with the children planning how they might build a car, using a selection of provided resources, such as cereal packets, plastic wheels, etc. They drew their plans and then built a prototype, which was tested and rebuilt accordingly. The final cars were raced and each child evaluated their own using two features they liked and one they wished they had included. Finally, children examined all the cars and selected their favourite feature from one of the designs.

These examples indicate a different approach to science learning and teaching that aims to promote and develop children's higher order thinking skills. ZPDs are specifically created to give children opportunities to act 'higher' than they would normally. The result is a higher cognitive level of expression and a desire to engage in science as a scientist. In other work (Murphy et al. 2010) children (8–9-year-olds) were invited to create designs of ancient animals using fossils. They were tasked to find out as much as they could using the internet and other resources during this activity, so that they would be carrying out this work in the same way that palaecologists reconstruct animals and ecosystems from the past. Questions children asked during this activity indicated a strong interest in knowing more and more as they learned. The awareness of how scientists worked in this field evidenced a contemporary view of the nature of science in which children described the work of scientists as systematic, but involving imagination and creativity. In her chapter (this volume) on questions learners ask, Seakins concluded that their questions are key to revealing much about their prior conceptions, interests, motivations and development, and could be used to a greater extent in science learning. Cowie and Khoo's chapter (this volume) discusses children's identity as scientists as a first step in developing scientific literacy.

Scientific Concept Development in Older Students

In post-primary schools the issues facing science teachers are different from those in primary or younger contexts. Whereas in the former, there are problems relating to teacher confidence to teach science and lack of support for teachers to promote IBSE, post-primary science is bedevilled with an outdated, crowded curriculum, assessment of factual knowledge, rigid schemes of learning to be followed by all departmental teachers in some schools and lack of time and support for IBSE. A consequence of these and other factors in post-primary school has led to disengagement of many students from science lessons. Scientific concept development in many schools follows the traditional approach (see Table 1), which is reinforced by the textbook and other resources.

Recently, I asked a group of 20 pre-service science teachers to carry out a quick survey of students in their classes (12–15-year-olds) to find out which was the most hated topic (science concept), and why. The most frequent response was *photosynthesis*; school students said they didn't need it, would never use it and that it was really boring to learn. Thinking of photosynthesis as a 'tool for understanding' as opposed to a concept to be learned made us reflect on how we might present it to students in such a way that they would be motivated to use it to explain something meaningful to them. Checking the ‘textbook’ introductions to photosynthesis revealed that the main questions for students to consider were the differences between plants and animals and how plants grow. Our next step was to think about a more meaningful context for teaching photosynthesis that might be of interest—perhaps the idea of what can plants do that animals can’t? When the pre-service teachers tried this opening discussion in class, it led to greater student interest, especially when it transpired that plants could make food and oxygen, despite not having brains. Despite the fact that most students would have learnt this already, it was the *context* of that learning—a problem which meant something to them—that motivated them to think: *Well, how can they do that?*

Collaborative investigation of this problem, in which different student groups tackled different sub-questions, led to much more engaged and satisfied responses from students, particularly in tackling more difficult questions such as how much photosynthesis is needed to sustain the growing human population, which currently stands at more than seven billion and different estimates project it will reach 10 billion between 2083 and 2100. Pre-service teachers reported student-generated questions on deforestation and world food production and distribution arising from these lessons. This example provides an illustration of the idea that concepts are contextualised, and we can make such contexts meaningful in different ways (see also Reiss, this volume).

Students can also be invited to consider why they find certain scientific concepts *difficult*. Indeed, students can be introduced to ideas as to how we develop scientific concepts, as well as ways in which those concepts were created during the process of scientific investigation. Voelker (1975) suggested that some concepts could be acquired by students in a similar manner as they evolved within the scientific community (such as classificatory concepts of animals, plants, physical and chemical change) whereas others are almost impossible to learn in this way. The best that can be done with the latter group is to give students samples of activities that played a role in the development of the concept so that they can perceive some association of the roles of time, experience and human intellect in the formation of some of the more abstract, theoretical concepts, such as chemical bonding.

Some concepts can be acquired via teacher-mediated mechanisms, whereby teachers help students to visualise inputs that aided the evolution of the concept and show how it has developed in sophistication and application, for example: what, why and how consequences (good, bad; scientific and social) that have emanated from the publication of Darwin’s theory of evolution have changed human behaviour, or how our understanding of the model of the structure of the atom has developed towards the potential impacts on society from nanoscience research. Van der Veer (1994) argued 20 years ago that students should be taught the tools of scientific thinking themselves. Such *thinking skills* are now a feature of school curricula in many countries.

My group of pre-service science teachers is currently working on a project to engage students by teaching concepts from the top-down, that is, by starting topics with challenges, beauty or wonders of science. For example, how life began; what is at the Earth's core; why the Moon is escaping the Earth; and how plants grow different shapes? For physics they are using a website developed for a public engagement project run by myself and science colleagues—http://www.dartofphysics.ie—that attracts people via 'adverts' and sustains the interest with an intense social media campaign and the website to generate a city-wide conversation about physics.

The work of Lancaster et al. and Rennie (this volume) also stress the link between 'real' science and school science as essential to future science learning. The role of the current teacher in making school science more engaging is considered by Loughran and Smith (this volume).

Summary and Conclusion: Revisioning Concepts in Science Learning and Teaching

This chapter has described the move from an individualistic model of a science learner and their learning to one that relies on social interaction, which is culturally dependent. For example, young children are taught to eat food with chopsticks in many Asian cultures, but with knives and forks in other cultures. Similarly, many Chinese students are taught from a Confucian perspective that the key to learning is *effort*, while little attention is paid to the idea of 'ability'. In most Western cultures, however, learning is frequently differentiated to address the learner's specific ability and 'learning style'.

In terms of learning and teaching scientific concepts, there are many differences between the traditional approach, which is individually-centered, and the socio-cultural approach, which has been addressed in this chapter. In Table 1 I have summarised these differences to provide guiding thoughts for teachers, learners, researchers, curriculum developers and other stakeholders in science education as ways to reconceptualise scientific concepts in science learning and teaching to make it more pleasurable, challenging, and, in the long run, more effective.

In conclusion, the work in this chapter provides a theoretical and practical exploration of scientific concept development. The aim is to provoke discussion and interest in looking at traditional science learning a bit differently. If we, as teachers, look at scientific concepts more critically as tools for science teaching (for example, as in the photosynthesis and http://www.dartofphysics.ie examples described above) we can make science lessons more engaging for ourselves and our students. We need also to change our learning environment so that students are engaged more actively in their science learning by promoting dialogue, student presentations, challenges and games. The move towards more collaborative and cooperative learning strategies in which students are encouraged and facilitated to repeat experiments as required mimics more closely the science world that they may wish to enter. Essentially, if we try to move from teaching the curriculum towards teaching students by engaging their interests and relating that work to the curriculum, we may significantly improve their scientific concept development.

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Making Science Beyond the Classroom Accessible to Students

Léonie J. Rennie

This chapter is based on the premise that the science students learn at school should enable them to become scientifically literate citizens, irrespective of what their future career ambitions may be. Students are best served by a school science curriculum that equips them with the knowledge, skills, desire and confidence to deal effectively with the science-related issues that arise not only during their school years but in their adult lives as well. They should be able to access science information when needed, assess its relevance, and apply it to the situation or problem at hand (see also Fensham, this volume). To learn to do this, students need to experience explicit connections between the science they learn in school and the science that happens outside of school. This chapter uses three case studies to illustrate how school-community programmes can promote students' access to science beyond the classroom and contribute to the development of scientific literacy.

Scientific Literacy as a Goal of Science Education

Scientific literacy is an often-used but ill-defined goal of science education. Feinstein (2011) referred to "the endless definition of and rationales for science literacy … it has come to mean everything and nothing" (p. 170), and asked, "What can be done to revitalise science literacy, to take it beyond the realm of politically useful slogans and make it into a goal that is both realistic and worthy?" (p. 170). Earlier, Roberts' (2007) analysis of this term suggested two "Visions" of scientific literacy/science literacy: Vision I is obtained by "looking inwards at the canon of orthodox natural science, that is, at the products and processes of science itself" (p. 730). Vision II looks outwards, to "the character of situations with a scientific component, situations

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that students are likely to encounter as citizens" (p. 730). Traditionally, science education has been discipline-based, concerned with the canonical concepts of science and its processes; a Vision I approach. We might think of this as the science used by scientists. However, people using science in everyday life do not think of themselves as scientists. Research, such as that by Layton et al. (1993), shows that people search out science-related information that is relevant to their needs and then reconstruct it into a form that has meaning to them and is useful for their purpose. People who do this effectively might be considered scientifically literate in the sense of Roberts' Vision II. Feinstein took a rather similar view by arguing, "we can salvage science literacy—make it into a meaningful educational goal instead of a mere slogan—by redefining it according to research on the actual uses of science in everyday life" (p. 183). He suggested a convergence between science education and public engagement with science; that science literate people "have learned to recognise the moments when science has some bearing on their needs and interests and to interact with the sources of scientific expertise in ways that help them achieve their own goals" (p. 180). Science educators generally agree that science learned should be useful and relevant, but how can science education move students towards this kind of scientific literacy?

Following a review of science education in Australia, Goodrum et al. (2001) argued for a focus on scientific literacy in school science curricula. They described scientifically literate people as those who are interested in and understand the world around them; engage in the discourses of and about science; are able to identify questions, collect data, and draw evidence-based conclusions; are sceptical and questioning of claims made by others about scientific matters; and make informed decisions about the environment and their own health and well-being. This view of scientific literacy holds promise. While acknowledging the importance of science concepts and processes (Roberts' Vision I), it is strongly underpinned by genuine engagement with science in daily life (Roberts' Vision II). It embodies the kinds of skills and abilities that enable people, including students, to cope with science-related issues in life both within and beyond the classroom. Given that most people will be non-scientists, it also fulfils what Norris (1995) regarded as "one of the primary goals of teaching science in school … to teach these people the wherewithal to deal intelligently with science and scientists despite their lack of scientific expertise" (p. 202).

If thinking about scientific literacy is expanded to embrace the huge range of informal contexts beyond the classroom, two issues about science must be considered. First, unlike the unidisciplinary approach to science represented in school timetables and frequently enacted in science classrooms, science in the "real world" is multidisciplinary. Understanding science-related community problems and finding answers to them requires integrating knowledge from science with knowledge from other subjects (Venville et al. 2008). Second, science in the real world is neither objective nor value-free; it is inflected with social, economic, and political values (Corrigan et al. 2007). Relevant science concepts will be integrated not only with different subjects but entwined with other, human issues at work in the local environment. Thus dealing with science in the community introduces values, such as social and environmental responsibility, in association with the relevant science concepts.

To learn how to tackle multidisciplinary, value-laden problems, students need opportunities to learn and practise using their knowledge and skills in circumstances beyond the classroom. Explicit connections need to be made between school knowledge and community issues. This means bridging the gap between school science and science as it is practised in, and impinges on, life outside school. Research and experience have shown this bridging is not easy (Rennie et al. 2012). To help students learn multidisciplinary skills, teachers themselves need to be competent in using them, and be able to deal with socio-scientific issues (Rennie 2011). They also need to find time in an overcrowded curriculum to bring the school and community closer together, because making links between them is essential to bridging the gap.

There are many kinds of school-community links. The simplest occurs when students access information from community sources to assist them to complete set tasks for school, such as seeking information from the local council for an assignment on weed control. The most difficult to achieve are those that entail a high level of involvement with, or contribution to, the community. Examples include long-term partnerships with community institutions, such as universities, museums . or wildlife centres. Here the linking activities involve more than the seeking or exchange of information, they involve interaction between partners, usually to the benefit of both. Activities in such partnerships take considerable time and effort for teachers to organise and implement and often require funding beyond what schools can afford. Consequently, most of these programmes are externally organised and funded from a combination of government, science-based industry and institutional sources. The specific aims of these programmes vary, but most hope to foster students' interest in science. and motivation to consider a science-related career.

In this chapter, case studies of three established school-community programmes are used to demonstrate the range of externally organised initiatives that aim to connect school students with science and scientists outside school. They are *Mildew Mania* (http://science.curtin.edu.au/outreach/citizen-science.cfm), a university-based, state-wide citizen science programme; Primary Industry Centre for Science Education (www.picse.org), an Australian national programme focusing on primary industries and implemented by local activity centres; and *Scientists in Schools* (www.scientistsinschools.edu.au), another Australian nationally organised, locally supported programme. Each case study includes an overview of programmes of its kind, a description of the specific initiative, its implementation, and the nature of its outcomes with regard to student learning.

Mildew Mania: A Citizen Science Project for Students

Citizen science can be simply described as "public participation in organised research efforts" (Dickinson and Bonney 2012, p. 1). It capitalizes on the motivation of citizens, including students and families, to be involved in subjects relevant to their own lives and interests, allowing them to collect data to contribute to resolving a science-related issue. There are mutual benefits: much more data can be collected than scientists could manage with their limited time and resources, and citizens may meet or work with scientists, learning both content and skills relevant to the project.

Bonney et al. (2009) proposed three models to encompass the range of projects that involve citizens in science. Most projects are *contributory*, with the public primarily contributing data. In *collaborative* projects, citizens help with design, data analysis, or disseminating findings. In *co-created* projects, at least some citizens are involved in the entire research process. Bonney et al. conducted a meta-analysis to measure the outcomes of several citizen science projects. There were clear indications that participation contributed to people's awareness, knowledge, and understanding of the focus science topic; increased their interest and engagement; and built science-related skills, but Bonney et al. uncovered few robust evaluation findings. They called for greater effort in research and evaluation of the many kinds of citizen science to learn how to build successful models.

Student-scientist partnerships are a contributory model of citizen science, usually based in schools, but frequently involving students in structured activities outside school. Cohen (1998) identified three primary characteristics of student-scientist partnerships:

> Scientists ask and use students to help answer questions [that require] large numbers of strategically positioned observers … students gather and analyse data [for] large-scale projects … that involve authentic and important scientific questions; science teachers are active intermediaries not only for explaining science, but for helping scientists and students implement their research. (p. 1)

Mildew Mania is a citizen science project aptly described by these characteristics. Students are requested to collect data for an authentic project, but their participation depends on the willingness of teachers to take part, and students' actions and science learning are mediated by their teacher's oversight of the activities.

About Mildew Mania

Mildew Mania began in 2010 as an initiative of a university research centre for the study of plant pathogens. The focus pathogen is a powdery mildew that infects barley and causes significant reduction in crop yield and quality, with resultant economic loss to the industry. A rapidly spreading mutation in one strain of the mildew is resistant to the commonly used fungicide. This citizen science project was devised by plant scientists to work with school children who could grow a particular cultivar of barley, allow it to become infected with powdery mildew, and then return the mildew samples to the university laboratory for further research. Identification of the pathogen in the students' mildew samples enables scientists to map the geographic distribution of the various "strains" of mildew. Using students' samples, these strains can be grown in the laboratory and tested for resistance to various fungicides. Barley cultivars that are resistant to the particular strains of mildew can also be identified, and plant breeding can create new cultivars with a high yield and genetic resistance to mildew.

Mildew Mania has four aims: to collect and test mildew samples from many locations throughout the state; to involve the community in agricultural research and development; to engage students in meaningful science; and to encourage enrolment in tertiary agricultural studies. The project is managed by the university's science outreach programme. Participating schools are provided with barley seeds, instructions and background information, sampling equipment, and reply-paid envelopes. Once mildew is detected on their barley, students email photographs to the scientists for confirmation, then infected leaves placed in agar tubes and swabs of the mildew are posted to the laboratory. During both 2011 and 2012, mildew data collection involved well over 100 classes from across the metropolitan and grain growing areas of the state. The programme continued in 2013.

Mildew Mania Case Study

Data for the case study were collected by two surveys and interviews. Teachers applying to participate in *Mildew Mania* in 2012 responded to a survey about their expectations. In addition, six teachers who had participated twice in the project were surveyed by email about their experiences. Semi-structured interviews were held with the Science Outreach Manager and three scientists in the research centre. Resources and materials available to teachers were also reviewed.

Findings from the Pre-participation Survey

Prior to their participation in 2012, teachers were asked: Why do you want to participate in *Mildew Mania*? What are you expecting from *Mildew Mania*? How do you think your class will benefit from this programme? The anonymous answers from 38 secondary and 22 primary teachers were available for analysis. The responses to each question were read carefully to identify themes. Results were collapsed across these questions because all answers referred to benefits for students. A total of 182 ideas, opinions or views were coded into 21 categories with most teachers' responses receiving more than one code. The 21 categories were clustered into five themes that accounted for nearly 92 % of the coded ideas. The themes were labelled 'Relevance', 'Investigative Skills', 'Beyond School', 'Real Science', and 'Engagement', and are described in Table 1.

There was a strong focus in teachers' views that *Mildew Mania* deals with real science concerning an important community issue, providing opportunities for students to develop their investigative skills (a significant part of the Australian school science curriculum) in a meaningful, relevant context that students find

Table 1 Description of student benefit themes from the 2012 teachers' pre-participation survey for *Mildew Mania*

Theme	Description of theme	Total codes
Relevance	Doing science that is meaningful, real-life, relevant to local area, useful, important	46 (25.3 %)
Investigative skills	Participating in hands-on science that will develop students' science process skills; ties in with investigation in the science curriculum	44 (24.2 %)
Beyond school	State-wide, community-based project, something different that extends students	31 (17.0 %)
Real science	Participating in real science/research, connection with scientists	29 (15.9 %)
Engagement	Students will be (or were last time) motivated, engaged, and taking responsibility for their work	17 (9.3 %)

engaging. One primary school teacher's expectations summarised many of these themes:

> (i) Children to be engaged; (ii) Children to learn about monitoring plant growth and looking after plants; (iii) Children to understand a bit about the impact that something so small can have on our farmers and economy; (iv) Biology understandings; and (v) A bit of pride in helping do real science.

Another teacher wrote:

> It provides students' input into a broader science project, giving them the understanding that science goes beyond the classroom and lab and has influence on everyday life right here in their backyard.

Responses to a fourth question, "How do you think your teaching will benefit from this programme?", were more focused on benefits to the teacher. Ten teachers new to *Mildew Mania* were reluctant to commit themselves to benefits, but 40 made 52 suggestions that were coded into 12 categories. Table 2 reports the five themes into which these categories were clustered, but only the first three of these (totalling

Table 2 Description of teacher themes from the 2012 teachers' pre-participation survey for *Mildew Mania*

Theme	Description of theme	Total codes
Professional learning	Extending teachers' knowledge base, improving confidence and providing background for "big picture" discussions with students	17 (32.7 %)
Resources	Additional resources to improve teaching	7 (13.5 %)
Curriculum fit	Project will fit into science curriculum	5 (9.6 %)
Students' skills	Opportunities for students to develop investigative skills and independence	12 (23.1 %)
Real world project	Opportunities for students to be connected to science in the real world in a meaningful way	11 (21.2 %)

55.8 % of codes) are benefits to the teachers; the other two (44.2 %) are potential benefits that the teachers can see for their students.

Although it was not possible to tell exactly how many responding teachers had previously participated in *Mildew Mania*, their responses indicated that many had. For example, one teacher commented:

> I participated last year and found doing action research for a state wide tertiary driven initiative very useful for giving my students relevance and purposefulness to their science experience.

Teachers were keen to find ways to connect their science classes to a context broader than their own interpretations of the curriculum, and they expected participation in *Mildew Mania* to provide this opportunity. They also foresaw additional resources for their classrooms.

Findings from the Teacher Email Survey

A total of 165 teachers participated in *Mildew Mania* in 2011 and/or 2012. Six of the 45 teachers who participated in both years and were enrolled for 2013 were invited by email to respond to questions about their experiences with the project, and what benefits or problems arose. All agreed and their demographics (using pseudonyms) are reported in Table 3. The proportion of rural and metropolitan schools, and of primary and secondary teachers, is similar to the sample enrolled in *Mildew Mania*.

The first questions asked, "What benefits did you hope to gain from participation in the *Mildew Mania* programme for you and for your students? Were they achieved?" All teachers noted the importance of having students collect data in a real science investigation with wider significance. Alice, in a small district high school, hoped to bring some contextual science into her programme, using science processes to collect some real data. She believed this goal was partially achieved, but thought she put insufficient emphasis on observing and recording data at regular intervals. Sally was pleased the programme aligned with the Australian curriculum

Table 3 Demographics of teachers responding to an email survey about *Mildew Mania*

Attribute	Albert	Alice	Sandra	Evelyn	Sally	Donald
School	Rural primary	Rural high	Metro primary	Metro primary	Metro primary	Metro high
Students involved	Years 6–7	Years 8–9	Years 6–7	Years 1–7	Years 5–7	Years 8 and 10
Success in growing mildew	2011; no, weather too dry	2011; yes	2011; yes	2011; yes	2011; yes	2011; yes
	2012; yes	2012; no, frost killed barley	2012; no, teacher absence	2012; no, ravens pulled up seedlings	2012; yes	2012; yes

and that it allowed "students to get in touch with nature, the problems for farmers and the solution provided by scientific research". Donald, referring to his city high school students, summed up other teachers' positive views:

> The benefits I hoped to gain were really through seeing the students become involved in a project where they were contributing original data to a research project addressing an issue of concern. I enjoyed seeing both classes being so involved in setting up the project, monitoring the plants' growth and collecting the data needed. Their involvement gave them an idea of how research studies are designed, how data are collected and the need for careful control of variables. They also enjoyed spending time outside the Science laboratories! They were pleased to know that their work was contributing to such an important project and gave them firsthand experience of the ways by which Science is used to solve problems of this nature. They also learned that crop plants are vulnerable to attack by fungi, and that fungicides won't always be effective in treating all strains of a particular fungus.

Not all classes were successful in growing mildew for the reasons shown in Table 3. Sandra's Year 6 and 7 students were excited at the first signs of what they thought was mildew growing on their barley and even more excited when the university confirmed their diagnosis.

Teachers were asked: "Do you think participation assisted students to make links with science outside of school? If so, in what ways?" There was strong agreement. Albert's students, who lived in a grain-growing area,

> responded very positively to feedback or contact from the scientists. The project helped them to make links, connections to people who work within the community doing science but not necessarily seen as scientists. They can see how this type of science plays an important role in industry such as agriculture and the impacts it can have on the long-term viability of these industries.

Sandra's city-living Year 6 and 7 students realised the social implications of farming:

> I'm sure before [*Mildew Mania*] that few students linked science investigations with farming. Their knowledge of crops grown in Western Australia was also very limited. They developed an appreciation of how difficult it is for farmers to sustain a living—relying on weather to provide the right growing conditions and how difficult it would be for farmers both financially and emotionally to lose their crops. One group of students was devastated to find snails had eaten their whole pot of barley plants.

Evelyn noted:

> Students engaged enthusiastically in the hands-on science investigation and expressed appreciation of the challenges faced by farmers. They learnt about economic and social implications, as well as other topics that came up as a result of the investigation, such as the pH of soil.

Teachers agreed that sufficient information was available from the university about the results and the value of students' efforts. They found a slide presentation about how the samples are used and maps of the distribution of results very helpful. Finally, teachers were asked: "Overall, were you pleased with the outcome of your participation? Why or why not?" All teachers were positive, and Albert's response echoed other teachers' comments:

> Yes we are pleased with our participation; the students now want to know when they can start this year's mildew project and value that they are contributing to science that will assist farmers. The students accept ownership of the trial and make sure it is cared for, they check for the required signs, collect the samples and forward the data and evidence. These types of projects make science the real thing for the students.

The Scientists' Views of *Mildew Mania*

Mildew Mania was designed to supply enough samples to facilitate an effective programme to develop a genetic means of controlling powdery mildew. The research leader reported that the first 2 years generated a large amount of data on the distribution of virulence in the mildew and fungicide resistance that was now being incorporated into scientific papers.

Mildew Mania was successful, but two problems arose. In 2011, mildew samples were returned from about 70 % of schools. However, the quality of the samples was compromised by slow postal return or the leaf samples "drowning" in the agar solution. Nevertheless, about a quarter of the samples were viable and from these around 100 "isolates" (individual samples of mildew) were able to be propagated and their DNA sequenced. The second problem was that most participants were city schools, so their mildew samples had limited value in mapping the geographic distribution of the pathogens. Consequently for 2012, more precise instructions for sample collection were given to schools, and encouragement given for schools in agricultural areas to participate.

When it became clear that the fungicide-resistant mildew pathogen was wide-spread over the state's grain-growing area, the research centre obtained industry funding to combat this disease. In 2013, the project was extended (as *Mildew Mania Plus*) to 20 rural schools located in grain-growing areas. A scientist visited schools to facilitate high-quality sampling of several barley cultivars, some treated with fungicide. *Mildew Mania* continues in parallel, managed by university outreach.

The Primary Industry Centre for Science Education (PICSE): An Example of Student Work Placements

Work placements, internships and apprenticeships allow students to experience science in research contexts. Placements .may be for a few hours over a period of time, or full-time over a shorter period. They may be a class requirement during semester or during a summer break, perhaps on a supervised project. There is diversity in the nature of the placement and also in the outcomes. A literature review by Sadler et al. (2010) identified 15 research studies of secondary students in apprentice roles. Students engaged consistently in research activities with a mentor over a sustained period of time (between 2 and 10 weeks); some students worked individually and others in groups. These studies revealed increased students' understandings of the complexity and uncertainty of scientific research, and the time and attention to detail required to gather valid data under sometimes difficult conditions. Most of the apprenticeships had a goal of promoting aspirations for a career in science, and Sadler et al. found that some students already interested in a science career became aware of more choices in the field. They urged that more research attention be given to direct and valid measures of outcomes.

Burgin et al. (2012) investigated the outcomes for 18 grade 11 and 12 students (age about 16–17) who worked on a mentored science project in a summer programme. All students learned science content, but interest varied with how much choice students had with their projects, whether they were in a research group or working individually, and their understanding of the reason for their given project. Burgin et al. suggested that students already interested in science would gain most benefit from such apprenticeships. The Primary Industry Centre for Science Education provides scholarships for interested students to learn more about science careers in which a central component is work placement.

About the Primary Industry Centre for Science Education

The Primary Industry Centre for Science Education (PICSE) aims "to attract senior high school students into tertiary science studies and to increase the number of skilled professionals in agribusiness and research institutions" (http://www.picse.net/HUB/overview.htm). It is funded nationally by the Australian government and several industry bodies and cooperative research centres. There are PICSE activity centres in five Australian states where a Science Education Officer (SEO) organises local delivery of the PICSE model by coordinating collaboration between the centre, school communities and primary industries. The components include professional development and resource materials for science teachers (see http://www.picse.net/HUB/resources.htm), and a scholarship comprising a camp and industry placement for senior students.

The PICSE Camp and Industry Placement Scholarship Case Study

This case study focuses on the camp and industry placement at an activity centre hosted by a university. Twelve students (selected from 34 applicants) attended a week-long camp in December 2012 and a 5 day work placement at a local primary industry prior to beginning university studies or returning to school in 2013. The data included documents, students' reflective reports on their camp and placement experiences, and interviews with the PICSE SEO and three students. Student interviews explored the opportunities students had at school to make connections between learning in their science classes and how science "works" in the community, how the PICSE camp and industry placement compared with school in making such connections, and how students' experiences affected their study choices.

During the PICSE camp students resided in on-campus housing and each day attended hands-on activities at the university or were transported to other sites for tours and participatory demonstrations. Each evening the students dined together and enjoyed various entertainments. Activities and tours covered disciplines associated with primary industries, and included short sessions on science communication, public speaking, photography, and career choices.

Ten student placements were related to primary industries at the university or government laboratories or field-sites, one was at a country newspaper and the other at the university science outreach. Students worked alongside primary industry scientists participating in their day-to-day activities. Following the placements, students attended a "reporting back" evening, gave a presentation about their experiences, and handed in their reflective report.

Findings from Students' Reports

Applicants for PICSE scholarships are able students already interested in science, and interpretation of their data must keep this in mind. Four students were in Year 11 and eight in Year 12; three boys and three girls attended a metropolitan school, four girls and a boy attended agricultural colleges in rural areas, and one girl attended a geographically remote coastal school.

Students enjoyed their camp experience, with all commenting on some aspect they particularly enjoyed, such as the passion of the speakers and the company of other "friendly and smart" students. One girl summed it up thus: "In a nutshell, the camp had everything: amazing people, great activities and plenty of science, all adding up to a truly unforgettable week".

Every student, including those attending an agricultural college, commented on the camp as an eye-opening experience that broadened their understanding of the importance of the science involved, and the variety of careers available in primary industries. As one city girl remarked,

> Agriculture is not just a farmer on a farm farming, but the collaboration of a range of jobs and people, with some being in the field, some being in a lab and some being in an office and each job being as important as the next.

A boy from an agricultural college wrote that his experiences

> … not only expanded my knowledge of science and primary industries, but gave a real in-depth understanding of why we as a country rely on science from everyday situations to global issues.

Other aspects students appreciated included the different tours of laboratories and other sites. They enjoyed the hands on activities, in particular making noodles "from scratch" and ice-cream using liquid nitrogen as the coolant. Five students drew attention to the importance, particularly in a global situation, of ensuring food security. A city girl wrote that the camp

> … greatly increased my understanding and appreciation of the processes and effort behind getting safe and good quality food delivered onto our plates—something I have often taken for granted. These talks also highlighted the integral role of food in our society, along with the challenges faced in terms of maintaining supply in the face of surging population.

In most placements, students moved between different sections of the work-place and joined in a range of activities, often including both laboratory and field work, experiencing the breadth of science carried out in that particular industry. Students commented that this strategy enabled them to get a "bigger picture" of industrial processes; the importance of "all of the people in the chain working together", as one student put it. All students commented positively on the passion, enthusiasm, and friendliness of helpful mentors or supervisors.

More than half of the students experienced activities requiring a high level of cleanliness and sterilization of equipment, and/or careful documentation and storage of specimens, finding this an important part of science they had not considered previously. Those students in laboratory situations were delighted to find themselves using highly specialised equipment to perform analyses or other techniques that were new to them.

Although the camp experience had given students an appreciation of the range of careers available in the sciences, particularly agricultural sciences, the work placement gave them a real feel for what scientists actually do, and the conditions under which they work. Although a lot of passion and hard work was involved, students found it could also be fun. One Year 11 student was excited that "having spent a year at agricultural college I was able to see how what I had learnt there was being researched and applied in industry". She also noted that, "my placement helped me to realise that opportunities for essential research can be constrained or promoted by political agendas and that there is a need to abide by ethical standards that may restrict experimentation and research". Three other students commented on learning about the important role of science in creating a viable future for the planet.

Findings from Interviews

Three students were selected for interview, as a proportional sample of the scholarship holders based on gender and location of their school. Paul and Ann from metropolitan schools and Jane from a rural agricultural college were nearing completion of the first semester of a university science-based bachelor's degree. All were enjoying their studies. The face-to-face interviews were structured around three questions.

The first question asked: “What kinds of opportunities did you have while at school to make connections between what you were learning in your science classes and how science ‘works’ in the community?” Paul had taken biology and physics at school, and Ann studied biology and chemistry. Both stated that their textbooks used a lot of real world examples to try to make the subjects meaningful. They believed that their teachers tried to make connections but were restricted by the need to complete the syllabus. Paul found subjects more interesting when he could see how science was used outside of the classroom, and Ann liked to see links, so that she could “see the big picture and how the sciences fit together”. A highlight for each student was a biology field trip during Year 12. Both trips had strong environmental and ecological themes and the students drew on their field-trip experiences to provide examples of biological processes in school assignments and examinations. In junior school, Ann was a member of Bushranger Cadets, an afterschool science club focused on environmental issues. It included theoretical work and many activities outside of school time, including camping. Ann believed her participation helped her to understand biology at school.

Jane had different experiences at agricultural college. She completed multi-disciplinary subjects in animal and plant production, and her courses were focused on livestock. Having grown up on a farm with sheep and large-scale cropping, cows and fodder were new, and she “learned how cattle and fodder worked by heart”. Much of Jane’s school-work was conducted out of doors, with many field-trips to various agricultural places, so she believed that her school science was closely linked with science outside of school.

Students were asked: “Has your PICSE camp and placement given you any advantages, or other assistance during your first semester at the university? If so, what?” All agreed that the camp gave them a head start on finding their way around the university campus, but mostly they wanted to talk about how much they enjoyed being with other science-interested students and having people from the university or industry giving the sessions.

Students enjoyed their placements, particularly participating in a variety of activities which gave them a range of experiences. Ann did some work similar to the people at the grain industry where she was placed, but also “just helped”. She could see the processes that were used in the industry and how the parts fitted together. She “enjoyed the laboratory work and other practical things, because they make more meaning”. Paul found that the “tasks were helpful but also sciencey”; he felt he was doing real science. “Sure, I was just cleaning ponds,” he said, “but I learned so much about maintaining the chemical balances in the water, about feeding and temperature and growth of fish.” He “really loved” the aquaculture part of his placement and has since set up his own aquaponics at home. Jane’s placement at the state’s botanic gardens exposed her to the broad field of research and restoration science involved in conservation and land management, and also the importance of health and safety in the laboratory and field trials. She found this a nice complement to her agriculturally-based school activities.

Finally, students were asked: “How do you think the PICSE experience contributed to your career plans?” Ann had always wanted to do something in science that “definitely involved investigating”, but also involved people. Her experiences in Bushranger Cadets and her placement, particularly the laboratory work, convinced her to pursue biology. She enrolled in molecular genetics and biotechnology and saw her future in this area. Jane liked to have an agricultural focus in whatever she was doing. When her family moved to a city she really missed farm life and requested to attend an agricultural college. Although she did not have a specific focus in her agribusiness degree, she “will see what turns up”. Paul was always interested in biology and his scholarship revealed “what an incredible range of jobs there are in agriculture”. Through meeting a scientist at the PICSE camp, he found a holiday job in the grain industry. His final comments demonstrate his appreciation for understanding the links between theory and practice:

> You can know how a plant works, but it’s still just a plant. When you want to feed it to cattle, you have to know about micro-nutrients and macro-nutrients, and how to grow the best feed plants; better plants, more beef!

The Scientists in Schools (SiS) Project: Teacher-Scientist Partnerships Designed to Benefit Students

Scientists visiting classrooms is a popular means of providing closer links between school science curricula and real-world science and scientists. Outreach programmes supported by universities, museums, . and other non-profit organisations, aim to stimulate students’ learning, interest in science., and consideration of science careers by providing enthusiastic scientists who offer hands-on workshops or other interactive activities for students. Laursen et al. (2007) described an established Danish programme where a “science squad” of graduate students presented science-based enrichment activities for K-12 students and teachers. Pedretti et al. (2006) evaluated another established programme in which volunteer scientists offered half-day workshops in K-8 classrooms. Although in both cases the outreach was brief, the researchers found that these interventions could enhance students’ attitudes about and interest in science, and assist them to relate science to real life; this finding was particularly so for girls, English language learners, and low socio-economic status students (Shanahan et al. 2011). A qualitative study of a week-long programme about nanotechnology in two classes of 10th grade students by Painter et al. (2006) revealed that such programmes could also address stereotypes about scientists.

Teacher-scientist partnerships involve a relationship more enduring than the brief encounter of a scientist’s visit, and repeated visits could be more beneficial for students’ learning. Some partnerships are aimed specifically at enhancing teachers’ professional knowledge in the belief that it will spill into their teaching practice. Drayton and Falk (2006) reviewed several year-long partnerships in which teachers carried out projects mentored by scientists and found that success revolved around careful negotiation of the scientist’s expertise, the teachers’ interests, and a clear purpose for the project. Of interest in this chapter are partnerships formed for the direct benefit of students, but it is worth noting that teacher-scientist partnerships also offer effective professional development for teachers and considerable learning experiences for scientists (Falloon and Trewern 2013; Rennie 2012).

About the Scientists in Schools (SiS) Project

The Australian *Scientists in Schools* (*SiS*) Project aims to establish continuing teacher-scientist partnerships that bring real-world science into classrooms, inspire and motivate teachers and students, and increase scientists' engagement with the public to raise science awareness and knowledge about science careers. *SiS* is government-funded and managed by the Commonwealth Scientific and Industrial Research Organisation—Education Branch. The *SiS* central management team recruits and matches teachers and scientists to make partnerships based on interests and location. The central team provides resources and oversees the programme, but most monitoring of partnerships is carried out by Project Officers (SiSPOs), based in each state and territory, who also support teachers and scientists and arrange networking opportunities. In August 2013, the partnerships in every state and territory totalled over 1,500, with at least one partnership in 12 % of Australian schools.

Scientists in Schools Case Study

Since it began as a pilot programme in July 2007, *SiS* has had three comprehensive evaluations (Howitt and Rennie 2008; Rennie 2012; Rennie and Howitt 2009). They employed a combination of interviews and focus groups with *SiS* team members, teachers, scientists, and students; document analysis; online surveys for teachers and scientists; student work samples; school visits; and observations of *SiS* networking events. These evaluations generated a large amount of data about a large variety of partnerships and this chapter presents some findings focused on students. To give an idea of the range of activity, five successful partnerships are overviewed in Table 4 using data collected by interview and focus groups with teachers and partner scientists during the third evaluation (Rennie 2012). This variety begins to demonstrate the range of additional activities available for students and considerable benefits to teachers, particularly in primary schools.

Teachers and scientists were asked, via an online survey, about the benefits of participation in *SiS* for themselves and for the students. In each evaluation over 30 % of both teachers and scientists responded. Findings for the perceived benefits for students from the third evaluation are reported in Table 5. Although item wordings do not match exactly (the surveys were refined after each evaluation), the results are not only consistent over the three surveys, but become increasingly

Table 4 Overview of five *SiS* partnerships at November, 2011

Length of partnership	Year level (s)	Description of partnership
4 years	10–12	The scientist mainly helps senior students with their major projects. He believes in "real-life practising scientists putting realism into the application of the school science curriculum". The teacher has gained a working knowledge of industry and how science works "at the coal face", which he considers a great advantage to students
5 years	K–6	The scientist visits this geographically remote school annually, but keeps in touch by students emailing him questions. A wide range of activities has occurred, including a community astronomy night. The teacher has gained in confidence, and now includes the open-ended science and technology investigations from the CREativity in Science and Technology (CREST) Awards programme and other science programmes in her curriculum
4 years	5–6	The scientist helps with many diverse activities, including rocks, eye dissections, and electricity. She feels welcome and comfortable in school. The teacher values the ongoing relationship, that the scientist is young and doesn't look like a "comic book scientist". She doesn't hesitate to ask for advice about science
3 years	12	In this low SES school, many students have little idea about science as it seems so distant from their background. The scientist aims to get them interested in science and a possible career. He has developed a Year 12 course with the teacher, and outcomes include seven students completing their studies early, increased engagement and school attendance, and more students taking science in Year 11
4 years	9	The scientist works with seven classes of Year 9 students on a 5-week immunology unit aiming to assist students to develop investigative skills and communicate their results to their class. The teacher says students love hearing the perspective of a scientist. Annual surveys of students show very positive responses to activities and science

positive. This finding suggests that partnership benefits increase with length of partnership.

The top four perceived benefits for students listed in Table 5 show that opportunities to see scientists as real people and to experience doing science with them were perceived by both teachers and scientists as very important outcomes of the partnerships. Increasing students' knowledge of contemporary science was a benefit perceived by more than 90 % of teachers and scientists, just a little more important than "having fun". The next five benefits closely fit the attributes described earlier as contributing to scientific literacy. These skills and abilities received strong support as perceived beneficial outcomes for students. There is likely to be some slippage between perceived benefits and the actual benefits experienced by students,

Table 5 Perceived benefits of *SiS* partnership to students

Perceived benefit	% agreement	
	Teachers	Scientists
Opportunity to see scientists as real people	99.1	98.2
Increased knowledge of contemporary science	93.5	90.6
Opportunity to experience science with practicing scientists	92.3	92.4
Having fun	87.5	94.2
Increased ability to recognise and ask questions about the world around them	87.2	88.5
Increased awareness of the nature of scientific investigation	86.9	89.3
Increased awareness of science-related careers	86.1	80.6
Increased understanding about using scientific evidence to make decision about health and the environment	76.9	75.7
Willingness to look to science to make decisions about their own lives	70.3	62.8
Access to science equipment and/or facilities	66.2	53.9

Note Responses from 382 scientists and 337 teachers

however, student data in the form of surveys, drawings and other work samples in other evaluations strongly supported positive outcomes for the students (Howitt and Rennie 2008; Rennie and Howitt 2009).

In a section asking for further comments on benefits for students, one scientist stated:

> Some teachers have told me (and I have observed) that students will respond to me, and my more informal "lessons", when that same student is not necessarily very responsive in a formal lesson. Also, some children can show knowledge that they have, but which they don't get the opportunity to show in a formal lesson (even some autistic and educationally disadvantaged kids). Also, I am able to pick up misconceptions and discuss them—with teachers and all the class.

An enthusiastic teacher wrote:

> I waited 3 years to get a *SiS* [scientist] and the wait was worth it! This year has seen the elevation of Science at my school to the point where the community engagement is almost overwhelming! Two major science projects have led to great community input, outside sponsorships and a flood of support from the scientific community. … The students are "buzzing" with all aspects of science and I am constantly challenged to improve/expand my teaching practice.

Of course, not all partnerships are overwhelmingly successful, nor do they last forever. A little more than half of partnerships begun since the inception of the programme have closed, with more than three-quarters of them lasting beyond 1 year (Rennie 2012). Around 44 % of closures were due to the changed circumstances (such as relocation) of one or other partner (many of whom began another partnership). Other factors included poor communication or lack of motivation to continue the partnership, often associated with pressures of time.

Unsurprisingly, the consensus of data collected in the evaluations indicated that successful partnerships require stable circumstances in the scientist's workplace and in schools; effective and respectful communication between partners who have realistic expectations of each other; and sufficient time, flexibility and commitment to make the partnership work. Sustaining partnerships requires effort to overcome obstacles, and also support from employers in the case of scientists, and school administrators in the case of teachers.

Discussion

This chapter began with the premise that the science students learn at school should enable them to become scientifically literate citizens. In the context of scientific literacy articulated by Goodrum et al. (2001), it was argued that opportunities to develop the skills and abilities that enable people to cope with science-related issues in everyday life are promoted when students experience explicit connections between science in school and science beyond the classroom. This is consistent with Feinstein's (2011) view, that science literacy may be "salvaged" by aligning it more closely to the actual uses of science in everyday life, and Roberts' (2007) Vision II of scientific literacy concerned with science situations that people may encounter as citizens. Three case studies of school-community programmes were presented to illustrate how these connections can be made.

According to their teachers, *Mildew Mania* gave students opportunities to perform curriculum-relevant science activities in a context made meaningful because it contributed to a significant project beyond their classroom. Students became engaged with monitoring their barley plants, were exposed to the real-life difficulties farmers face, such as weather and plant diseases, and learned how scientists were endeavouring to control barley mildew. Students attending the PICSE camp were able and science-interested, yet all of them were surprised to discover the breadth of science-related careers in primary industries. Apart from demonstrating "the big picture" of industrial processes, the work placements. also increased students' understanding of the need for attention to detail, safety, and ethical standards in research. They developed some understanding of what scientists do, their working conditions and the equipment they use, and in some cases became aware that political agendas needed to be negotiated.

In *SiS* partnerships, scientists provided students with a range of experiences that were usually additional to, but invariably in greater scientific depth than, what their teachers could provide. Importantly, students found that scientists were real people who could take the time to work with them, often on projects that took them outside the classroom. A large majority of scientists and teachers were convinced that students were developing the attributes of scientific literacy.

These encouraging outcomes are congruent with other research findings. Based on their review of the nature of science learning in the formal school system and in the more informal avenues for learning science, Stocklmayer et al. (2010)

concluded that a stronger school science education results from exploiting the opportunities for science learning that exist outside school. They found that school-community programmes involving social interaction, confidence-building, real-life relevance, and purposeful activity on the part of participants are effective in narrowing the school-community gap. Stocklmayer et al. gave some examples, and there are many more, in many countries, from small projects such as a single teacher's class working with a wildlife centre to monitor birdlife in the local wetland, to international programmes such as GLOBE (the Global Learning and Observations to Benefit the Environment) Programme, which is "a worldwide hands-on, primary and secondary school-based science and education program" (http://www.globe.gov/). GLOBE is nearly two decades old and, according to its website in October 2013, involved 112 countries, 27,000 schools, with over 118 million measurements contributed to the GLOBE database. GLOBE has extensive resources available online, and GLOBE projects are frequently interdisciplinary, integrating science with mathematics, geography, language and art, for example, and providing many avenues for collaboration between schools and students internationally.

From a curricular perspective, it is worth questioning the nature and value of the science students learn in these collaborative, community-based activities. It was noted earlier in this chapter that people tend to reconstruct science-related information into a form that has meaning and is of use to them (Layton et al. 1993). Students do the same. Rahm et al. (2003) explored teacher-scientist partnerships developing school-yard plots and high school students working with scientists to collect data to learn about fire ecology. It was evident that the science that eventuated and made meaning to the teachers and students was not the "scientists' science" or the science espoused in curriculum documents. Rather, it was a science "grounded in the relations between the world of scientists, teachers, and students" (p. 751), a negotiated, constructed science that was meaningful to teachers and students within their own needs, interests, and contexts. Rahm et al. suggested that the emergence of authenticity was assisted by sustained involvement over time and by the participants assuming ownership of the project. In this view, the emphasis is on the processes rather than the products of science and might "lead students toward an understanding of science that has something to do with the real world of theirs and is meaningful to them" (p. 752).

Rennie et al. (2012) argued that knowledge that is meaningful to students has the potential to be more useful to them than strong, disciplinary science knowledge (Roberts' Vision I of scientific literacy) because it empowers students to become more active participants in their world. Consistent with Rahm et al.'s (2003) findings, Venville et al. (2008) found that students' learning outcomes from community connections in an integrated science curriculum tended to be idiosyncratic, and their knowledge of science concepts was likely to be integrated across other subjects as well as issues in their local environment. Rennie et al. (2012) advocated for science curricula to provide a balance between disciplinary and integrated knowledge, and clear connections between local and global knowledge. They proposed

> that STEM curricula provide a mix of disciplinary and integrated knowledge, set in carefully chosen local problems that can be applied to more global issues. The nature of that mix, finding the point of balance and the degree of connection, is dependent on the particular educational context, and will vary from school to school and from place to place. (p. 140)

Such an approach to curriculum would certainly involve the school-community connections that enable students to develop the kind of scientific literacy that underpins this chapter.

Projects such as *Mildew Mania*, PICSE and *SiS* are engaging and provide extended opportunities for students to come to believe that science is useful and relevant to them. Experiencing how science is used in daily life encourages students to recognise the multidisciplinary and value-laden nature of real world science. They can learn to think about how science-related problems and issues relate to them personally and to the community. They may learn to develop a trust in science (see Fensham, this volume) as a way of finding dependable answers to questions about health and the environment, for example. Further, school-community programmes involve collaboration, not only among teachers, students and members of the community, but also collaborative work among the students. This factor, together with the different kinds of science encountered and the variety of people involved in science-related careers, contribute to an understanding of the diversity in the world around them, as well as among students themselves (see Reiss, and also Simon and Davies, this volume).

This positive picture must be qualified by noting that these outcomes do not come "free"; there are costs involved. All three programmes require significant funding to operate and considerably skilled staff to ensure they are managed efficiently. All three rely on scientists volunteering their time, and *Mildew Mania* and *SiS* are successful only in partnership with cooperative, enthusiastic teachers who have the desire, time and space in their curriculum to become involved. The challenge is to encourage more schools, communities and teachers to embrace the opportunities that such programmes offer and enable them to become more mainstream. There are no easy ways to do this, but there are hints available from other research. For example, Rennie (2011) outlined guidelines for successful school-community projects and discussed how teachers could be helped to bridge the school-community gap. Fundamentally, such projects must be perceived as worthwhile by the potential partners. Members of the community are generally reluctant to invite themselves into a school, so even if the proposed project is one that is of vital interest to the community, there is often the need for a "broker" to bring the sides of the partnership together. In the *SiS* project, the management team and the SiSPOs served this role and their participation is essential to establish many partnerships and often to overcome impediments that threatened continuity.

Most importantly, there must be a legitimate place in the science curriculum for such projects which may need adjustment of the primarily content-based objectives to include more affective and social outcomes (see Matthews this volume). School-community projects invariably require the use, and therefore assist the development of, inquiry skills, and they provide ample opportunity to demonstrate that science is a human endeavour, important outcomes of science curricula that help students learn to deal intelligently with science and scientists (Norris 1995). Cementing a place in school curricula, however, needs assurance that students' participation in these projects is assessable. The need for schools to demonstrate accountability by having students achieve in summative assessments drives much of what happens in schools, especially at the senior level. Fair, equitable and authentic assessment, particularly of non-cognitive outcomes, remains problematic and both researchers and practitioners must give more attention to improving it (Corrigan et al. 2013). Fensham and Rennie (2013) pointed out that a profile of achievement over time offers a more authentic representation of what students know and can do than a summative score. Because of their diversity, what students learn from school-community programmes is often idiosyncratic and strongly attitudinal, making it even more important that a range of outcome measures be employed to demonstrate achievements. Broadening the assessment approach to capture the range of student learning would help to justify the inclusion of out-of-school science-related experiences in mainstream science curricula.

Tailoring school curricula to include opportunities that allow students to make connections with science outside of school makes the achievement of scientific literacy a meaningful goal of science education. The evidence presented in this chapter and elsewhere suggests that school-community programmes help students to build the abilities and skills that contribute to a scientific literacy that enables them to cope effectively with science beyond the classroom.

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Children Learning Science in and for a Participatory Culture

Bronwen Cowie and Elaine Khoo

Introduction

If becoming a scientifically literate citizen involves developing a certain autonomy and capacity to communicate and act (Hodson 2009) we propose that, as a first step, children need opportunities to enact a science identity grounded in sharing what they have learned with those who are close and dear to them—their peers and families. Science education is increasingly adopting a sociocultural explanation for learning and classroom interactions (Lemke 2001). Sociocultural views of learning acknowledge that students belong to multiple communities and so it becomes important to look both within and beyond the classroom to understand students' science learning trajectories—their motivations and accomplishments.

Information and communication technologies (ICTs) are increasingly playing an important role in today's educational contexts. The New Zealand Curriculum (NZC) (Ministry of Education [MOE] 2007) validates the important role ICTs have in assisting with making connections, facilitating shared learning, catering for diversity and supporting active participation. ICTs already play an important role in students' lives out of school (see Selwyn and Cooper, and Shanahan, this volume), to the extent that Jenkins et al. (2006) have proposed that many young people are involved in a *participatory culture*. Within a participatory culture ICTs allow those with shared interests to communicate, collaborate, share and learn from each other in ways that previously would have been difficult. Such a culture has the potential to expand and enhance student opportunities to learn science as a process and outcome of classroom participation.

In this chapter, we consider what Jenkins et al. (2006) notion of a participatory culture might mean for the learning of science by children when the central goal for their learning is that they experience science as a positive force in assisting them to

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make sense of and exercise agency in their world. The chapter is underpinned by an understanding that young children are more than capable of achieving this goal when they are given opportunities and support. Although our main focus is on children's learning, we acknowledge that it is important that teachers are enthusiastic and confident about using ICTs as part of their teaching (Woolf 2010). We provide three examples, taken from projects that we have been involved in, to illustrate these ideas. But first we elaborate on current trends in the goals for science learning and the potential for ICTs to contribute to teaching and learning.

Trends in Science Education

Student participation in school science ideally involves them developing their understanding of science concepts and of how scientists go about developing theories and explaining natural phenomena. Their classroom experiences influence how students see themselves in science (Chen and Cowie 2013). Given that science plays an important role in many of the challenges and opportunities facing society today, we are interested in how young students can be supported to see and experience themselves as confident and proficient learners and users of science (Bolstad and Hipkins 2008; Tytler 2007). Specifically, we are concerned that an education in science prepares students as citizens who are ready, willing and able to participate in science-related issues and science-based occupations. We agree with Hodson (2009) when he asserts that science education needs to empower students to exercise a measure of intellectual independence and personal autonomy in forming intentions and in choosing and carrying out science-informed actions across the various contexts of their lives, both personally and socially (see also Fensham 2009). Roth and Lee (2004) endorse and illustrate this wider vision for student learning in their work on science education "as and for participation in community life" (p. 263). This orientation, they argue, sets up the potential for lifelong participation in and learning about science-related issues.

An important part of participation is a student's identification of curriculum subject matter and practices as meaningful and important for their growth and development across all aspects of their lives. Greeno (2006) alerts us to the importance of establishing learning environments that encourage participatory learning processes. We agree with his assertion that these processes rely on "both the contents of what is learned and the agency with which those contents are deployed in activity" (p. 538). Both aspects are important in order for children to take up agency and accountability for their science learning. However, opportunities for students to experience what these aspects might mean in relation to their science learning will need to be created in the classroom context. One way forward is to make use of ICTs as tools to facilitate higher levels of student collaboration, communication and knowledge construction. Referring to the way ICTs are reconfiguring how scientists collaborate, legitimate and communicate new knowledge Pea and Collins (2008) argue that, "[it is] hard to see how science education can adequately reflect changes in scientific practices and affiliated habits of mind without greater technology integration into educational activities" (p. 12).

ICTS as Technologies for Participation

New media technologies are resulting in new communities based on new forms of communication, learning and self-expression (Ito et al. 2008). As noted earlier, many of these communities are grounded in a participatory culture where 'not every member must contribute, but all must believe they are free to contribute and that what they contribute will be appropriately valued' (Jenkins et al. 2006, p. 7). A participatory culture focuses on community involvement and contribution through collaboration and networking rather than individual expression. Within a participatory culture there are rich opportunities to initiate, produce, and share one's creations; be involved in peer-to-peer learning; collaborate with a wider group of interested others; and to make connections that are global in reach.

A participatory culture can be integrated in schools through collaborative work whereby students are encouraged to contribute their own expertise as part of developing a shared understanding (Brown et al. 1993). This is a process many students encounter readily in their out-of-school participation in blogs, wikis, Facebook, etc. In these contexts, the generation of knowledge is social and distributed as students share and compare ideas and practices with each other towards a common goal. In a classroom, as in wider society, these processes can be catalysed and realised through the use of ICT tools. Research in science education has identified that ICT use can lead to students' school science experiences being more interesting, authentic and relevant through the expansion of their opportunities to observe phenomena and to collect and analyse data (Webb 2005). ICTs can also enhance the opportunities students have to collaborate, discuss and communicate findings with others, including groups outside their classroom such as younger students, family, and community groups (Williams et al. 2013).

Possibilities for Participatory Science Learning in New Zealand Primary Classrooms

New Zealand primary school classrooms provide a setting for student science learning that gives more freedom and responsibility to school and teacher than is the case in many other contexts. There is no formal national testing in the primary years as formative assessment is given priority and schools design their own formats for reporting to families. The national curriculum provides a framework rather than a prescription for teacher planning; there are no formal and mandated textbooks or units of work. The NZC places a priority on teacher planning to build on from student and community strengths and needs: The curriculum has meaning for students, connects with their wider lives, and engages the support of their families, *whānau* (the Māori term for families and kinship between related families) and communities (MOE 2007, p. 9). The NZC also sets out five *competencies* that students need to develop to "live, learn, work and contribute as active members of their communities" (MOE 2007, p. 12). The competencies are: participating and contributing (active involvement in communities); using language, symbols and texts (understanding the different forms of knowledge representation); thinking (using cognitive processes to build knowledge from information); relating to others (interacting effectively with a diversity of people); and managing self (self motivation and independent learner capability). These can be read as encompassing the skills and capabilities embraced within a participatory learning culture orientation. In addition, the NZC states that students need to be able to confidently use ICTs to make connections and to communicate and share their learning within and beyond the classroom.

In this section we provide three examples that illustrate some of the ways New Zealand primary teachers have used readily accessible ICTs to orchestrate student science learning as a participatory process that includes *a wide range of interested others in their learning*. The first example reports on teacher use of a range of ICT tools to support collaborative meaning-making and multimodal communication of scientific ideas. The second and third examples provide more elaborated evidence of how teachers can use ICTs to involve a wider group of interested people (families, informal science-related communities, peers from other schools) in students' learning. Table 1 is a summary of the ways teachers across the three examples adopted ICTs in their practice in support of participatory science learning.

Example 1: Making New Connections with the Local River

This first example of participatory science learning comes from the second year of a two-year study that investigated the potential for ICTs to enhance teaching and learning in primary science classrooms (Otrel-Cass et al. 2011). The unit task was for students (age 10 and 11 years) to collect and identify a rock taken from the bank of the local river and explain how it might have got there. The river was within walking distance of the school and is a major feature in the city of Hamilton where the school is located, having both economic and cultural significance. The teachers (Tina and Clara)[1] expected that all their students would have been driven by the river many times but that not all of them would have visited the riverbank. They anticipated that the learning task would provide students with a meaningful experience of what it meant to think and work like an earth scientist. That is, they had conceptual and epistemological goals for student learning.

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[1] Teachers' and students' names are pseudonyms.

Table 1 Participatory science learning mediated by ICTs across the three examples

Participatory aspects/participants	ICTs used in Example 1	ICTs used in Example 2	ICTs used in Example 3
Peers in student's class	Class blog Individual blogs Wallwisher Web-based resources Flip video cameras Digital cameras		
Teacher outside formal lessons	Class blog Individual blogs Wallwisher	Email	
Peers in other classes (local/overseas)	PowerPoint		Class website
Family/*whānau*	PowerPoint		Class website and face-to-face meetings
Other community members			Face-to-face meetings
Science 'experts'	Face-to-face meeting Wallwisher	Web-based videos (Science Learning Hub)—note not direct, but does enable wider student access to NZ scientists	
Informal science communities		Monarch Butterfly website	

Prior to visiting the riverbank the teachers introduced students to some of the ideas and language they might find useful and students compiled a glossary of key terms that they shared with their peers via their class blog. At the riverbank, the students worked in groups to select a small number of rocks for analysis back in class. They shot and narrated a video about the location of particular rocks and their reasons for selecting them. The rock selection and video tasks required the students to observe and think carefully about rock appearance and location, including what information might later be important for them to know. The narration provided an opportunity to use the science language they already had before the lesson and that which they had been given that day.

Back in the classroom, the students worked in groups to sort their rocks according to physical characteristics (colour, shape and size), and to consider what dynamic processes might have been involved in transporting and shaping them. They broke the rocks open and used a digital microscope, books, and resources from home and the Internet to help identify the rock types. They used a variety of geological maps and Google Earth to investigate the landforms in the river catchment as a means of determining if/how a rock of their proposed type and shape could have been transported to the riverbank.

Student discussions with their teachers, peers and earth science Masters students (as experts) were central to the students' rock identification process. For example, they used Wallwisher (a free online noticeboard) to pool their ideas and develop a *rock vocabulary list* wall as part of their class blog. Eight earth science Masters students visited the class to discuss students' rationales for their rock type categorisation and their explanations for how their rocks had come to be where they were found (e.g., through erosive forces). As a follow-up to this visit, individual students posted their ideas on the Wallwisher and the experts responded with prompts for further consideration as well as messages of affirmation and encouragement. For example, one of Clara's students, Zoe, began her wall by posting the question, "What is erosion?" followed by a possible answer: "Erosion is a process of rocks and soil moved from one place to another (6th May)." Two of Zoe's peers and her expert responded to her post by elaborating on the concept of erosion and how it was caused:

> Peer post 1: How is erosion caused? Erosion is formed by wind, ice, water or ocean waves chipping away at the land (6th May)
> Expert post: There are three different types of erosions: wind, ice and water (21st May)
> Peer post 2: Erosion is a process that can move rock or soil and sometimes being helpful by making another landforms like volcano, hill, mountain, islands and some more!!! (10th June)
> Expert post [in response to Zoe and her peers' postings]: You seemed to have a good understanding of erosion, well done! Maybe think about the processes your [rock] sample went through to get down the river (10th June)

Here we can see how Zoe's peer introduced the mechanisms of erosion. Her expert endorsed them and prompted Zoe to think further about their implications for her rock sample. Students do not usually have an opportunity for sustained interaction with visiting experts but in this case the Wallwisher provided a means for interaction at a distance. Zoe told us that it was "a cool experience" to talk with her expert because she got to know about different types of rocks and their origins, and she was comfortable asking questions about her rock.

Another student described how the experts' visit had been fundamental in probing and challenging their thinking about their rock type in relation to the dynamics of rock cycle processes in earth science:

> It was good to learn more about rocks. Our expert pointed out the colour, texture and other features, which we didn't think of before. He showed us that our thinking that our rock sample came from the South Island [this was based on their comparing their rock with images of rock samples on the Internet] would not have been possible as our rock could not have travelled so far [Hamilton is in the middle interior of New Zealand's North Island]. The currents would have been too strong and the rock would crumble before it arrives here. We wouldn't have known otherwise.

The teachers' inviting in of Masters students, while initially a pragmatic decision (it was easier to arrange for them to visit a class than it was to arrange for a university lecturer to do so), proved to be strategic—the students were able to engage with young adults, who, although they were still students, were nevertheless comparative experts. This action also introduced the children to wider a community of learners and the idea that earth science learning has a long trajectory; the Masters students were approachable role models.

In addition to using Wallwisher, students also posted their ideas and questions, useful resources (images, videos, web links, PowerPoint presentations, etc.) and examples of their work on individual blogs that were accessible from the general class blog. While peers commented on one another's blogs in school time, it was more typical for students to blog after school. The students commented that blogs were useful for "letting others [including their teachers and peers] see and comment on my work", which they could then improve on. The students also appreciated being able to "visit the (multimedia) resources" their teachers and peers had posted in the class blogs, and that the blogs provided a 'more permanent record of learning' that they could show their parents if they forgot to take their science books home. One student noted the blogs were valuable as 'people can see how good you are!' as an affirmation of their learning development and outcomes. Further, parents could view their child's postings and contribute their thoughts, and three did. In this way, the use of ICTs extended and sustained student learning beyond the school day and, for some students, engaged their families with their learning journey.

As a culminating activity for the unit, the student groups developed a PowerPoint—'Our Rock Story'—that summed up what they had learned. The production of this multimodal expression of their learning required the students to review, synthesise and elaborate their ideas in order to showcase their learning in a manner that would both educate and entertain an audience of their peers, family and other school community members (Buxton 2010). Teachers and peers provided formative feedback on student presentations to ensure they showcased their learning to its full advantage.

Students' PowerPoint presentations contained a combination of text explanations, images of their rock samples, and materials sourced from Google Earth, physical maps and animations. The students spoke confidently about their findings, representing their ideas using the science terminology they had learned. An example of their discourse follows:

> We think that [our sample] rock once was magma underneath Mt Tongariro [an active volcano in New Zealand's Central North Island]. Then one day in 1896, the volcano erupted and the magma shot up through the pipe and the vents. The magma, which is now called lava, poured out onto the side of the volcano. We think it came from the eruption. We think that originally the rock was jagged and sharp… If we had not picked up the rock from the side of the river, we think that it would have kept rolling along the river bed. Then it will be pushed along by the current and other rocks until it reaches the ocean floor. It will be eroded down into sediment.

The student presentations provided for greater transparency in and social accountability of the students' learning process and outcomes (Kalantzis and Cope

2004; Vaughan 2007). Parents who attended the presentation were impressed with the quality of the students' investigations and ideas. The students were very pleased with the audience response to their presentations and their learning overall. A representative student interview comment was: "I learned more about the process that changes our earth, how landforms change over time, about rocks, what types, where they come from and how they change, and describe the area where the rock is found". Interestingly, the students were keen to take their learning further and to share both what they had learned and the learning process with others now that they had developed some expertise. For example, one student reported:

> I enjoyed learning about volcanoes, and rivers and rocks. How they are formed, where they are from. I would like to find out more about how this relates to glaciers, like how much time does it take for the sun to melt glaciers? I want to learn about it [this unit] again. Now I can be an expert. Other people [his group peers] were being expert, they were saying, "I'll do this", "I'll do that". Now that I am an expert I can help and guide others. (Student interview)

In this first extended example, readily-accessible ICTs complemented and augmented student learning of science concepts, providing support for student independent inquiry *and* a forum for peer-to-peer feedback (via the Wallwisher and blogs) and interaction at a distance with family members as well as experts they had already met in person. Students, therefore, had opportunities to participate in science learning and self and peer assessment through a variety of ICT-based multimodal means, which allowed them to establish richer and more productive collaborative links with a wide range of people who had an interest in their learning. The ICTs provided students with a richer means for authoring ideas and communicating what they were puzzling about and learning. The culminating presentation of their 'Rock Story' exemplified this and allowed students to express their ideas in rich and diverse ways.

We have used this example to demonstrate how participatory science learning was made possible with and through the use of ICTs. The technology supported and extended the range of resources and people (peers, families, experts) that students could draw from and be informed by, enriching their learning experience and the learning of others, including peers, family members and the two teachers. This place-based unit was therefore meaningful, not only in terms of enhancing students' understanding of earth science, but also that of their families.

Example 2: Connecting with a Wider Community of Interest

The second example involved students (age 7 and 8 years) learning about New Zealand butterflies and butterfly life-cycles using Science Learning Hub (SLH) resources (Chen and Cowie 2013). The SLH is a website (www.sciencelearn.org.nz) that has been developed to profile the work of New Zealand scientists. It includes videos of scientists talking about their work, images, articles and teaching and learning activities. The unit focused on butterflies, their life cycle and the plight of New Zealand native butterflies, including monarch butterflies. Anne, the teacher, planned that the students would take on the role of 'citizen scientists' (her term). She began the unit by suggesting to the students they could become 'butterfly warriors'—people who would want and know how to take action to protect butterflies. Student web use was central in providing students with access to up-to-date New Zealand data on butterflies and in enabling students to contribute to a New Zealand community group with an interest in monarchs, the Monarch Butterfly New Zealand Trust (MBNZT, see www.monarch.org.nz).

Over the course of five lessons, the students read about and drew butterfly life cycles, hunted, tagged and released butterflies, and published the data from the butterflies they had tagged on the MBNZT website. Anne used text, high quality photographs and videos of New Zealand butterfly scientists and New Zealand butterflies from the SLH to alert the students to the existence of New Zealand native butterflies, which tend to be 'small and secretive' and do not often feature in everyday conversation or school science. Anne also guided the students through the MBNZT website, which shows butterfly migration worldwide, to introduce the idea of migration and the growing international concern for the declining numbers of monarchs. She then showed students the MBNZT website, which documents where monarchs have been tagged, released and recovered in New Zealand. The students were particularly interested that butterflies had been both released and recovered in their own city. Anne shared the statistics that only two butterflies are recovered for every 100 butterflies tagged, highlighting the need to tag many butterflies in order to recover a few.

When demonstrating the tag, release and publish process, Anne positioned the students as scientists, explaining that, "Because you're scientists you need to follow scientific processes". She emphasised the need to be gentle when handling a butterfly because butterfly wings are very thin and fragile, and demonstrated how to hold a butterfly to minimise harm. Students practised their own tagging skills using a paper butterfly and placing a small round sticker on the underside of a wing. Anne clarified that data posted on the NZMBT website would be available to scientists (and the public) to help track butterfly movements as part of the worldwide conservation effort. That class data would be used by a wider community of interest led naturally into a discussion on the need for attention to detail and accuracy.

> Anne: If somebody does find a butterfly, tag it, and then publish the data on the MBNZT website what happens?
> Student 1: The scientists can see that.
> Anne: Do people like us see it?
> All students: Yes.

Anne and the students tagged and released a number of butterflies in class time. Further, important to Anne's ambitious goals for student learning, a group of students observed and tagged butterflies on their own initiative during lunchtime. The students posted the tag information on the MBNZT website and emailed Anne about their actions, signing themselves as "your butterfly warriors":

> Dear [Teacher Name],
> Student 1, 2, 3 and 4 caught 4 butterflies and tagged them at lunchtime! They say it was hard catching them and holding them on the wings especially the first one! There were two males and two females.
> Cheers,
> From your butterfly warriors! :-)

In the unit evaluation, Anne asked the students for their views of who are and can be citizen scientists. The consensus was that citizen scientists might not be as knowledgeable as real scientists, but they were interested in science and had some scientific knowledge and skills. They followed scientific procedures although they did not conduct experiments and/or work in a laboratory. The students thought they could be citizen scientists and protect butterflies, other animals and the environment. As in the following example, the students were able describe activities they might participate in into the future:

> I would like to protect, research, and tag them [butterflies]. Maybe, if you find the rare species you can help them grow up. If they're broken or something, you can take them into where you go and look after them. (Student interview)

Some students shared their butterfly knowledge with their families and continued to investigate butterflies at home:

> Student 1: I talked with my family and they were surprised that I knew so much stuff. We have milkweed plants in our garden and we had a look for caterpillars. We have got heaps of caterpillars and they live on our swan plants [*Asclepias physocarpa*]. I will bring in some of them in and talk with [Teacher Name]. (Student interview)
>
> Student 2: I made a slide show of all the different kinds of butterflies. You just go to the Internet, click, and go to the images, and then out comes a lot of butterfly images. You can copy them, and put them onto a slide show. They [her family] said it is really good. (Student interview)

At a follow-up student focus group interview 6 months after the unit ended, the eight students who agreed to participate each described actions they had taken related to the unit, intimating that, as a consequence of their participation in the tagging programme, they had learned to 'respect' butterflies. In group discussions they expressed a wider commitment to conservation of animals and the environment in the 'hope in the future the world is still sustainable'. Anne considered that the students' interest had been stimulated and sustained by their being able to 'make a difference in their world'. She explained:

> I think the reason they loved this unit is because there is an opportunity for them to make a difference in their world about something they already know and care about. It was real and meaningful… So I think that's why they loved it and wanted to learn more. They were all inspired. They surprised me how they acted and just wanted to keep going…before this other people have helped them, but this time they felt they could help others. That makes a difference.

Anne had introduced the possibility that students could be citizen scientists at the start of the first lesson and kept reminding students of this potential throughout the unit. This expansive framing provided a possible connection between prior, present and future activities in which students might use what they were learning, and positioned students as contributors to a larger community of people interested in what they were learning about (Engle 2006). The NZMBT website provided a direct link to a wider community of interest and the SLH videos of New Zealand scientists talking about their butterfly-related research alerted students to the passion and commitment of scientists working in this field in New Zealand.

The unit developed and deepened students' understanding of butterflies and contributed to their sense of personal worth through their being able to share their learning with others who were important to them beyond the confines of the classroom. In addition, what they had learned and how they had done so stimulated some students to think about other species they could extend their science-in-action conservation efforts to. ICT use was pivotal to introducing students to this process and linking them with a wider community of interest, and it allowed students to see possibilities for extending their interest and activity beyond the unit. In this example, students were therefore able to use ICTs to continue a school science activity that had meaning beyond their individual and collective class endeavours.

Example 3: Making Stronger Connections with Families and Communities

Our third example comes from a study in which teachers and researchers worked together to extend the use of culturally responsive pedagogical practices in junior primary science classrooms (Cowie et al. 2011). It is taken from findings from the second year of the study. The teacher, Jude, had a goal to engage her students' families and community more actively in the students' science learning. To do this she instigated a number of new practices. First, the children (age 6 and 7 years) wrote a letter to their families inviting them to an afternoon tea where the unit topic and research study would be introduced and discussed with them. This invitation was taken home in the children's 'Home Learning Books' (HLB) (Parkinson et al. 2011). On the advice from another teacher in the study, Jude used the strategy for the first time with her class as a tool to engage parents in conversation with their children about science.

At the afternoon tea meeting Jude explained that the children would be studying space and the science of night and day and the seasons and shadows. Jude introduced the HLB as something parents and families could use to share their ideas and experiences with their child and the class. In preparing for this meeting, Jude also invited two important *kuia* (a Māori term for elderly women), affiliated with many of the *hapu* and *iwi* (Māori terms for sub-tribes and tribes) of families in her class, to be present and talk about how Māori knowledge connected with and contributed to these topics. Their participation was a signal to Māori students and their families that Māori knowledge and understanding were important and would be affirmed during the unit.

The children valued this occasion. All of them included the invitation in their portfolio of work that they later discussed with their families. A number of students, in conversation with a researcher, identified the invitation as one of the things they were most proud of because their parents had come to class to talk about their learning. One student explained: 'This was for a science meeting and we had a meeting in the library. Mum thought that it was amazing'. In Jude's view, the families present at the meeting found it 'very valuable' and it 'set the scene for all that this is a learning journey together'. A number of parents told her they were very appreciative of the chance to find out what their child would be learning about and they valued the opportunity to clarify how their own experiences and expertise might be linked with and contribute to their child's science learning. Jude commented that throughout the unit a number of children 'dragged' their parents into the classroom to 'come and look at this and look at this'. She also reported that the parents who had attended the meeting contributed more ideas in their child's HLB than those who had not.

Over the next 3 weeks Jude taught lessons on day and night, the seasons, shadows, and the stars and constellations. The lesson on constellations linked to the school focus on *Matariki*, the rising of the Pleiades star system that signals the beginning of the Māori New Year. One of the *kuia* volunteered her nephew, an expert in celestial navigation, to contribute his expertise and present a *kōrero* (Māori term for talk) to the school. He did this using PowerPoint and video to illustrate his points. All eight students interviewed at the end of the unit commented on this presentation, implying the expert's use of visuals had added impact to the talk. For example, one reported:

> I think that was actually quite cool. I found out heaps of stuff. He told us about how he sailed on the *waka* [Māori term for boat] because he looked at the stars and he sailed and he showed us pictures from his computer, on the screen. He went from where he was living to here because he sailed the waka and he was looking at the stars.

Alongside the more teacher-directed activities, Jude asked the students to brainstorm and record everything they knew about space and then to think about what they would like to know more about. Students recorded their inquiry learning questions in their HLBs and discussed these at home. The next day Jude provided the students with some broad themes to help them sort their questions into categories. They then chose to work as individuals, in pairs or as a small group, to investigate their selected research question. Most chose to find out more about a planet or a constellation. The students typed up and formatted their findings along with a piece of their own artwork and posted the results on the class website.

Jude had developed this website specifically for the unit as part of her commitment to the school's ICT project. The research team helped her with this because it was thought that it might enhance family and community engagement as an aspect of Jude's culturally responsive pedagogy. Jude posted a lot of resources and links and additional information on the class website and the students were able to upload their own work and material themselves. The website offered students a new and different purpose for their investigative work because it provided an authentic purpose and audience for what they had learned beyond themselves. The students could access the website from home to talk about their work with their families, which some of them did. For example, one student reported: ‘My aunt, she was really pleased when I showed her everything on Room 13’s website’.

The website supported the sharing of information in a way that allowed families insight and input into student learning during the unit. A number of parents told Jude that their child was doing a lot of sharing of their work on the website. Parents also reported their children posted material from home. In many ways, the website served as a complement and parallel to the Home Learning Book in supporting the extension of learning out of the classroom into the home.

In addition, Jude’s class used their website to make a connection with a class in Austria, where one of the research team was based. The classes communicated through postings of descriptions and photographs of themselves doing activities. (A member of the research team translated the Austrian students’ postings as required.) The students also shared their art work. The Austrian class provided an authentic audience and added incentive for Jude’s students to carefully complete and report on their activities and learning. Once their research had been posted on the class website, students eagerly monitored it for any comments or emails from the Austrian students.

Students in both classes were intrigued at the differences in time zones, the seasons and the star constellations they could see. They shared and were interested to learn of the different cultural myths about the New Year. In the words of one student, the experience of talking about what they were learning with a class on the other side of the world was ‘Pretty amazing. I learned so much. I can’t believe that they could actually send it to us’. The following commentary is representative in identifying science and social-relational benefits from the experience:

> Researcher: What did you think about talking to the kids in Austria?
> Student: It was cool.
> Researcher: What was cool?
> Student: How we can share on the computers and make new friends. It is night-time over there and daytime here.
> Researcher: Why is it daytime here and night-time there?
> Student: Well the Earth orbits the sun and the moon orbits us and every time we spin we get night-time and the other side of the Earth gets day-time.

As can be seen here, not only were the students able to talk about the science they had learned but they also valued the chance to make new friends. Jude considered that the students’ interactions with the Austrian students gave added purpose and context to their learning—they were intrigued by the seasonal and time differences and different attitudes of the students and were keen to share and discuss their ideas and experiences.

Over the course of the unit, a number of ICTs were used to support student participation in science. These breached the boundaries of the classroom and supported students to make a personal connection with other children across the boundaries of physical location and time. The class website complemented the

HLBs as an incentive and a forum for students to talk to family members about their developing understandings and extend them. As the website had a wider reach, more members of the community could be informed about their work, which, in turn, allowed for more feedback and input to inform students' thinking. In each of these instances, students communicated with an authentic audience genuinely interested in their work. The fact that communal knowledge was affirmed and valued in the unit widened students' conceptions of science beyond their typical notion of what it might mean to act and think like a scientist. This was very evident in the way the children shared their knowledge with siblings and family members (both their own and those of peers) at the session that concluded the unit.

Discussion

We began this chapter by asking what ICT-assisted participatory practices might look like in classrooms where teachers were aiming for their young students to learn science as a process of knowing in action (Greeno 2006). We have illustrated some possibilities, through three telling examples, that flesh out different ways in which participation might feature and be fostered. The three examples were concerned with different science content and understandings but each was grounded in phenomena that were familiar and accessible to young children, both physically and conceptually—they could visit the river; capture and tag butterflies; and star gaze. In each case the learning was underpinned by a *big* science idea—geochemical processes (erosion) and classification, life cycles and conservation, astronomical systems and time. In each case, too, students' science learning was woven into activities and relationships that could reasonably be expected to be accessible and of value to them as part of their lives outside school. Their science learning had the potential, which for the students we spoke to was realised, to strengthen and add value to these activities and relationships.

Through their science learning, students became more knowledgeable about the local river, butterflies and the stars and seasons and they were keen and able to share their new knowledge. They developed an understanding and appreciation of what it might mean to be an earth scientist through sharing what they learned with interested members of the community (experts and parents). Their interest in butterflies was deepened and extended to include a wider concern with conservation through their experiences of being 'butterfly warriors'. Finally, students found added meaning to their learning about the stars when engaging and communicating with their families and community members, including overseas peers.

ICT use was integrated into all three examples to support students' science conceptual learning by facilitating participatory learning, communication and action. In the first example, reasonably well-known and accessible ICTs were used to help students observe, analyse, communicate, collaborate and share their developing science ideas in multimodal ways. The fact that ICTs enabled student access and communication beyond class time allowed for new groups of interested community members (Masters students) and even parents to contribute to and become stakeholders in student learning and achievement. ICT use in the second example, in the form of the students emailing their teacher to update on their efforts and posting data to a dedicated website, made possible links between students and a community concerned with butterfly conservation. This extended into other conservation efforts well beyond the unit. In the final example, ICT use complemented other teaching activities to connect students with family and *whānau* who were then able to more actively participate in and contribute to the students' learning. Parallel use of HLBs and a class website informed and engaged students' families and *whānau* in different but mutually reinforcing ways, with the website having a wider reach compared to the books. The class website and email also supported long distance collaborations between New Zealand and Austrian children. The integrated use of ICTs in the three examples therefore blurred the boundaries between children's participation in science learning and knowing at school and out of school contexts, allowing them to draw from a wider range of resources and people to contribute to and enrich their learning experiences (see Grant 2011).

Concluding Comment

We suggest that children, as a first step, need opportunities to enact a science identity grounded in sharing what they have learned with those who are close and dear to them—their peers and families. This prepares them to be ready, willing and able to share their ideas and take actions that have a wider reach and impact; a demonstration of science learning in action highly depictive of participatory cultures. ICTs play a central role in establishing a participatory culture in support of students' sharing of their ideas and experiences through multimodal means, expanding on their learning when it suits them in/out of the classroom, and allowing them to initiate and sustain connections with experts outside the classroom. Our chapter has indicated some possibilities for how teachers might use ICT to support participatory science learning of traditional science topics and with readily accessible ICT tools. It is our hope that the ideas and examples described will contribute to contemporary thinking and discussion about the potential for children's science learning.

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The Elephant in the Room: Emotional Literacy/Intelligence, Science Education, and Gender

Brian Matthews

The main purpose of this chapter is to present an argument for the future of science education through, potentially, a transformative process for pupils, teachers and society. I will argue that the answer to the question ‘What is in it for the learner?’ is ‘A better future’. There are many important discussions on how science education should change. For example, Millar and Osborne (1998) and Hodson (2008) call for an approach providing opportunities to develop future scientifically literate citizens. However, the importance of the role of emotions in science learning is under-explored. Emotions are the elephant in the room and this chapter sets out why they are important, and why they require explicit attention in the classroom. Science education is not only concerned with cognition but involves a wider range of aspects, including asking what science is for and who benefits from the advancement of science and technology. Students’ emotions need to be considered if questions such as these are to be answered. The importance of developing scientific emotionally aware citizens to play an active role in society should not be under-estimated. Furthermore, the relationship between emotions and gender needs exploration if all young people are to be engaged in science learning.

To this end the chapter will look at science as a cultural activity that involves the emotions from a philosophy of science perspective before considering political and economic factors. To explain the importance of students forging personal responses to science I discuss a school-based action research project that explored how teachers worked on developing pupils’ emotional literacy and interest in science.. The chapter will conclude by considering the impact of emotional literacy on education.

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Science as a Cultural Activity

Science is traditionally seen as an objective and neutral pursuit devoid of emotions, and often schools teach it in ways that reinforce this view. With this model it is possible to argue that science should be value free. However, there are many calls for values to be incorporated into science education (Corrigan et al. 2007). This is because it has been recognised that science exists within culture and so has a social context. Other chapters in this volume (e.g., Reiss; Shanahan) make this point clear and indicate that science education can help pupils see the connections between science and society. Crucially, it is important to recognise that having values involves emotions and emotional commitment. As Rennie (2007) points out, values are undisputedly linked to beliefs and attitudes, or life stances, and so values have an emotional component. Panizzon, Lancaster and Corrigan (this volume) posit a Learner Development Framework that includes the values of 'Learning to live together' and 'Learning to be'. Similarly, Murphy (this volume) argues that science is, in part, an emotional activity.

Since we cannot have values without affect it is crucial that we make this connection explicit. One may, for instance, have a commitment to a value, say, equality. It is possible to discuss what this would mean at an intellectual level. To help tackle inequalities, though, a person would have a commitment to being involved in trying to influence others and take action. In a sense, what really matters is how one furthers the value in life. For the moment I will focus on sexism, which would involve a commitment to improving one's attitudes and interactions with males and females, lesbian and gays. Interacting with people of different sexualities can involve a person having to work with their feelings at a deep emotional level. This process is putting values-into-action in order to effect change both in oneself, and in society, and is an essential aspect of progressing a value. Hence, in this chapter, when I refer to 'values' I am using it as a shorthand for 'values and their associated emotions'. There is an implication for schools in that it is not enough to have policies that pupils are aware of, but that all parties need to be aware that pupils have to be engaged emotionally with others and that this involvement can affect how these youngsters behave and learn.

I will now consider how science is linked to values and emotions. Some people may argue that while there may be values in the way that science is used in society, science itself is valueless and unemotional. However, there is much evidence to counter this argument and to view science as a social activity fuelled by human endeavour and I will now give a brief outline of some points to support this contention (Feyerabend 1993; Kuhn 1996b; Mosley and Lynch 2010; Sharrock and Read 2002).

Loving (1991) analyses different philosophical views on the nature of science. One influential figure discussed by Loving is Kuhn (1996a, b), who argues that emotions have to be involved in science. Kuhn (1996a, b) believes that scientists work to prove that their theories are correct and that their passion and emotional commitment are essential for science to progress. Scientists will produce a theory but, in its early stages, it may not explain all the observed phenomena. However, when things do not ‘fit’ their theory, scientists will work at it in the hope they find a way round the problem later, and not take this as falsification (see Shanahan, this volume). Hence, emotional commitment is essential to scientific progress (Easlea 1973; Hodson 1998), and Hodson (2008) argues that tenacity is also essential. People live in the world and accept the main views, explanations and beliefs of society; this is called a world-view. Hence, scientists work within a world-view and their explanations reflect their social context, i.e., they often work within the world-view of their research department or of their funders. Consequently, according to Kuhn, science is value-laden. It is not possible to go into a full explanation here but, for example, it is argued that quantum mechanics arose in Germany and northern Europe because of the cultural context that was antagonistic to determinism (see Forman 1971 for a full discussion).

Other philosophers also view science as a social activity. For example, Feyerabend (1993) argues that science involves rivalry, irrationality and a struggle to get ones views accepted (see also Fensham, this volume). The fight against polio provides an example where, according to Williams (2013), the research to find a cure involved skulduggery, unethical rivalry, manipulating results and deriding promising avenues of research. Mosely and Lynch (2010) argue that

> Science does not happen in a vacuum; it is not set in an ivory tower. Science has always been a part of the world within which it is practised, and that world is subject to all the usual complexities of politics, personality, power, passion and profit. (p. 9)

If these views are taken into account it is difficult to talk about an objective ‘scientific method’. I have run a session with pre-service teachers on ‘What is science?’ One aspect involves discussing how scientists often work, rather than the ‘plan, method and conclusion’ presented in school science curricula. In this session I ask the students how, from their experience, they think scientists go about their research. Each year a chart depicting “how scientists work” is adapted in light of the discussions we have. The chart (current form is shown in Fig. 1) includes the main ideas that have emerged, with the components that obviously involve *emotions* placed inside oval shapes.

The pre-service students involved are science graduates, including some who have conducted scientific research (Ph.D. degrees, etc.). This chart reflects the collective views of these students of the emotional and cultural progress of science, which is usually presented as a simple rational exercise in schools and universities. The chart is only a schematic and includes examples of human endeavour within it. For example, as the pre-service teachers have pointed out, a ‘conference’ could include a presentation of results and a peer review and also a response and questions from the audience. In some instances, there is collaboration and sharing of ideas while in others there may be competition in cases where companies keep results secret and do not share them. However, it suggests that social and emotional factors play their part. There is no simple path and only the end point, the ‘experimental write-up’ (bottom right) is fixed. The latter step of ‘rationalisation’ is very important as it enables review and evaluation of ideas. The impetus for science

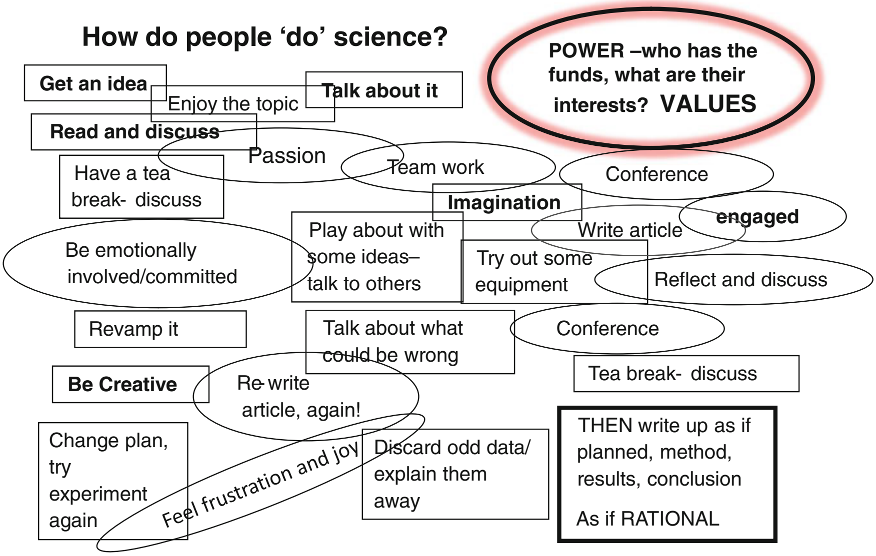


Fig. 1 How scientists work

is to begin with ideas and passion and end dispassionately. However, the emphasis on the 'objective' summary can hide the social and emotional parts that occurred within the process of the science inquiry. These parts are non-linear and complex and contribute to making science so varied and interesting. As Hodson (2008) argues, there is a disparity between how scientific inquiry is performed and how it is reported. Scientists can indicate an underlying emotion when they describe a solution as being 'elegant' and 'beautiful'. Indeed Penrose and Gardner (1999) argue that "… aesthetic criteria are enormously valuable in forming our judgments […] A beautiful idea has a much greater chance of being a correct idea than an ugly one" (p. 421).

So far then, I have argued that science can be seen as a social activity involving emotions. I would now like to explore another possible link between science, emotions and culture, in order to consider how much it is the teacher's responsibility to raise certain issues with pupils.

Easlea (1973) used Kuhn and the social nature of science to argue that scientists should be aware of the political nature of science and that they should work towards achieving liberation:

> … some scientists … are realising the necessity of mobilizing themselves in support of the oppressed and exploited peoples of this earth, in solidarity with all groups of people who are struggling to build a non-exploitative world society. Such a commitment by scientists … the balance might just be tipped in favour of life and liberation in the difficult years to come. (p. 341)

Easlea argued that capitalism was an obstacle to moving toward a more liberated society. Similarly, Bencze (2000), Carter (2005, 2008) and Jenkins (2007) discuss the way that science is linked to the nation, private commercial interests and capitalism. Bencze considers the extent to which science education serves the interests of capitalism rather than the needs of the pupils. At one level school science can be seen as embedding pupils in a culture where they 'consume' knowledge, rather than question and generate it, and Carter argues that the processes can work to marginalise democratic and social justice agendas. She suggests that "we develop curriculum content that views Western science as shaped by, and reproductive of, the culture and society in which it is articulated" (2008, p. 628). According to Carter, science can be studied to consider if it upholds capitalist principles and how it both supports and harms people's lives. As such, values and emotions could be part of discussing science. If we consider that the science that gets done is that which is funded, as suggested by Fig. 1 (top right-hand corner), then, since science funding originates from private enterprise and state funding, it is clear that the science that gets developed could reflect the capitalist enterprise. What follows is an example to illustrate how the choice of approach taken by scientists is value-laden.

The Green Revolution

Learners' emotional investment is perhaps best realised when they consider issues that affect inequality in society. The 'Green Revolution' is the name given to an attempt to increase grain production in India. The solution, developed by scientists working in the USA, was to use technology to mechanise agriculture and to use chemical fertilisers, pesticides and genetically modified plants. The approach did indeed increase the amount of food and ensured that the US companies made money. Rich farmers could afford the tractors and fertilisers but smaller farmers often went into debt, which could lead to them losing their farms. The increasing mechanisation led to more unemployment among workers. The wealthier farmers could buy more and produce more food, so gradually the rich got richer and the poor got poorer.

The Green Revolution illustrates how the choices that scientists make in an industry can uphold a capitalist perception of science, which has embedded values—in this case it promotes solutions that will ensure money is made but can lead to social divisions. The scientists could have avoided this approach and argued for solutions that were based on expanding agrarian reform and exploration of local seed varieties and matching them with the soil. This strategy contrasts with the hi-tech approach, which used mono-culture seeds so that fewer varieties were being explored. According to Ross (1998), the Green Revolution weakened socialist movements that emphasise social reform and exploring local resources. To the extent to which this is true, the example shows how the science that gets done is value-laden. In this sense, it is an analogy for the Kuhnian view of scientists working in a world-view that can incorporate a set of values—in this case capitalist. However, let me stress, this is only an illustrative example as Kuhn was describing a world-view and not the unquestioned perceptions of the purpose of business. Being value-laden does not in any way diminish the importance of the rational explanations of science. No matter how much you believe that your car can run on water it won't make it go. The ideas that scientists explore have to match or correlate to nature, so the fertilisers and seeds had to be appropriate for that habitat. The choice of approach is laden with values and therefore it is important to consider the emotions involved. The values a person holds, to make money or to work with the poor to improve their circumstances, are social and emotional decisions. The questions that can then be asked are, What is our responsibility to pupils? Should we raise issues of the social context when talking about technological solutions to plant growth, or ignore them?

An example of how science can be seen as a cultural activity that has values might involve classroom teachers discussing mobile phones/TV/computers and asking pupils how they would like to see them develop (see Buntting and Jones, this volume). Pupils might come up with suggestions that make it easier for people to increase their isolation and communicate with fewer face-to-face interactions, for example through phones and the internet. A friend had a problem with a sink that was leaking. I said, "Your neighbour is good at home maintenance, they almost certainly know a good plumber so go and talk to them". "Oh no", came the reply, "You just need to go on the internet to find someone". The role of modern technologies in enabling people to accomplish a wide range of tasks without meeting face-to-face is a concern and is linked to social anxiety (AnxietyUK 2012; La Greca and Lopez 1998; Pierce 2009; SP/SAA 2013). If scientific advances that allow the technological development have a part to play in increasing social anxiety then clearly values are incorporated. On the other hand, it is possible to develop technology so that people are more likely to meet. Should these issues be made clear and pupils asked instead: 'What technological changes would you like to see in phones/TVs and would your suggestions make it more likely that people will meet to talk, or less likely?' In this case the values incorporated into scientific solutions, and what areas are researched, will be made explicit. One could also discuss whether or not a technological development would be likely to increase or decrease employment. Leaving the discussion in the classroom only to the level of the science content involved implicitly reinforces the status quo as it pretends that no values are present, but does not let the pupils realise that this is the case.

One important aspect of considering values and the extent to which science can be seen as a liberating or a dominating activity is in relation to the amount of money that goes into the military. Military technologies can be dominating and sometimes the same technologies can be used on the population (Bennett and Lyon 2008; Lyon 2002). In the USA nearly 60 % of government funding goes into military research and development (Bennof 2011; Massey 2010), while Hersh (2012) points out that the situation in the UK is unclear. Should the extent to which military funding can support domination and authoritarian values be discussed with pupils in the classroom? At the moment schools ignore such issues but, at a minimum, pupils could discuss, in general terms, the areas of research that are funded and the possible implications for society of the funding streams. Hence, discussing such interconnections of science and values also means considering how culture might change for the better, which I will now consider.

Values, Science and Contributing to Society

It is possible for pupils to consider the conception and purpose of science, and how much it should be democratically accountable. Examples such as the Green Revolution and military funding raise political issues about how different ideas can impinge on whose interests are served by science. Similarly, climate change is an example where science contributes to society at large, but climate change deniers do not believe the science, and their emotions obfuscate. In such considerations emotional factors play a part. What should scientists be exploring, how and to what end? Once pupils see how science can be constructed by people, incorporating dialogue and emotional factors, science is less likely to be seen to proceed only through induction. If science is seen as an objective search for truth the context of science can be excluded; once science is seen as part of culture with emotional overtones then a range of discussions could be central to education. Hence, science education should not just be about cognition, but a wider range of aspects, including asking what science is for. As such, science education would incorporate a discussion on values and their associated emotions (Corrigan et al. 2007). Pupils can understand how the values of science are an area for them to engage with as it will affect their lives.

There are many positive precedents to approaches to values, personal development and emotions in science. Lovat and Toomey (2009) argue that values and quality teaching form an interlinking spiral and that a values-based education can strengthen pupils' self-esteem, confidence, commitment to personal fulfilment, and the ability to exercise ethical judgments and social responsibility. These are all underpinned by emotional development, although this is not mentioned. Bencze et al. (2009) argue that the wellbeing of people and societies can be threatened by factors associated with science and science education, while Scoffham and Barnes (2011) consider that personal fulfilment and happiness are connected to educational values and that personal growth should be integral to education. Reiss (this volume) argues that an aim of education is to enable pupils to lead flourishing lives.

It is also possible that as people see science as incorporating emotions we are less likely to try technological solutions to social problems (Bronson 2012). For example, Wilkinson (2000) and Wilkinson and Pickett (2009) have shown that the health of a population is connected to inequality, and the greater the equality in a country the healthier the society. This connection between poor health and inequality is due to a complex web of effects that include the relationship of the individual to society, psychological pressures, social status and identity. These affect both rich and poor and, according to Wilkinson, the solution rests with increasing equality. However, many people and politicians do not see removing inequality as contributing to health, but look only to technological solutions. For example, although this is not at the level that Wilkinson analyses, a government could fund research so that drugs can be developed that will be sold, rather than focussing on prevention. At the same time, the approach may not benefit society in general, since research on prevention may be a more egalitarian approach. Another example is that inequality can arise when context is not considered before research is funded. There is research into the DNA of foods that can be sold worldwide, such as maize, rice and soya, but much less into crops such as yam, cassava and finger millet that are the staple diet of many Africans (Vidal and Tran 2013). Often only the technological and commercial solution is focussed on and discussions hide the social base to many issues.

One response to the possible interconnections between scientific research and emotional commitment to a vision of society is to argue that they should be discussed in schools. For example, Hodson (2011) argues that the curriculum should be for social activism. He argues that scientific literacy should raise the cultural, moral and ethical issues for individuals and society, as well as contributing to democracy—to which I would add social justice (Matthews 2006; Matthews and Asaria 2013). Hodson discusses liberation ethics and the struggle against social and political norms, concluding that science education should help pupils explore alternative views of what is desirable and how to change the current inequalities between societies. These are threads that go back to the book *Teaching as a Subversive Activity* (Postman and Weingartner 1971) and Freire (1972, 1997) who argued that it was teachers' responsibility to enable pupils to question society. Questioning society involves debating the values generally held in society and what one might be socially and emotionally committed to. This approach necessarily involves making explicit personal values.

I want to stress that I am less concerned with which, or whose, ideas on the nature of science are correct, or accepted currently, and whether or not science serves capitalism, but rather, 'Given that science can be seen at least in part as a social and emotional activity, what are our responsibilities to our pupils, and what has this to do with future paradigms for education?'

Having said this, of course, most science education must be concerned primarily with teaching scientific explanations. As I have argued, and is illustrated in Fig. 1, rational explanations are vital to science, but the process of doing science also involves social and emotional aspects. Hence, the development of science and society intersects with personal views, and it is to this point that I now turn.

A Personal Response to Science

So far I have argued that science is both rational and emotional and that it incorporates values. Further, Head (1985) argues that each pupil has a personal response to science. The individual's understanding of science is reliant on the complex set of beliefs, knowledge and values that are held. These can incorporate all sorts of ad hoc beliefs and stereotypes such as science is impersonal, remote, little to do with their everyday lives and devoid of values. If this view is accepted then science can be a cloak to escape from their emotional selves. In order to counter such views, Head argues that the personal and affective aspects of science should be made explicit. To have a positive personal response to science, boys and girls need to understand and experience science as personal through engaging their emotions and discussing values. Engaging with emotions in lessons legitimates pupils developing a personal response and a positive emotional connection with science education. I will now illustrate this point with reference to gender.

Girls, Science and Emotion

The personal view a pupil has of science is important for both boys and girls, but here I am going to focus on girls. In this section, I want to argue that one of the problems with girls and science is the avoidance of discussing emotions directly. Women have been excluded from science in many ways. One way has been to align male/female with non-emotional and objective/emotional and subjective, a position that was strengthened during the Renaissance. Merchant (1980) shows how, during that time, the scientific revolution produced theories that turned the view of the world from a (female) organism and nurturing mother to a dead world—she called it the death of nature—that accelerated the exploitation of natural resources. This was at a time when capitalism required a dead world to mine and exploit the Earth; psychologically this was difficult all the time there were strictures against digging into a live female world. These changes occurred at the same time as Bacon (1620) argued for the removal of the emotions from scientific exploration. Hence men, in contrast to women, were seen as natural scientists (Bencze et al. 2009; Easlea 1981; Porter and Teich 1994), which indicates a connection between science and gender. Girls can come to accept that science, and especially physics, is a subject for boys, as it is impersonal and objective; traits that can be aligned with being male. Hence, many girls can feel excluded from the culture of science classrooms (Brotman and Moore 2008).

Feminist studies have critiqued the way that the objective portrayal of science has affected the theories that have been generated and helped keep women oppressed (Easlea 1981; Keller 1985; Sayers 1982; Wyer et al. 2008). To the degree that masculinity and femininity during adolescence are seen as different, school science can be seen more as a masculine activity at a crucial stage in education (Head 1997). Wood et al. (2013) argue that in the classroom the individual can be shaped by culture. So, if the classroom culture is one that promotes objectivity, the individual is affected. However, the culture can be shaped if pupils share their cultural and emotional expressions in a group, that is, through discussions of the feelings they have about the values of science. Hence, if we want more girls to enjoy and take up science we cannot leave changes to science education at the level of curriculum content. Changes such as including girl-friendly topics in physics can help, but more importantly the culture of the classroom and view of science has to change. If science is seen as a subject that incorporates values, emotions and social contexts, then girls will be more able to relate to science education. I argue that this pedagogical change is essential as one part of tackling sexism in science education.

Having made this emphasis, I will now briefly consider boys' attitudes. Firstly, I believe that much of the dichotomy is false and that boys are also interested in discussing science, its place in society and its values, and so this approach will also appeal to boys, even if less so than girls. Secondly, in Fig. 1, the processes of science are portrayed as being both social and rational. The rational reporting of science is essential to its progress. Hence science is both a rational and social activity and so can appeal to both boys and girls. Therefore, I will now turn my attention to showing how pupils can be encouraged to see that a social and emotional response to science is legitimate. I will show how it is possible for pupils to have an emotional engagement in science, help each other learn and be more likely to want to continue with science.

Emotional Literacy in Science Education

While the extent to which the emotions are involved in science itself is under debate, when the future of science education is discussed, emotions are almost always an elephant in the room. It has been known for some time that interconnections between emotions and learning exist (see Murphy, this volume). Greenhalgh (1994) links learning and emotional development and argues that the human condition always changes depending on our experiences (our outer world) and how it interacts with our inner world. He argues that learning depends upon our ability to manage our inner and outer worlds. The connections between emotional development, language and learning go back to Vygotsky who developed a cultural form of psychology and argued that "Every function in the child's cultural development appears twice: … First *between* people (*interpsychological*), and then *inside* the child (*intrapsychological*). … All the higher functions originate as actual relations between human individuals" (Vygotsky 1978, p. 57, emphasis in the original).

Murphy (this volume) emphasises how Vygotsky. integrated emotional and cognitive learning through integrating affect and intellect. Science education would, therefore, be helped if learning was integrated with emotional development (Alsop 2005). I have previously re-defined emotional literacy as including:

> the recognition that emotional literacy is both an individual development and a collective activity and is both about self-development and the building of community so that one's own sense of emotional well-being grows along with that of others, and not at their expense …. It is a dynamic process through which the individual develops emotionally and involves culture and empowerment. For example, it includes understanding how the nature of social class, 'race' and gender (sexism and homophobia) impinge on people's emotional states to

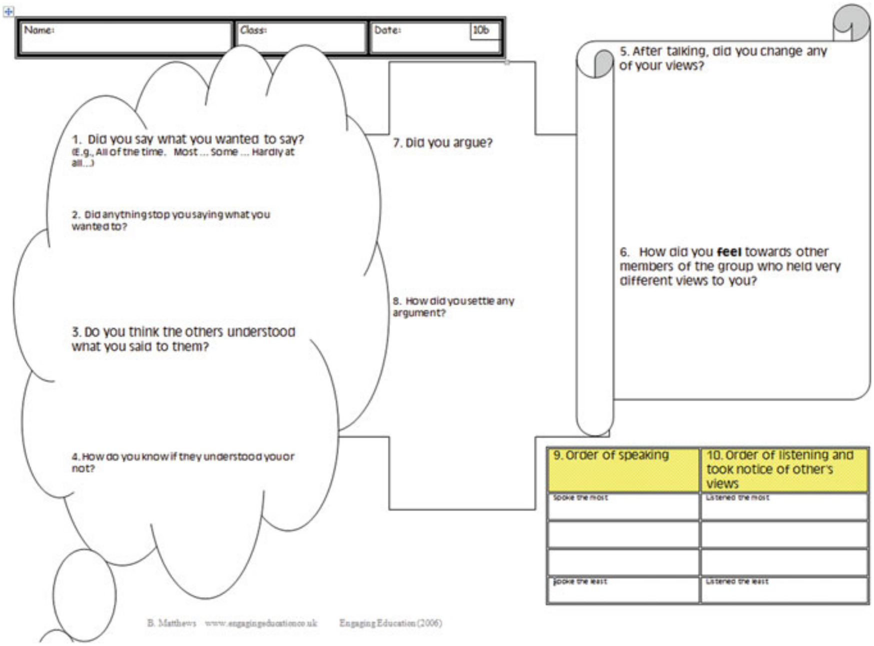
> lead to an understanding of how society could change. Hence it incorporates an understanding of power exchanges between people and a challenging of power differentials. (Matthews 2006, p. 178)

This is a radical re-working of the term, as previous definitions have ignored equality and power. This definition is culturally situated and suggests that a social learning situation should be used. Learning theory, such as constructivism, often reinforces such approaches, as learning is seen as socially constructed using language and reflection with others. Hence, values, social and emotional interactions and personal responses to science can all be integrated. I will now turn to describe a research project linking emotional literacy and the science classroom.

Encouraging a Personal Response to Science Through Engaging the Emotions

One aspect of enhancing a personal response to science and values is to enable pupils to engage with their emotions in the classroom and to make these explicit. As head of science in a school in an inner-city area, I was concerned about improving the uptake of the subject. I wanted to encourage equal opportunities and believed that co-operative learning and group work were important in getting pupils to interact and to learn about each other across sexual and racial divides. The research involved two inner city co-educational multi-ethnic schools in England, each with a middling range of attainment intakes. The pupils were 12 years old. Control (n = 83) and research groups (n = 82) covered exactly the same science curriculum content of the National Curriculum. Only the research groups were engaged with the range of techniques that developed emotional literacy. The pupils in the research groups discussed not only their learning but also their social and emotional interactions. In what follows, I will give an outline of the results of the research along with references for interested readers who would like more detail.

A series of answer sheets was developed to encourage pupil-pupil dialogue. In order to encounter a wide range of social and emotional viewpoints, multi-ethnic groups, comprising both boys and girls, were encouraged to work together co-operatively on a science task. An example of a task could be to complete a worksheet with only one copy being provided for the group, and the pupils having to agree on their answers. This tactic encourages the group to interact with one another, to consider one another's ideas and, importantly, to reach a consensus as a group. Another would be doing a Directed Activity Related to Text (DART) or an experiment, where again collaboration and cooperation played an important part in completing the activity. The pupils worked in groups and, when the task was finished, they individually filled in *Discussion Sheets* that focused on different aspects of learning. Initially the focus was on cognitive learning and interactions, but Figs. 2 and 3 show two samples that concentrate more on social and emotional interactions:



Name:

Class:

Date: 10b

1. Did you say what you wanted to say?
(E.g., All of the time. Most … Some … Hardly at all…)

2. Did anything stop you saying what you wanted to?

3. Do you think the others understood what you said to them?

4. How do you know if they understood you or not?

7. Did you argue?

8. How did you settle any argument?

5. After talking, did you change any of your views?

6. How did you **feel** towards other members of the group who held very different views to you?

9. Order of speaking	10. Order of listening and took notice of other's views
Spoke the most	Listened the most
Spoke the least	Listened the least

B. Matthews www.engagingeducation.co.uk Engaging Education (2006)

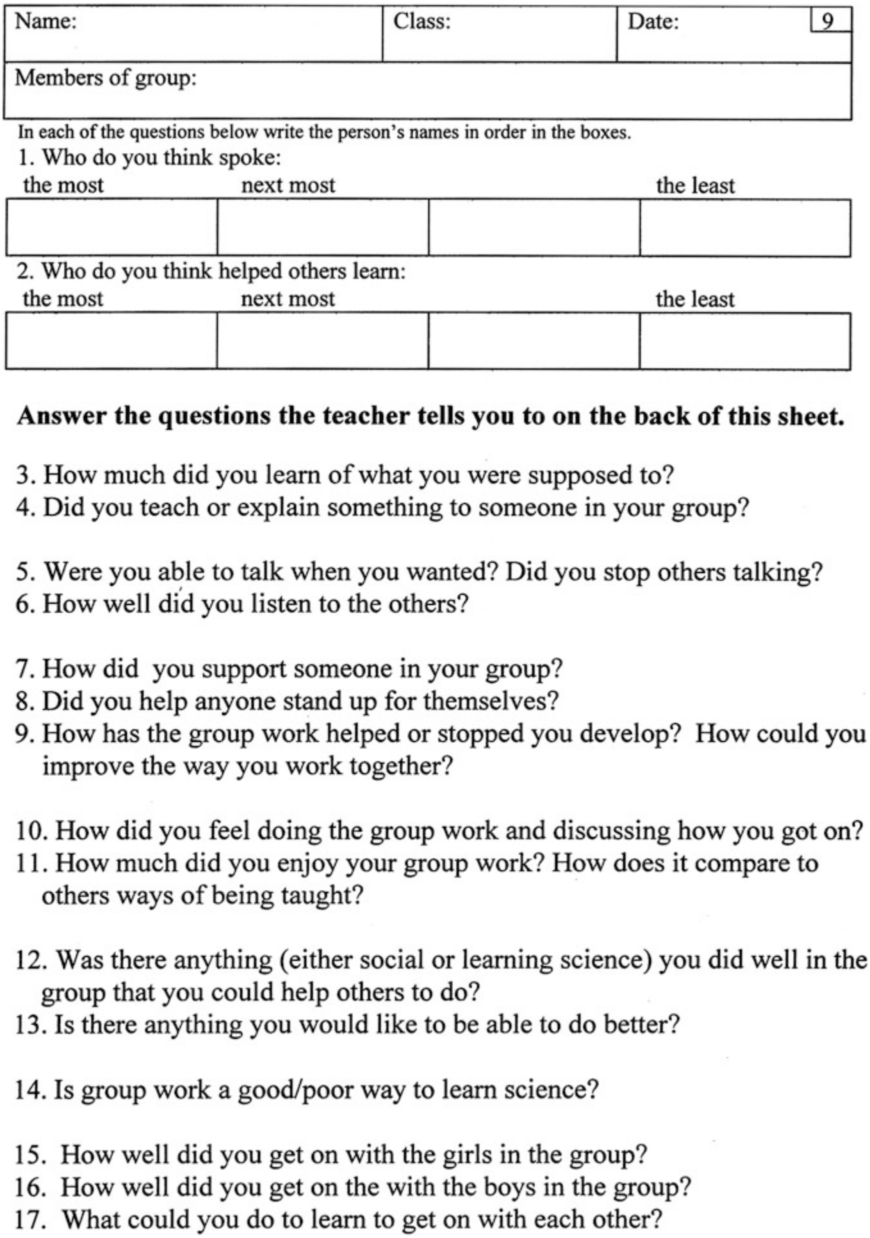
Fig. 2 Discussion sheet 10 on viewpoints

In the next sheet, the teacher would select which questions they felt were most appropriate for the pupils to answer, or add their own at the bottom, depending on how the class were responding to the lesson.

Once each pupil had filled in the sheet, a group member collected them in and ran a discussion with the pupils on how well the group had interacted and learned. This classroom strategy enabled pupils to:

- Think and reflect on social processes and feelings.
- Make explicit what the interactions meant to them.
- Compare this with what other people thought had gone on.
- Hence, they could learn about and empathise with each other. It was then likely that the pupils learnt science and became aware that it involves emotional and social interactions (Matthews 2006, p. 96).

The sheets were to provide a structure and framework to generate discussion with explicit expression of feelings being legitimated. It was of vital importance that the emotions present were made visible and hence open to change. During the discussions, the pupils experienced learning science cognitively along with developing socially and emotionally. Through explicitly raising issues concerning learning and relationships, pupils can accept that learning to get on together is part of science. Hence a personal response to science is embedded within the classroom



Name:	Class:	Date: 9
Members of group:		

In each of the questions below write the person's names in order in the boxes.

1. Who do you think spoke:

the most	next most		the least

2. Who do you think helped others learn:

the most	next most		the least

Answer the questions the teacher tells you to on the back of this sheet.

3. How much did you learn of what you were supposed to?
4. Did you teach or explain something to someone in your group?

5. Were you able to talk when you wanted? Did you stop others talking?
6. How well did you listen to the others?

7. How did you support someone in your group?
8. Did you help anyone stand up for themselves?
9. How has the group work helped or stopped you develop? How could you improve the way you work together?

10. How did you feel doing the group work and discussing how you got on?
11. How much did you enjoy your group work? How does it compare to others ways of being taught?

12. Was there anything (either social or learning science) you did well in the group that you could help others to do?
13. Is there anything you would like to be able to do better?

14. Is group work a good/poor way to learn science?

15. How well did you get on with the girls in the group?
16. How well did you get on the with the boys in the group?
17. What could you do to learn to get on with each other?

Fig. 3 Discussion sheet 9 that allows the teacher to select an area

culture. This process can be part of developing flourishing lives (see Reiss, this volume). Another outcome of the research was how much the pupils assisted one another, which was considerable.

Helping Each Other

An important factor that came out of the research was that pupils helped each other learn. The pupils were given a questionnaire that was administered at the beginning and end of the school year. Here are some quotes from the questionnaires, where pseudonyms have been used (f = female; m = male):

> Salma listened to others well and contributed to the discussion on forces (f)
> Brian contributed very well and put forward different views and expressed them clearly to us (f)
> You learn more from each other, you can ask the others (m)
> Group work helps us to learn as we share ideas, learning from each other, but it is no good if they talk about something else (f)
> Understand better because teacher uses complicated words I don't understand (m)
> You learn how to cooperate and how other people think (m)

The results indicated that the pupils showed a significant increase in helping each other. In each case the research groups reported that they felt they could get support from their classmates to a greater degree than the control groups. An external evaluator, who interviewed students and observed them working in the classroom, reported on how well the pupils helped each other. These results indicate that the research groups took a more collaborative approach to learning.

To some extent, helping each other to learn science could mean that pupils also accept that both sexes can learn science, and could contribute towards changing personal perceptions of who could become scientists. It is important to note that, overwhelmingly, pupils of both sexes reported that they felt that it was important that they learned about each other and to understand each other, even though it was emotionally difficult (Matthews 1996, 2005). The following quotes come from teachers involved in the project with 11–12 year-olds who were interviewed 3 years after the project started (Morrison and Matthews 2006). The teachers were asked about the whole class and how the pupils had developed:

> Once the research got going it made them really focus and think about their behaviour, especially the loud ones, you know how they would usually take over a discussion. It actually made them stop and think 'It's X's turn now'. They definitely learnt those skills. I think because they were willing to listen to each other, […] they were more willing to talk and put their point of view, or just talk about whatever they wanted, because they knew that there was always somebody who was going to listen and support them. It took a long time [6 months] to build that up, lots of group work.
>
> Certainly, from what I've seen pastorally, they emotionally support each other. When someone's having a bad day, others rally round, they are extremely caring, very concerned about the well-being even of people they don't normally go to or get on with. When one of the boys is upset a lot of the boys are concerned not just the girls so it crosses gender. It's also the same with showing emotions to each other and getting support from each other.

Hence, the boys and girls discussed their feelings and interactions with each other, and so involved values (equality)-in-action.

Table 1 Proportion of pupils indicating that they are likely to continue with science

	Research (%)	Control (%)
Boys	85	71
Girls	85	76

Continuing with Science

Another aspect of the intervention was that girls indicated they were as likely as boys to take up science (Matthews 2004, 2005; see Table 1) indicating that their personal response was affected.

A high proportion of both boys and girls wanted to continue with science as a subject. One possible reason for this finding could be that, as mentioned previously, the individual can be shaped by culture, and that culture can be shaped by pupils (Wood et al. 2013). Hence, by including emotional aspects, pupils' views of the nature of science changed. The culture in the classroom was changed and science was seen as a social activity for pupils. I believe that this is one of the reasons why girls and boys in the research groups showed a greater interest in science. than the control group; it was partly because pupils were introduced to science in a way that centrally involved the emotions. The culture of the classroom was changed to incorporate explicit emotions so girls could feel more included, which affected their personal response to science. This is, as I argued earlier, one aspect of improving the uptake of girls into science.

Further evidence on why the research groups may have been more interested in science lessons comes from the classroom-based *Opinion sheets*. The pupils indicated that doing group work with the feedback discussions made science more interesting and was a good way to learn science (Matthews et al. 2002). Through these techniques, pupils can become aware that science learning involves social and emotional dimensions, and that boys and girls can help each other learn, with both sexes achieving at science.

If the results of this research could be reproduced more widely then it could perhaps contribute to future scientists being more supportive of one another and reduce sexism in science teams. The pupils could potentially learn a set of emotional rules or habits where they, through experiences, discuss social and emotional practices along with cognitive learning of science (Trainor 2009). It could become normative for pupils to learn to discuss emotional aspects of their lives together across the boundaries of social class, gender and 'race' (Alsop 2011; Matthews and Sweeney 1997). It is possible, as the above research was completed in academic science lessons, that emotions, cognitive learning and social interactions can be intertwined. Tobin et al. (2013) see emotions as central to holding groups together and, in turn, society. They also show how the emotional climate of the classroom can affect the emotional energy positively or negatively. The above quotations indicate that a constructive emotional climate had been developed in the research classrooms. Throughout this group work involving discussions of feelings, girls were as important as boys, their values were equally valid and the values—

scientific, personal and emotional—were shared. The indications were that such a strategy could help pupils develop positive personal attitudes to science and each other.

It is easy to exaggerate the importance of a single piece of research. However, I believe the procedures outlined here, which made emotions explicit, are a valid avenue to explore and develop. There were indications that the pupils engaged with science in a more multilayered way than usual and that learning science could be accepted as an emotional and social activity. Only the conventional science content was taught in this research. However, if curriculum changes were made that allowed more discussion of values and the nature of science, there is the potential that pupils could relate to science in a way that goes beyond the usual view of science as a rationalist, emotionless pursuit. In turn, pupils might engage in debates about the future of science in a multidimensional way while engaging explicitly with their emotions at different levels. If we value emotional responses to science, this point needs to be reflected in what is valued in the school curriculum and assessment systems and to move away from high-stakes testing so as to appreciate emotions.

Teaching Science with Emotions

Science education rarely addresses such questions posited above. This might be because science is largely seen as an objective cognitive learning exercise, and so is ‘above’ such questions. It is possible, as Bernstein (1971) explained in his work on classification and framing, that science is held in high status because it is seen as objective. Scientists can give opinions and be listened to as it assumes they are ‘unbiased’. Hence scientists have power. The adherence to science being neutral also allows scientists to hide their feelings behind the search for an unemotional truth. These are not, however, sound reasons to continue to propagate this one-sided view. Suppose that science is seen, at least in part, first as a cultural activity involving the emotions and, second, as having connections to power and being culturally situated. Since scientists are funded by people in power we might then pose the questions: Given science is a cultural activity, how could it be organised so that science serves, more than it does now, people of all genders, social classes, etc.? and How can values be made explicit?

Jenkins (2007) argues that science education should reflect philosophical and methodological differences while incorporating creative and imaginative aspects. He continues that pupils should:

> engage with a range of personal, social, economic, or political issues that stem from the role the sciences have come to play in society and to understand the uncertainties and ignorance associated with their role in the realm of practical action. Arguably, it should also offer at least a rudimentary insight into the ways in which the sciences are now allied with civilian and military power and with commercial and industrial concerns, often on a global scale. (p. 278)

Similarly, Hodson (2011) argues that science curriculum decisions should include: (i) What values are included? (ii) Whose values are included? (iii) Whose values are excluded? and (iv) What is made explicit and what remains implicit? A key factor generally not discussed even by Jenkins or Hodson is how values have an emotional base and cannot be easily changed by logical explanations (Crompton 2010). For example, if people are presented with the scientific evidence on smoking or junk foods, it does not stop them harming themselves. In order to make change more likely, then recourse to basic values and feelings has to be made (Chilton et al. 2012). Hence, if pupils are to fully consider the future of science in a transformative way, their emotions and values need to be engaged. I have indicated ways of doing this in the previous section. Additionally, teachers can discuss the rational and emotional nature of science as an activity as in Fig. 1.

It might be postulated that one of the reasons why people are wary of science is that the population can only react to the science and technology that is produced. As a result they can be alienated from it and experience science as being remote. Science impinges on people's lives and, whether it is seen as positive or negative, they have little control over it. People might want a science that leads to more co-operation and human interaction if they could influence its direction. Does the profit motive and the wish to control people dictate what science gets done rather than what would be beneficial to most people? As long as science is seen as difficult, remote and emotionless, the population is more likely to accept that science is for experts who are the only ones who can make decisions as they are the only people who can understand the complexities. However, as science can be seen in its social, emotional and cultural context then it is possible that pupils can feel they might get involved. I have illustrated one approach that can be used in the classroom to help pupils understand how science can incorporate social and emotional factors, and how pupils can be encouraged to appreciate that it can be a co-operative enterprise across gender, ethnic and social class divides.

The aims and forms of science that could be learned should not be separated from why science is taught and its position in society. As Vygotsky (1997) said:

> Pedogogics is never and was never politically indifferent, since, willingly or unwillingly, through its own work on the psyche, it has always adopted a particular social pattern, political line, in accordance with the dominant social class that has guided its interests. (p. 348)

We are now at a stage where we can see that a science education could take the form of a critical transformative pedagogy, *but only if the emotional base is acknowledged*, brought to the fore, and is integral to the science curriculum. Pupils may then come to understand the true importance of science and emotions as integral aspects of their lives. Pupils could develop routines where they discuss emotional views while learning science and, perhaps, develop a positive personal view of science. It is possible to achieve deep emotional engagement with others, and an understanding of the influence of our underlying values. We are principally emotional people and this recognition can lead to a more tolerant and equal society with science education making a significant contribution. As educators this, I believe, is our responsibility to our pupils and to society.

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Initiatives to Prepare New Science Teachers for Promoting Student Engagement

Shirley Simon and Paul Davies

Introduction

In England and in many other countries there is a continuous need to review science curricula, not only in response to current political ideology, but also to maintain an appropriate focus for students in a changing world. The concern for science education is to include valuable components of scientific knowledge and inquiry in the curriculum while responding to the call for change. We need to provide a curriculum that not only enables students to progress in their scientific understanding and demonstrate successful performance, but that also has the potential to stimulate students' curiosity and interest in science. To implement the curriculum to enhance students' affective response to science requires skilled teachers who have a repertoire of teaching approaches that can provide stimulating experiences and learning environments. In this chapter we explore contemporary thinking on student engagement in science and how this might be enhanced through the development of initiatives in the training of new science teachers.

Student engagement is conceptualised in different ways, but can be considered to involve a behavioural component when students do science, an emotional component as they become interested in science, and a cognitive component when they are motivated to want to continue with science in higher education or as adult citizens (Hampden-Thompson and Bennett 2013). We are concerned with all three components and how they are influenced by teachers and teaching in science classrooms. The day-to-day teaching of science primarily focuses on behavioural and emotional engagement, as teachers aim to prepare lessons where students can do science activities that they find interesting. A longer-term aim is to provide positive experiences in science classrooms that will motivate students to invest sustained effort in learning science. Thus not only is positive engagement seen as a

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means of enhancing science learning in school, but as fundamental to securing future career scientists, promoting scientific literacy, and preparing all students for engaging in scientific issues in adult life.

An assumption underlying interpretations of emotional and cognitive engagement is that attitudes towards science determine interest in and choice to study science beyond compulsory schooling. Hence there have been a substantial number of studies concerning students' attitudes to science (Barmby et al. 2008; Krapp and Prenzel 2011; Osborne et al. 2003; Simon and Osborne 2010) which have shown a range of influencing factors. The steady decline in students' attitudes towards science as they progress through school, particularly secondary school, has been well-established. We question whether this decline can be overcome, given that some studies show how school factors can contribute positively to sustained engagement (e.g., Vedder-Weiss and Fortus 2011). In this chapter we shall explore what we have learnt from such studies that can make a possible difference in schools, though it may be difficult to draw simple conclusions given the complexity of student attitudes (Barmby et al. 2008). In particular we will focus on findings relating to teachers that can inform an agenda for preparing new science teachers to address students' engagement in science.

Understanding students' cognitive engagement in science involves knowing what factors motivate students to want to learn or carry on working with science and how students perceive the relevance and value of learning the subject in relation to their own lives (Aikenhead 2006; Osborne and Collins 2001). Moreover, the ways in which students identify with the science culture embedded within the science teaching and learning they experience (Archer et al. 2010) can also contribute to engagement. The first part of this chapter will focus on the concept of engagement by reviewing recent understanding of attitudes towards science, and issues of relevance, motivation and identity with the subject.

Learning to teach science involves developing the knowledge of how to prepare lessons that enhance students' interest and motivation to want to learn more. Our experience shows that adult teacher learners do not always know what interests and motivates students in science. Supporting such understanding in student teachers (STs) is clearly an important feature of initial teacher education (ITE) programmes, but making this knowledge explicit and providing opportunities for the exploration of these ideas is not straightforward. The second part of this chapter will focus on how initiatives for teacher training with STs address components of student engagement. In particular we will look at how student/teacher relationships develop as STs provide out-of-classroom learning experiences, how STs can deploy digital technologies to provide interesting and relevant contexts for students, and how action research projects with STs can lead to the creation of innovative resources that promote all aspects of engagement. The examples we present here show how certain features of our Postgraduate Certificate in Education (PGCE) course are designed show STs what is possible in science education. The STs are introduced to theoretical perspectives that explain why certain pedagogical approaches might be useful, and given time and space to develop their skills in using a variety of approaches. These skills allow STs to design learning experiences that enable students to fully participate in science programmes and that encourage the building of positive relationships between teachers and students.

Attitudes Towards Science

Studies of attitudes towards science using a range of methodological approaches and theoretical positions have provided many indicators of the influences that can come to bear on students' engagement in the subject (Osborne et al. 2003; Simon and Osborne 2010). The meaning of what is meant by 'attitude' has been much studied (Barmby et al. 2008), but essentially has a component of behaviour, as captured in a definition adopted by Ramsden (1998):

> attitude is best viewed as a set of affective reactions towards the attitude object, derived from concepts of beliefs that the individual has concerning the object, and predisposing the individual to behave in a certain manner towards the object. (p. 13)

Behaviour has, therefore, become a central focus of many studies concerned with students' attitudes. However the picture is not straightforward, as positive attitudes may not necessarily lead to future engagement when other influencing factors are prominent. A student may be interested in science but not show positive engagement if motivated to behave in a certain way by the influence of peers who have a negative attitude. Many studies of attitude and behaviour are driven by the need to investigate reasons why students do or do not choose to study science beyond compulsory schooling, some drawing on theories of behaviour such as the theory of reasoned action (Ajzen and Fishbein 1980; Fishbein and Ajzen 2010). Here, behaviour is seen to be determined by intention—a product of attitude towards the behaviour and how others regard that behaviour (the subjective norm).

Studies of peer and others' influences are not, however, conclusive in linking attitude and behaviour. A study by Korpershoek et al. (2013), framed by the theory of reasoned action, investigated why some students do not continue in science-oriented studies in higher education though suitably qualified and interested in science-related subjects (Science, Technology, Engineering and Mathematics, or STEM). The authors looked into influences by significant others on students' choices and found that many students, though advised by others to choose STEM subjects, did not actually do so. The authors conclude that the influence of significant others on students' study choices is still unclear, but suggest teacher initiatives aimed to "develop new salient views" (p. 500) that strengthen intentions towards science. Sjaastad (2012) also studied the influences of others on students' STEM choices, and of the contribution of others to defining and modelling the self and STEM in ways that students come to see themselves as STEM-oriented. Essentially, those persons who have most influence have interpersonal relationships with students.

Research clearly points to the effects of influence by others on attitudes and behavior. How should we take this finding to inform our work with STs? As well as foregrounding the need to get to know their students and present science in a positive way, new teachers also need to learn how to make learning environments positively engaging for students, to convey in their interpersonal relationships with students an enthusiasm exemplified by an engaging agenda. Our initiatives—which place STs in teaching situations outside the classroom, or show the potential of digital technologies or innovative activities as part of action research, all of which involve reflective evaluation—are designed to help them to learn to address aspects of student engagement as they plan their science teaching.

In a study of students' voices, Logan and Skamp (2013) investigated the relationship between interest in science and pedagogy. Their findings show that students' perceptions of their learning environment, including practices and teacher attributes, determine interest. Specific practices identified by Logan and Skamp as stimulating interest include: experiments, particularly with the student as investigator; debates on socio-scientific issues; making science relevant to their lives; different uses of information and communication technologies (ICTs); clear explanations; and out-of-school excursions. These reiterate earlier findings from Barmby et al. (2008), that students stress the importance of practical science, teachers explaining things well, and science lessons being relevant, and by Raved and Assaraf (2011) whose students noted the importance of variety, including "peer teaching and discussions, contests and games, movies, presentations, models, field trips and experiments" (p. 1213). Thus from a host of studies on attitudes towards science and what influences student engagement, the quality of teaching is consistently identified as contributing to student engagement, in particular the appropriate choice of teaching and learning activities (Hampden-Thompson and Bennett 2013) and the development of interpersonal relationships. The findings from all these studies reinforce our understanding of ways in which STs can be encouraged to take into account student voice and perceptions.

Providing a meaningful learning process requires an awareness of what influences attitudes so that poor and irrelevant learning experiences are avoided (Raved and Assaraf 2011). It is, therefore, important to focus on the attributes that can be fostered in ITE that enable the ST to become a 'good teacher', as defined in what Raved and Assaraf identify as professional and emotional attributes—which include interpersonal relations between the teacher and students. The initiatives presented here aim to address these features as STs learn what to do to engage students.

Relevance, Identity and Motivation

Central to students' cognitive engagement is the need to make contexts more meaningful and contemporary, and this has been a feature of recent developments in science curricula. Holmegaard et al. (2014) suggest that students may see the potential of science without necessarily being able to understand every aspect themselves. They also maintain that students have different ways of interpreting what relevance to everyday life means: relevance may mean direct influence on their own lives or a broader view of what is important to society. Whatever their view of relevance is, how students see the purpose of STEM being taught is one of the decisive factors students consider in making subject choices (Holmegaard et al. 2014). Thus it is important for teachers, and STs, that they listen to students and do not make assumptions that their own ideas of what is relevant predominate, or that what counts as relevant is 'fixed'.

There has been much recent work on identity with science (e.g., Archer et al. 2010; Taconis and Kessels 2009), and we argue that better portrayal of the subject to students by focusing on its image and potential relevance/usefulness is important for individual students to feel that they can identify with science. The typical form and content of school science may be at odds with how students see themselves or how they want to be. For example, the idea of being "an autonomous self-managing individual" (Holmegaard et al. 2014, p. 209) may be in tension with traditional science teaching and learning that leaves little space for self-determination, which might 'drive' students to be motivated in their learning. Taconis and Kessels (2009) refer to identity as managing one's personal choices that relate to everyday matters, such as clothes, taste in music, sports, but is also related to school and classroom. Engaging in and choosing science is part of identity development and "school science is perceived as not allowing room for self-realisation or intellectual freedom" (p. 1117). Thus the culture of science teaching that is promoted in the classroom leads to self-selection by students who will fit well into that culture. For most students this cultural gap is large (Aikenhead 2001), and selecting a subject for future engagement is made on the basis of matching oneself with a specific subject culture (Taconis and Kessels 2009).

In addressing the issue of declining motivation to learn science, researchers have looked to psychological theories to define and explain motivation, for example, achievement goal theory (Ames 1992). The key construct in this theory is goal orientation, which in the context of school science is how and why students engage in learning the subject. Vedder-Weiss and Fortus (2011) use achievement goal theory to consider student engagement in science in terms of both classroom engagement, which includes behaviours such as effort, persistence, concentration, attention, asking questions and contributing to discussion, and also continuing motivation to be engaged in science beyond the classroom—which should be an important outcome of science teaching. These authors focus on school culture beyond the classroom and show that in certain school cultures (democratic schools), classroom engagement and continuing motivation are more stable through early adolescence. This is an important finding as it appears that the decline in motivation is not inevitable; school and classroom culture can make a difference. That new science teachers should embrace these ideas and contribute to positive school cultures is an important aim for the PGCE science programme.

Enhancing the prospect of cognitive engagement is therefore an aim embedded within our PGCE initiatives with STs. In a study of PGCE student teachers' views about what features make a creative science lesson, Manning et al. (2009) showed that at the start of an ITE course, their focus is on variety, relevance to the learner and the need to establish an appropriate classroom atmosphere. We surveyed one cohort of STs towards the end of their PGCE year and asked them to name something they learnt during the course that would help to engage their students' interest in science. For the 57 out of 72 STs who responded, we grouped the 'things' they mentioned thematically, some of which matched the findings of Manning et al. (2009). The range of ideas the STs reported is broad, with most important being those which provide motivation and interest. For example, the use of exciting visual representations of science, especially using technology challenge, and relevance to students' lives either through things they may have seen or experienced. This finding in many ways matches the study of students' voice by Barmby et al. (2008) and Logan and Skamp (2013). These data suggest that our PGCE course is helping to support the development of the next generation of teachers who, in turn, can change the "salient views" (Korpershoek et al. 2013, p. 500) of their students and encourage engagement in science at school and beyond. Through our initiatives with STs we aim to embed these fundamental ideas about the importance of and influences on school students' cognitive engagement in science. The following section provides details of how these initiatives are introduced in our PGCE programme.

Initial Teacher Education Initiatives

Designing learning experiences that are engaging for school students involves providing motivating experiences that support the development of a personal identity with science and that help them to recognise relevance in what they are learning. Much of our PGCE course is designed to do this through encouraging the STs to be both creative and reflective in their teaching. However, these skills are not necessarily easy to acquire and require careful support to ensure that their development becomes embedded in the STs' professional practice, and not simply an 'add-on'. In the discussion below we explore three training initiatives that we have developed as examples of the way that our ITE course is purposefully structured to provide opportunities for the STs to develop their own practice. These initiatives exemplify the way the relationship between some of the important research and expertise of the PGCE tutor team have become integrated in the course and how this is then translated into teacher preparation. The three initiatives we discuss are:

- Learning science outside the classroom
- Learning science with technology
- Supporting teacher creativity through action research

Learning Science Outside the Classroom

There is a long tradition in science education of learning outside the classroom, for example, in museum and field visit settings (e.g., Falk and Storksdieck 2010; Rickinson et al. 2004) with experiences of this type having been shown to provide unique opportunities for encouraging students' learning. Moreover, according to Falk and Dierking (2000), when the experiences are well organised they facilitate both intrinsic and extrinsic motivation. An essential element of non-formal learning is that teachers and students recognise the differences between the established norms and values of the everyday classroom setting and those of the non-formal learning environment. This is important because, while liberating to both teachers and students, this shift can be potentially problematic if the new norms and values are neither articulated clearly between teacher and student nor recognised by both parties as being important. That is to say, transferring teaching from the classroom to the 'outdoor classroom' does not mean bringing with it the structure of school and the expectations surrounding what typically takes place in school. Instead, learning experiences away from the classroom are experiential and liberating exactly because students are not expected to act as if inside the classroom (Braund and Reiss 2006) and go some way to support the closing of the 'culture gap' that Aikenhead (2001) identifies as being a major barrier to students' learning in science. Non-formal learning in science is also important because, as Hodson (1996) argues, it can provide students with 'real-world science' or 'authentic' learning experiences. Although debate exists about what is meant by authenticity in science (Braund and Reiss 2006), the central tenet is that it means providing experiences in ways that are similar to the activity of 'real' scientists. This feature has important implications as it echoes ideas of students identifying with science and seeing utility in their learning.

Use in Initial Teacher Education

Despite the importance of non-formal learning in science, its use in initial teacher education is in decline (Lock and Glackin 2009). Members of our tutor team have specific interests in this area of science education and we have developed an extensive teaching outside the classroom programme as part of our PGCE course. The programme involves the STs working at both the Royal Botanical Gardens, Kew (Kew Gardens) and the Science Museum, London, details of which are in Table 1.

A major emphasis of our training is that the STs should consider how the non-formal learning experience affords creative learning opportunities that engage students in their learning of science. Here, we draw on work undertaken by the tutors into the role of field visits (Amos and Reiss 2006, 2012), museums (Chapman and Herrington 2008) and the Queen Elizabeth Olympic Park (Amos and Robertson 2012) in learning science. This work has explored the importance that

Table 1 Details of the work that STs carry out at the Royal Botanical Gardens, Kew and the Science Museum

Stage	Details
Briefing	Students are given logistical information about the work they will carry out, as well as details about the theoretical assumptions associated with non-formal learning
Training day	Students receive a half-day training session at both Kew Gardens and the Science Museum. Tutors, and in the case of Kew, tutors and Kew staff, introduce them to a variety of activities suitable for school children aged 11–13 years
	Working in groups of 5–7, the STs then plan a range of activities. At Kew Gardens they are free to use the various glasshouses and outdoor areas, with a focus in on sustainability. At the Science Museum they are able to make use of three major galleries, as well as an interactive zone
	The plans are then discussed with ITE staff and the STs are encouraged to justify and reflect upon their design
Teaching day	Students from schools that work with us on the PGCE programme come to Kew Gardens and the Science Museum and the STs teach groups of about 18 children
	The days end with a reflective, summary session that draws out the major themes learnt by the STs through the experience

‘place’ plays in being both engaging and motivating students, for example, in providing access to what Braund and Reiss (2006) call ‘rare materials’ not normally available within a classroom setting and learning experiences that are both interesting and provide ‘memorable moments’ (Bebbington 2004). In addition, we draw on the theoretical perspectives of Holzman (2010) who emphasises the significance of creativity and play in learning. Holzman’s work is mainly situated within ‘Arts’ subjects but has much to say about how student learning benefits from settings that allow them to explore their own understanding and develop their own meanings. In doing so, she reconceptualises Vygotsky’s (1978) Zone of Proximal Development by arguing that “creative encounters” support accelerated learning; what Vygotsky calls “becoming a head taller” (Vygotsky 1978, p. 102). These ideas, where students have a degree of freedom and autonomy in their learning, have proved useful in explaining why working outside the classroom can be so powerful for student learning and engagement.

In preparation for the teaching days at Kew Gardens and the Science Museum, many of our STs are anxious about the logistics of ‘controlling the students’ and ‘not knowing the students well enough’, as well as worrying about their own expertise and ability to ‘answer tricky questions about things I’m not sure about’ (e.g., Chapman and Herrington 2008). Typically the STs are also concerned about how the students might behave away from the structures of schools. However, through these experiences, they reconceptualise the novel learning environments and recognise the special opportunities they offer, both in terms of learning and in the building of positive interpersonal relationships (Raved and Assaraf 2011). The training and planning stages (see Table 1) of the process give the STs confidence in their ability and change their perspective on what is important in terms of the learning experience, with a notable shift from the mechanistic organisational aspects to one very much focused on student learning and the special significance of the learning environment. Almost all of the activities that the STs design are creative in nature, for example, a ‘time machine’ which ‘transports’ the students to important periods of history in the “Making the Modern World” gallery in the Science Museum, as they examine how communication devices—technologies which are particularly significant to students—have changed since the invention of the telegraph. Activities of this type provide the learner with opportunities to relate the context to their own lives (Aikenhead 2006) and, in doing so, give students opportunities to see relevance in their learning in terms of its utility and relationship to their own lives. Helping students to identify with science in this way (Taconis and Kessels 2009) has powerful implications for learning, and observations of students working in these settings reveal a high level of engagement, with evidence of the development of links between what appear at first to be disparate pieces of information and ideas.

Using Technology in Learning Science

Supporting student engagement has also been enhanced through our PGCE course through encouraging STs in the use of emerging digital technologies. While the course provides experiences of using technology within the classroom, we also place emphasis on its effective use in out-of-classroom learning, where it has much to offer. Hammond (2014), for example, discusses the important role that digital technologies play in allowing students to learn in new ways and promote engagement in science (see also Cowie and Khoo, this volume). However, while the range of digital technologies available to both teachers and students in schools is great, much of it is often underused or used in limited ways (Cox and Webb 2004; see also Selwyn and Cooper, this volume). An important concern is that while digital technologies have an important role to play in providing novel opportunities for learning that are motivating and engaging, the integration of these tools and appropriate pedagogies is challenging and problematic because teachers are ill-prepared for their effective use (Mishra and Koehler 2006; Muijs and Lindsay 2008).

While many teachers are enthusiastic and motivated by the potential learning experiences offered by digital technologies, and are keen to integrate them into their practice (Russell et al. 2003), their use has still tended to be for fairly ‘low-level tasks’ such as word-processing or presentations, with teachers most commonly using them with students for internet-based research (Kreijns et al. 2013). Unsurprisingly, teacher confidence with using digital technology plays a key role in how technology is used by the teacher and students, and the frequency of use (Hennessy et al. 2005). There is still a lack of emphasis within teacher training programmes on using digital technology in the classroom and this is something that appears to be changing only slowly (Hammond et al. 2011).

Use in Initial Teacher Education

Our PGCE course aims to support STs in their use of technology, and by drawing on a range of expertise within science education and technology education we have developed a number of initiatives using digital technology. One example is a recent project, *GeoSciTeach*, which made use of mobile technology to promote spatial thinking skills in science. This project provided a good example of how STs becoming involved in a research project as participatory-designers immerse themselves in learning experiences and show features of developing sophisticated pedagogical approaches (Price et al. 2013).

The project involved 12 STs designing a smartphone application (app) called *GeoSciTeach* that was developed to support spatial thinking in science for use in the work that the STs carry out in Kew Gardens. Spatial thinking encompasses a suite of skills related to understanding the nature and representations of space (Downs 2006) and mobile devices can support spatial thinking through their easy to use Global Positioning Systems (GPS) technology. Basing the design on the concrete example of the Kew Gardens activity provided a scenario to ensure that the application 'worked', and enabled the STs to think about the technology—where and why it might be functionally useful—while also linking this with spatial concepts. The project involved a number of workshop sessions where the STs reflected on their use of technology, planned the development of, and tested prototypes of the app, and planned activities for using it at Kew Gardens. Data were collected from each stage of the project through mixed methods of observation, focus groups and interviews.

At the start of the project, most of the STs' experiences of using digital technology within school had been related to sensor and data logging equipment, a common use of technology in school science (Donnelly et al. 2011). Relating their use of technology to spatial thinking was always at a fairly superficial level, with tagging collected data to specific locations. As the project developed, and having trialed the prototype *GeoSciTeach*, the STs developed a greater understanding about how the app could support understanding science and spatially-related ideas (for a fuller discussion, see Price et al. 2013). Towards the end of the project, the project STs worked in mixed groups with non-project STs to design a learning activity using the app at Kew Gardens in teaching and learning episodes with students aged 11–12 years. The collaboration within the groups gave the project STs the chance to share their knowledge and, in doing so, reflect on how they had changed—something that was profound for a large number.

The learning activities the groups developed were engaging in a number of ways: they encouraged the school students to work collaboratively and develop understanding about various aspects of plant biology through problem-solving and they allowed the students to draw on additional information, for example from websites, to support and deepen their understanding. In doing so, using the 'tools' as well as the processes of science arguably transformed the students from learners of science into scientists, promoting their identity as people capable of 'doing' science. This project was focused on a specific area of research, but from the success of this work a number of initiatives have emerged that we have incorporated into the PGCE in terms of how STs can use technology to develop engaging learning experiences.

Teacher Creativity Supported Through Action Research

As highlighted in the introduction, understanding the nature of engaging activities is something that many of our teachers want to develop and that provides a focus for much of their thinking. Two important aspects for consideration are how motivation and relevance can be used to encourage engagement in the classroom and how teachers can be supported in their work in this area. Providing a challenging learning environment is an important feature of engagement (Schweinle et al. 2006; Turner and Meyer 2004) and something we see develop in our STs as they progress through the PGCE course.

Engaging students in learning science can be a challenge, and a key aspect of developing effective pedagogy is teacher reflection. As mentioned previously, development of the 'reflective-practitioner' model of teacher education is an important feature of our PGCE course, with many of our teaching sessions designed to support the advancement of this skill. In addition, we have developed a specific focus on reflection through the Masters-level assignments where the STs carry out a short action research project. In the spring and summer terms (semesters), the STs work on a 5000-word assignment that investigates the use of creative resources in assessment of student progress. Very much embedded in classroom practice, the assignment requires the STs to engage with the literature on learning theory, assessment and children's ideas in science and, using this literature and their evaluations of what makes effective practice, develop a novel resource which supports students' understanding of a specific scientific concept. The resource is then used in the classroom to assess student progress against nationally prescribed assessment criteria. The STs evaluate the use of the resource in terms of how it encouraged student engagement, how it supported student progress, and whether it proved effective in allowing both teacher and student insights into student progress. The assignment culminates in a section where the STs reflect on the process of producing their own resources and consider how their personal progress on the PGCE course has evolved and how they are positioned as they move from being a student teacher to an in-service teacher.

The range of resources the STs develop is impressive and includes games, practical activities, technology-based learning experiences, and role-plays. A good example was an activity entitled 'A theatre production of the placenta' that, as part of a teaching sequencing on human reproduction, involved 11–12-year-old students using the classroom space to enact the function of the placenta in providing the fetus with oxygen and food, and removing carbon dioxide and returning it to the mother. The ST, Steven, had experienced a very traditional education, having been schooled in a private boarding school for much of his childhood. At the start of the

PGCE course he adopted a transmissive, teacher-led approach in the classroom and found personal reflection a challenge and “something I have never been asked to do before”. Steven identified that students were often confused by the role of the placenta in fetal growth, thinking, for example, that blood from the mother flows directly into the fetus and having little awareness that materials the mother ingests and inhales may affect the developing fetus. Having reviewed the literature and considered his and other teachers’ practice, he decided that role-play would be an effective tool to support student learning because it has been shown to deepen understanding of scientific ideas (Abrahams and Braund 2012) and provide an opportunity for students to engage with all their senses. The activity involved the classroom tables being rearranged to have narrow spaces between them, forming a semi-permeable barrier between the ‘fetal’ side of the room and the ‘maternal’ side of the room, each of which was demarcated by its own ‘home-table’. The students represented the blood in either the fetal or maternal circulatory system and walked in single file in a loop, in the opposite direction for the fetus and mother, to represent a counter-current blood system. As they passed their ‘home-table’, the students collected and dropped off cards, which represented carbon dioxide, food, oxygen, etc. The cards were ‘exchanged’ at the placental interface to represent materials moving across the placenta. Assessment was carried in a number of ways: teacher observation of the activity, students’ oral explanations of their role in the activity and what they were doing at certain times, and a short written task.

In reflecting on the effectiveness of the lesson in supporting student understanding of the function of the placenta, Steven reported that the role-play had been very effective in engaging the students in understanding an abstract concept and had enhanced their ability to explain how blood materials are passed between mother and fetus. He reported that the students were excited by the prospect of the activity and talked about it in subsequent lessons, requesting that similar activities be used in the future. Following Di Bianca’s (2000) notions of criticality, Steven’s reflections were sophisticated as he considered the limitations of the approach, including organisational issues, the need to model the role of the umbilical cord in transporting materials to and from the placenta, and the benefits of asking the students to reflect on the effectiveness of the role-play as a model. Something that was important to him was that the students began to feel like ‘experts’ and grew in confidence in their use of scientific language and explanatory skill, a response that echoes work of Taconis and Kessels (2009) surrounding the development of identity. In this example we see the changes that are typical of STs throughout the PGCE course: starting with a teacher-centred pedagogic approach and struggling with the challenges of self-reflection and critical analysis before moving towards a more student-centred pedagogy with growing confidence and reflective abilities. Steven is not unique and demonstrates a typical model of how many of our STs develop throughout their training.

Conclusion

In this chapter we set out to review contemporary views on student engagement in science to show how our current initiatives in training new teachers aim to help them to address components of engagement in their practice. The literature shows that issues of motivation, relevance and identity are important factors in supporting sustained engagement and that students become engaged through establishing positive relationships with their teachers. Developing this understanding in STs is clearly an important feature of ITE programmes, but making it explicit and providing opportunities for the exploration of these ideas is not straightforward. The examples we have presented demonstrate how aspects of our PGCE course are designed to show STs what is possible in science education as well as provide time and space for them to develop their skills in using a variety of pedagogic approaches. These skills, both generic and specific (Harris 2010), enable STs to design learning experiences that allow students to fully participate and encourage the building of positive relationships between teachers and their students (Anderson et al. 2004).

Evidence from STs at the end of the one-year PGCE course suggests that they are aware of activities that engage students, but that there are a variety of possible approaches for fostering engagement, as experienced on teaching practice. STs need to develop the skills to enable them to provide the seeds of student engagement through becoming competent with a variety of teaching approaches. Yet the combination of curriculum requirements and the complexity of learning to teach science often means that the affective agenda for science education takes second place to the pressure for examination success in the school setting. It is hoped that immersing STs in initiatives like those presented here will enable them to build a repertoire of approaches that can be used to maintain student interest in their science learning while addressing curriculum and assessment requirements. At a time when, for example in the UK, routes into teaching are rapidly changing, and student and public engagement in science is worryingly low (Wellcome Trust 2011), it has never been more important that we understand good practice in preparing the next generation of science teachers. Further research on the effectiveness of our ITE approach would help to inform future teacher education programmes for both pre- and in-service teachers.

Many of our student teachers continue their professional development by undertaking further study for a Masters degree in Science Education. For their dissertation, we find that many science teachers want to undertake an enquiry to explore some aspect of student engagement. Teachers sense that engagement is essential to successful teaching, not only as they believe it optimises the prospect of good cognitive outcomes, but also because student engagement gives high job satisfaction. Such Masters' studies usually explore how initiatives and interventions are perceived, or how a learning environment impacts on engagement. Clearly student engagement is a central issue for teachers not only at the outset of their teaching, but as they continue to develop their practice. Although there is a wealth of accessible research about influences that relate to engagement, such as students' attitudes towards science, perceptions of relevance and identity with science, *our teachers continue to want to explore these issues for themselves in their own contexts*. We conclude that student engagement is complex and fluid—its multiple influences are ever-changing and are determined by an environment that is also constantly changing. Our concern as teacher educators is how we can prepare new teachers to value and understand student engagement as part of their ongoing professional learning so that they have the confidence to listen to students and be alert to exploring pedagogical practices that are relevant to them.

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Futures Thinking in the Future of Science Education

Cathy Buntting and Alister Jones

Introduction

In a world of unprecedented scientific and technological advancement there is increasing need for students to become equipped and empowered to contribute meaningfully to change, both in their places of work and in their social and political world. One aspect of this need is an ability to identify preferred future scenarios from a range of possibilities, and to then work towards these. Such decision making—about possible and preferred futures—forms part of what is variously called the futures field, futures studies, futures research, futuristics, prospective studies, or prognostics (Bell 1996) and has its origins in the strategic planning of governments and large corporations. Here, we use the term 'futures thinking' and consider its potential place in science education.

Futures thinking is beginning to find a place in school and tertiary curricula as 'futures education'. For example, New Zealand schools are required to include a future focus as a foundational principle in curriculum design and implementation (Ministry of Education 2007). This principle is about "supporting learners to recognise that they have a stake in the future, and a role and responsibility as citizens to take action to help shape that future" (New Zealand Curriculum Update 2011) and it is intended to permeate curriculum design decisions. Within science curricula, too, there is often implicit reference to future scenarios. For example, the national curriculum in England proposed for 2014 includes as an aim for science education that students are to be equipped with the scientific knowledge required to understand the uses and implications of science, today and for the future

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(Department for Education 2013). In the United States, one of the science benchmarks for Grades 9–12 reads: “Scientists can bring information, insights and analytical skills to bear on matters of public concern. Acting in their areas of expertise, scientists can help people *understand the likely causes of events and estimate their possible effects*” (AAAS 2009, emphasis added).

Futures thinking has strong natural associations with science education in that many current and future global issues have scientific and/or technological underpinnings. As such, futures thinking in science aligns closely with the exploration of socioscientific issues, or SSIs (Zeidler et al. 2005). Indeed, it is the futures focus of SSIs that many students find most alluring (Osborne and Collins 2000). However, futures aspects appear to be largely implicit in many SSI programmes, and we advocate for a much more overt inclusion in order to specifically develop students’ futures thinking skills. In other words, while we applaud the intent of SSI programmes to develop students’ moral reasoning, we believe that there is also potential for such programmes to develop students’ futures thinking—but that, to date, little systematic work has been undertaken in this area.

As well as the natural association between futures and SSIs, futures thinking is also particularly relevant to science education since science (and technology) often form part of students’ images of the future (e.g., Otrel-Cass et al. 2009). In addition, futures thinking is highly contextualised in that scenarios are developed from a range of stated parameters. This means that developing the futures thinking skills of students fits well with a context-based approach to school science. However, the field of futures thinking in science education is still pre-emergent in that there is very little research evidence of appropriate pedagogies, or the impacts on students’ conceptual and affective learning.

This chapter considers one major aspect of the field of futures thinking in science education: the potential for futures thinking to engage reluctant learners in thinking about science. Here, ‘thinking about science’ includes thinking about the social, cultural and political milieu to which science contributes, and the relationship between science and technology. The context for the study was a programme involving one class of Year 9 (13 year-old) students of lower mixed ability. The research builds on earlier work using the framework for futures thinking developed by Jones et al. (2012). This framework includes five components—understanding the current situation, analysing relevant trends, identifying drivers, exploring possible and probable futures, and selecting preferable futures. In order to ground students’ discourse in possible futures in science teaching and learning, a sixth component—underpinning science—was introduced.

Futures Thinking in Science Education

While ‘futures studies’ relates to the academic field of inquiry into possible futures in a broad range of contexts, ‘futures education’ refers to the translation of futures concepts into learning experiences that are appropriate for school students (Hicks

2012). The plurality of the name—futures—is deliberate, highlighting the range of possible futures and notions of alternatives (Slaughter 1996).

Futures thinking—which underpins both futures studies and futures education—assumes that the future world will differ from the present world; that the future is not fixed, but consists of a variety of options; that people are responsible for choosing between these options; and that small changes can become major changes over time. Most futures work incorporates considerations of the following factors:

- input data (observations, raw data, and empirical evidence that are analysed and synthesised to produce trends),
- trends (trajectories, extrapolations, projections, and predictions, based on an analysis of the input data; trends tend to be continuous and monotonic, i.e., relating to one aspect only, such as the increasing proportion of the world's population living in developing countries),
- drivers (groups of trends that share a common theme, e.g., demographics, globalization, economics, science and technology, equity issues, and environmental change),
- wild cards (high-impact, low-probability events, e.g., natural disasters), and
- outcomes (possibilities and scenarios) (DERA 2001).

The cumulative effect of even small uncertainties in any of these factors means that the range of plausible future worlds is very large.

Although the potential for explicitly including futures thinking in science education has not yet been extensively studied, some initial investigations have been carried out by David Lloyd and colleagues (e.g., Lloyd 2011; Lloyd et al. 2010; Lloyd and Wallace 2004; Paige et al. 2008). In addition, a small number of classroom resources exist, often with an environmental focus (e.g., Fisher and Hicks 1985; Hicks 1994; Slaughter 1995; UNESCO 2002). Extending some of these ideas, Jones et al. (2012) developed a conceptual framework to develop students' future thinking skills. Within this framework, students' attention is focused on identifying and analysing the existing situation, trends and drivers. Student understandings of these are then used to explore possible and probable futures in a structured format that reduces guesswork while still encouraging creativity. A consideration of the social context within which the changes might occur can take place at a personal, local, national, and global level. The intention is that recognising this range of levels will help move students' decision-making from an ego-centric activity to one valuing the welfare of the planet and all its occupants. Futures thinking should, therefore, provide opportunities—through the building of possible, probable and preferable future scenarios—for students to reflect on their own as well as others' values. Taking into account multiple perspectives and world-views is important for exposing students to some of the complexities and ambiguities associated with SSIs.

The potential benefits of developing students' future thinking skills therefore include fostering their creative, analytical and critical thinking skills; developing their futures vocabulary (e.g., past, present, future, the extended present, alternatives and choices, sustainability, future generations) as well as their values discourse—all critical for inculcating the foundations of a futures perspective (Slaughter 1995). Ultimately, futures thinking has transformative potential through empowering individuals and communities to envisage, value, and work towards alternative futures (Carter and Smith 2003; Delors 1998; Hicks 2003; Rawnsley 2000).

When students' images of futures are explored and valued, they can be a powerful vehicle for learning (Lloyd and Wallace 2004). There is, therefore, potential for futures thinking to engage students in science learning, and to increase their perceptions of the relevance of their science learning. There is also the potential for futures thinking to help students develop their understanding of key scientific concepts, including those related to the nature of science, and to evaluate the positive and negative potential impacts of science and technology on society (e.g., Carter and Smith 2003; Paige et al. 2008). The focus of the study presented in this chapter was on the first of the above outcomes—the influence of futures thinking on student motivation in science.

Futures Thinking to Engage Reluctant Learners

While our earlier work has investigated the usefulness of the futures thinking framework with academically able students committed to their education (Jones et al. 2012), we were also interested in its value for engaging reluctant learners in thinking about science. Such students pose significant challenges for science teachers, and there is considerable global concern about how to increase their engagement and achievement in science.

This chapter describes a small classroom-based case study where futures thinking was introduced to junior secondary science students. The class was a Year 9 class (13 year-olds), the first year of secondary schooling in New Zealand. It was culturally diverse—of 20 students, half were New Zealand European, almost a third Maori, and the remainder East Asian. The class size had deliberately been kept small by the school in an effort to make classroom management easier, and, as is common in this context, class attendance was very erratic. During the six futures lessons, only five of the twenty students attended all lessons, and four of the students were stood down from school during this time for three different thieving incidents. The class was described by the school as 'lower mixed ability', and only four students out of 17 passed (i.e., achieved a grade greater than 50 %) an end of topic test just prior to the futures lessons (three students had been absent for the test). There was significant disengagement in science learning, with many students choosing to not participate in class activities.

Since the 'success' of the futures thinking lessons was going to depend, in part, on the teacher's content knowledge and pedagogical content knowledge (Magnusson et al. 1999), the class was taught by Cathy (the first author). This strategy circumvented the need to 'upskill' the science teacher. While such teacher development will be a valuable future pursuit, it first requires evidence of the merits of including futures thinking in science—and there remains a dearth of such evidence given the pre-emergent state of futures education in science. Cathy is a familiar personality in the school, and she attended seven science lessons prior to teaching the futures lessons in order to develop rapport with the students and get to know their interests and classroom habits and behaviours.

Methodology

In order to investigate whether futures thinking could be used to engage the students described above—disengaged junior secondary learners enduring rather than enjoying science, and school in general—the class participated in a series of six lessons. An interpretive case study approach was adopted, described by Bassey (1999) as "enquiries into educational programmes, systems, projects or events to determine their worthwhileness, as judged by analysis by researchers, and to convey this to interested audiences" (p. 58). Accordingly, data were collected to enable the research team (the two authors) to "(a) explore significant features of the case, (b) create plausible interpretations of what is found, (c) construct a worthwhile story, and (d) convey convincingly to an audience the argument or story" (p. 58).

Because of the tight scheduling of the year's science programme, the futures lessons were taught during classes that were normally timetabled for students to be in English—but they were reminded each time that they were in the class to learn 'science'. All lessons were audio-recorded so that interactions between the teacher and students could be analysed, and students' written work was collected at the end of each lesson and photocopied. The English teacher, Mandi (a pseudonym), took great interest in the project and chose to observe all six lessons. This offered the research team an informed outsider's reflections on the lessons and how students had responded.

The Futures Lessons

The six futures lessons are described below alongside some of the students' responses as a window into how the futures thinking framework played out with this particular group of normally reluctant junior secondary learners. Readers' attention is drawn to the variety of focal artefacts used to initiate and facilitate learning conversations, and the malleability of the futures thinking framework to be customised depending on the purpose of the teaching programme—in this case, to engage the learners in thinking about science and its role in everyday life.

Introducing Images of the Future

In order to introduce futures thinking and ground the lessons in contexts with which students were familiar, the first lesson consisted of two parts. First, a series of examples of past predictions were displayed and discussed, for example, delivering airmail using parachutes (predicted in 1921) and a surprisingly accurate prediction from 1900—a vision for Skype. The focus of the discussion, led by Cathy, was on how difficult it can be to predict the future, but that often science or technology is involved. In the second part of the lesson, students were shown photographs from three movies set in the future and asked what images of the future these movies evoked. Whole-class discussion focused on potential impacts on society as well as identifying some of the science that might be involved. In other words, both science and the potential social impacts were explored. For example, the movie 'Total Recall' predicts a highly automated society living and working in extremely tall buildings with little access to nature. This stimulus was used as the basis for discussing materials development and power generation (to enable such tall buildings to be built and supported), where and how food might be produced, and the potential impacts on people when they are disconnected from nature.

Next, students worked in small groups to choose a movie with a future theme and identify three predictions about the future that it portrays. The students were able to access computers for this task, and many of them watched movie trailers. In the second lesson, students reported back on the movies they had chosen and images of the future portrayed in the movie. Movies that were identified by students included: 'Looper' (set in 2074, includes time travel), 'Iron Man 2' (time unknown, includes powered armour), 'Total Recall' (set in 2084, involves memory replacement), Avatar (set in 2154, involves interplanetary travel and avatars genetically matched to their human operators), and 'Oblivion' (set in 2077, involves inter-planetary travel).

Mandi, the English teacher, highlighted the value of this approach for developing students' critical literacy. She commented after the lesson:

> The movies are great. It's what these students are most likely to connect with. They're not going to be reading or thinking about articles questioning future issues and challenges, or what the impacts might be on society. They don't watch movies critically either, but if there's going to be a forum that starts to get them thinking about things that are going to have an impact on their lives, it's going to be movies. And if you start the process now of thinking critically about what is being revealed, hopefully some of it will embed, stick.

Through facilitating the discussion, Cathy was able to keep steering the focus of the discussions to possible features of the future world, science understandings that might be needed, and social implications. She also deliberately created opportunities for all students to participate in the discussion in an effort to retain their engagement and focus.

Identifying Trends, Drivers and Relevant Science Knowledge

During the second half of lesson 2, Cathy led a whole-class discussion on past, present and possible future cell phones in order to introduce students to 'trends' and 'drivers' as concepts. Cathy created a bridge into this part of the lesson by pointing out that while it can be difficult to predict the future, we can develop possible scenarios by examining the present situation and changes that might shape future developments. In order to stimulate discussion about trends in cell phone development, an advertisement from the 1980s (available on *YouTube*) was played. Similarly, *a YouTube* clip of a 'futuristic cell phone ad' was used to initiate discussion about possible future developments in the cell phone industry. Table 1 captures the notes that were written up on the board to record class discussion.

The third and fourth lessons were used to reinforce the concepts of trends, drivers and possible futures, once again using whole-class discussion focused around stories, images and movie clips to recap the earlier lessons as well as consider possibilities for future cars and foods. Cathy summarised student responses on the board, and they also had worksheets on which they could write their ideas. Heavy reliance on teacher-student dialogue was considered to be somewhat risky by Mandi, who indicated that the students were much more used to spending time copying notes from the board—and that this was seen as a mechanism for 'managing' student behaviour, particularly in classes considered to be 'disruptive' and 'reluctant':

> Students are so conditioned to value what is written down. Even if they complain about writing, they've been conditioned to believe that *that* information is valid and important. It's also often used to manage their behaviour. But I think that's one of the tragedies—we've totally undersold discursive learning, or learning by discussion.

Table 1 Cell phones: past, present, future

Past	Current	Changes (trends)	Reason for change (drivers)	Future possibilities	Science involved
Bulky, heavy	Thin, light	More portable	Market share—companies developing new ideas to sell more phones	Transparent materials—new materials	Signal transduction
Cords	Multi-functional—phones, apps, Internet, games, cameras	Cordless	Consumer demand	Holographic displays	Electronics
Telephones only (single function)	Wide range	Increased functionality	New technologies (LCD screens, touch screens, changing battery sizes)	On or in our bodies	Sensor technology (touch screens)
Expensive	LCD screens	Increased accessibilty			
		A fashion item			

Mandi was surprised by the sustained level of student engagement and participation in the class discussions, and their connection with the intended learning:

> They've been able to sustain a high level of thinking—higher than normal for them. What I was impressed with today [the fourth lesson] was that they've continued to be engaged with the process, and it hasn't seemed to wane. And they're making the connections. The way they were able to reflect on what was discussed in the previous lesson—there was the right balance of prompts to remind them, and they came up with the terminology—trends, drivers.

Importantly, by facilitating the class discussions, Cathy was able to maintain an emphasis on the scientific knowledge that might be needed to underpin future developments. In order to reinforce this, she used narratives to introduce science developments that had been necessary stepping stones in developing modern technologies. For example, LCD screens depend on the late 19th century discovery that cholesteryl benzoate has two melting points, and between these it has properties of both liquid and crystals. The purpose of this and similar narratives was not only to engage students in some of the stories of science but to emphasise the importance of scientific discoveries in many contemporary technological developments. Short explanatory movies about possible futures were also selected because of their references to the underpinning science. For example, a clip of the Google self-drive car was chosen because of its narration by Kathy Sykes, a British physicist and broadcaster, who describes some of the science-based features of the car, including a 64 laser scanner on the top of the car to measure the distance of surrounding objects.

The social context and implications were also discussed in all of the examples that were talked about, for example, the reliability of self-driving cars, the challenge of feeding a growing population. Again, this discussion needed to be mediated by the teacher, who throughout the lessons had the following clear goals in mind:

- to help students identify changes over time (trends) and what might be influencing them (drivers),
- to highlight the importance of science in possible future technological (and other?) developments, and
- to contextualise the future within a broader social framework.

Pulling it Together

In the fifth lesson, students were tasked with choosing a context in which they would explore: the past, the present, trends, drivers, possible future developments, and the underpinning science. In the following session they would share their ideas. As a class it was decided that at least three trends and drivers would need to be identified, two possibilities for the future, and two aspects of science that would be needed. The students, therefore, helped negotiate the assessment framework.

The students had access to computers and there was a mix of individuals and pairs or threesomes working together. Each individual or group had a worksheet with a table with headings as shown in Table 1. Key to the discussions was choosing a suitable context and then being able to effectively search the Internet for relevant material (ICT literacy). Cathy circulated around the class, interacting with all students about both of these issues, helping students to refine their topics, suggesting terms to use in Internet searches and then helping students filter the results to identify useful information. For example, Tammy and Leah (pseudonyms) wanted to explore future fashion. Cathy reminded them that they would need to think about links to science and suggested that they investigate how fabrics have changed, why there have been these changes, and what new materials might be developed in the future. However, she quickly realised that the limited background knowledge of the two girls would significantly impact their ability to make progress—they were almost immediately distracted by references on the Internet to ‘cellulose-based fibres’ and ‘synthetic fibres’ and did not have even a rudimentary understanding of different materials such as cottons, linens, polyesters and nylons. Because of this lack of understanding, Cathy suggested that they choose another topic. Here again, her guidance was critical in refining the context for investigation—from specific singers/bands that would become more popular (Tammy’s first idea), to ways in which music is accessed (‘changes in the music industry’ resulted in a particularly fruitful Internet search).

For students who very seldom experience lessons where they need to work independently of the teacher, with ready access to computers, there was a high level of on-task behaviour. Although some groups complained about the amount of reading that was required to identify information relevant to the task, with encouragement they persisted. Discussions among the student groups tended to be animated but focused, and several students found fascinating images of past and possible futures related to their topics. One boy also drew heavily on his funds of knowledge (Moll et al. 1992), leading his group’s discussion about future possibilities for televisions by drawing on his father’s experiences as manager of a large electronic appliance store and telling the others about some of the new televisions that were about to be introduced into the market. In contrast, a group of four boys were significantly disruptive and were repeatedly asked to focus on what they were doing. Closer examination suggested that these boys all had very low levels of literacy and ICT literacy, and searching the Internet was an extremely challenging task for them.

The presentations of student work in the subsequent lesson were deliberately low key so as not to force students to take on a role of ‘speech maker’ in front of the class, which many would have found intimidating. Although Tammy and Leah had prepared a PowerPoint presentation to which they spoke, the remaining students sat at their desks and read out their ideas and the teacher collated these on the board. This process facilitated the creation of a visual artefact that all students could access (Wenger 1998), and enabled important learning conversations between the student offering the idea, Cathy clarifying this idea, and other class members contributing refinements. It also meant that in cases where individuals or groups had developed the same context, ideas could be collated. In addition, Cathy could reinforce technical language, for example, ‘market share’ rather than ‘sell more than other companies’ and ‘multi-functional’ rather than ‘decent phones’ or ‘has lots of apps and things’. While the majority of the class participated actively in the discussions, a small group of boys (all of whom had missed earlier lessons) were disengaged and disruptive throughout the lesson.[1] It was encouraging to notice, however, that one boy in their midst still chose to contribute his ideas despite overt pressure not to do so.

In total, five different future themes were developed: cell phones, cars (both with substantive additions to ideas previously discussed in class), televisions, future food, and the music industry. Of these five, the best developed was past, present and future ideas associated with televisions, as shown in Table 2.

At the end of the lesson, Mandi reflected on the students’ contributions and behaviour:

> They’ve come a long way. Teresa, Lindsey, Lance [pseudonyms]—if you could see their behaviour in other contexts the difference would be extreme. And I think the level of thinking that was happening—that had probably been happening in the first lessons and then solidified in the computer lesson—I think that was very encouraging and hopeful. It’s been a huge shift for them.

Her reflection on the culture shift that had begun to occur was more disturbing:

> Perhaps the tragedy of what’s happened is that you’ve highlighted what’s missing. They’re only just going to really start unpacking why this is different, and what the potential is for their learning, and now they’re going back to the way things normally are, where they actually have very little opportunity to really give their ideas.

This reflection is a salient reminder of the extensive research evidence supporting student-centred, interactive pedagogies—juxtaposed against a classroom culture in which teachers seek to ‘manage’ behaviour and ‘cover’ content by limiting opportunities for interaction and exploration.

Student Views

In order to gain insights into students’ views of science prior to and after embarking on the futures lessons, a short questionnaire was administered at the beginning and end of the six lessons. From the beginning, students’ views were positive about science, in spite of their high levels of disengagement in their school science

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[1] One of these students, a key player in the disruptions, was subsequently excluded (expelled) from the school for a series of illegal activities. His story is included here both to be true to the description of the classroom environment, and to highlight the leading role that some students play in influencing class culture. In spite of his insidious influence, including notorious bullying, many of his peers showed admirable determination to contribute meaningfully to the classroom interactions.

Table 2 Televisions: past, present, future

Past	Current	Changes (trends)	Reason for change (drivers)	Future possibilities	Science involved
Big boxes	Flat screens	Larger, thinner screens	Increase market share—people want to buy 'the latest'	3D and interactive experiences	LCD screens
Originally black and white and no sound	Multiple channels	Increased quality	Reducing cost	Voice- and movement-activated	Sensor technology
Limited channels	Surround sound	Increased choice	New technology	Multi-screen displays	Electronics—sending and downloading the digital signal
Pixellated	High definition	Analogue to digital			
Bunny ear aerials	UHF aerials	Multi-functionality			
Analogue	Digital	Greater user choice and control			
	Recording multiple channels				
	Remote controls				

lessons. For example, of the 16 students who completed the questionnaire before the futures lessons, all 16 agreed or strongly agreed with the statement *I like finding out about new ideas in science*. Nearly all (14 out of 16) agreed or strongly agreed with the statements *I think science can be interesting* and *Science is important for New Zealand's economy*. Fewer—11 out of 16—agreed or strongly agreed that *Science is important in my everyday life*. Given the positive perceptions prior to participating in the futures lessons, it is not surprising that no attitudinal gains were evident when the questionnaire was administered after the futures lessons, except that three students ranked *Science is important in my everyday life* more positively than they had done previously.

Similarly, students' responses to how much they had enjoyed the futures lessons did not reveal any clear trends: half the students indicated that they had enjoyed the lessons a lot (8 of the 16) and half had enjoyed them 'a little'. Similarly, half indicated that it was the topic that had been most important and the other half indicated that it was the teaching style. The teaching style was described as 'fun' and 'cool', with specific mention made of how the teacher had included all students in the class discussions (e.g., ‘she talked to everyone’) and summarised discussions on the board (e.g., ‘I like the way she set it out on the board’). It is therefore difficult to disentangle the impact of ‘futures thinking’ as an area of learning, and the new pedagogical approach on students’ engagement. However, it does seem that the nature of futures education in general, and the futures thinking framework in particular, lends itself for a more transactional pedagogy rather than a transmissive one.

Re-visiting the class five months later, Cathy asked the students what they remembered about the lessons they had done with her. She was impressed by the extent of their recall, particularly about some of the broad areas of science that had been discussed (solar panels, network connections, data management, signal recognition). Students were also able to participate in discussions about trends and drivers, giving examples. Perhaps most encouraging was that students recognised that the lessons had been ‘science’ lessons, despite having taken place during classes timetabled for English, with their English teacher present, and with considerable discussion about social implications. Interestingly, some students went on to talk about whether the lessons had been science or technology, and what the differences between these might be. This presents an area for fruitful future development with these students. It also indicates the value of using technological examples to engage students in science—an approach that has long been advocated in curricula and research (e.g., Fensham 1988; Jones and Kirk 1989).

Discussion and Conclusion

The study described above was designed to investigate whether the futures thinking framework could be used to engage a group of normally disengaged, reluctant 13-year-old learners in thinking about science. This was the students’ first guided foray into the world of futures thinking and it was encouraging to see how many of the students not only engaged in the process, but did so enthusiastically. As such, this small case study offers insights into the potential value of structured exploration of possible futures for connecting students’ science learning with contexts in which they are interested. As Lloyd and Wallace (2004) argue, futures thinking can be considered to be an integral part of students’ worldviews, and their futures images constitute prior knowledge that can influence motivation, conceptual development and what is valued as knowledge. Although the focus had not been on developing students’ conceptual understanding about specific science concepts, but rather to engage them in thinking *about* science, the lessons could potentially have been extended to engage students in further learning *of* science.

The pedagogical approach of transaction—where students’ ideas were solicited and then woven into and used to direct whole-class discussion—was not one with which the students were accustomed, as evidenced in conversations with both the students and their English teacher. (In addition, earlier observations of the students’ science lessons indicated that when students were asked questions, the teacher was usually seeking one ‘correct’ answer.) Student engagement was generally high throughout the lessons and some students specifically commented on how they had valued the way their ideas had been included. Taking students' ideas into account also meant that the learning conversations remained grounded in experiences with which students were familiar. For example, considerable time was spent discussing the resistance of future materials to 'tagging' (graffiti)—raised by one of the students in response to a scene in a movie clip of digital road signs—and this was used by Cathy to introduce discussion about materials science. In other words, the interactive, transactional pedagogy enabled classroom dialogue to form around the ideas that were contributed by students. However, the general direction of the conversation was controlled by Cathy. Key to her approach was her clarity with respect to the goals for the discussions—identifying trends, drivers, possible futures and the underpinning science.

Identifying the relevant science was a key goal because futures thinking had specifically been introduced as a way to engage students in thinking about science. Formative interactions were critical in supporting students to explore their thinking and develop their learning in this area. For example, Cathy needed to keep asking questions like 'What science do you need to know about in order to develop…?' While the students likely did not have deep understanding of what they were identifying as science (e.g., how cell phones detect and transmit electromagnetic radiation, or even what electromagnetic radiation is) the emphasis in this case study was on highlighting scientific knowledge as being important for many potential technologies. Further research is needed to investigate how these initial conversations can be leveraged to engage students in learning about specific scientific concepts. For example, Mandi, although situated in an English teaching tradition, was excited about the potential for contextualising science within a futures scenario:

> I can see how you could build a whole science course around futures thinking—use the futures thinking to introduce the science concepts and unpack these in more detail. And maybe even use this kind of course to create greater cross-curricular opportunities.

Unfortunately, while the students' usual science teacher had been curious about the research, his allegiance to a traditional science curriculum meant that he remained unconvinced about the place of futures thinking in a science classroom. Herein lies a significant challenge to the shifts that will be required if science education is to be relevant and worthwhile for students in the future.

While there was some discussion about the similarities and differences between science and technology in Cathy's later visit to the class, these two fields draw on different epistemological assumptions (Jones 2012). A useful extension of this study would be to investigate the impacts of explicitly exploring with students differences in the nature of science and the nature of technology using examples introduced in the futures thinking lessons. A narrative approach to introducing aspects of the nature of science appeared to be well received by the students. While any changes in their subsequent understanding of the nature of science were not evaluated, the interactions did highlight the potential for such narratives to introduce various aspects of the nature of science. For example, the story of the discovery of the liquid crystal phase by Friedrich Reinitzer, an Austrian botanist studying chlorophyll, was used to highlight the serendipitous nature of some scientific discoveries, the need for collaboration and corroboration (Reinitzer approached a physicist for help in confirming his finding), and that innovation often occurs at the intersection between the sciences and technology (a botanist discovered something that was eventually developed into a product by physicists and engineers). Of course, the discussion of these insights was only possible because of the Cathy's content knowledge with respect to both the details of the narrative and relevant aspects of the nature of science. In preparing for the futures lessons, however, she was cognisant of how easy it was to locate appropriate reference materials on the Internet that she could draw on in class.

Another avenue for deeper learning is the values dimension of futures education, which was not explored in this case study in that students were not required to identify and distinguish between possible, probable and preferred futures. However, the values dimension represents an important extension for student learning (see Matthews, this volume), and is offered as a key justification for including futures thinking in school (e.g., Hicks 2003). For example, it is values discourse and decision making that will enable students to become increasingly aware of their own and others' values, and the complexity of decision-making in contexts laden with social, political and economic nuances. This is consonant with Barnett's (2004) exploration of how students can be prepared for a complex world of interrelated systems. He concludes that learning for uncertainty, for what he calls an 'unknown world', cannot be accomplished by the acquisition of either knowledge or skills; the challenge for educators is to prepare learners to cope with, and thrive in, a situation of multiple interpretations. It must also be noted, however, that the multifaceted process of learning about various possible futures can challenge existing thinking and so be unsettling, emotionally as well as cognitively, for individuals (Rogers and Tough 1992, 1999).

What the study does show is the potential of the futures thinking framework to support a transactional pedagogy, and the ways in which it might be modified to suit different teaching contexts. In this case, the purpose was to engage reluctant learners in thinking about science, but there was significant potential to extend this learning to developing students' conceptual understanding of specific science concepts, and/or their values discourse in evaluating alternative possible futures. The incorporation of futures thinking in science education continues to be relatively un-researched, and we hope that the study presented here offers encouragement to science teachers and science education researchers to delve more deeply into identifying the possibilities that might exist. Indeed, as educators of the next generation of global citizens and leaders, it may be irresponsible to do otherwise.

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Revealing Questions: What Are Learners Asking About?

Amy Seakins

Introduction

Questions are clues. Asking questions shows curiosity, interest and intrigue on the part of the questioner. As learners attempt to access information, understand new content and form connections to their existing ideas they ask questions—questions are indicators of active learning. This chapter focuses on the questions asked by learners around science. The first section addresses literature around question-asking, and the second discusses data from a study into learners' questions within a museum.

New trends in educational theory and curricula have placed more emphasis on learner questioning. Inquiry-based learning in particular allows more space for students to explore their own questions and investigate their own areas of curiosity. With a focus on active participation in their own learning, students are encouraged to ask questions as well as offer answers to the questions of the teacher. Questions are particularly pertinent in science education. Science is described in the first line of the Australian National Curriculum for Science (ACARA 2013) as providing "an empirical way of answering interesting and important questions about the biological, physical and technological world". A parallel movement in science communication and learning in out-of-school settings has placed emphasis on encouraging non-experts to ask questions of experts. Rather than traditional one-way transmission of information, more recently two-way dialogue is encouraged, with questioning and discussion between non-experts and experts.

Questioning is endless, and happens throughout our lives. Questions arise in all environments and over time, and are not only confined to classrooms, but occur in museums . and online environments, at work, during conversations with friends and family, and they can be triggered immediately or much later after the original

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experience. A focus on learner questions, therefore, encompasses the notion that learning occurs across time and in different environments, and maintains the focus with the learner themselves, and their self-directed learning.

Although the study of questions is by no means new, in this chapter I argue that there is more that questions can tell us, and that exploring the questions learners ask as they come across new experiences can reveal much about the learner, and their own understanding, attitudes and interests. Looking at the progression of questioning can reveal the impacts of a particular learning experience and, therefore, may be of use as an assessment tool. An emphasis on learner questions also brings the learner into the forefront of their own experience and has implications for the way that learners can shape and help develop education experiences in, for example, classroom lessons, museum activities and online environments.

A focus on questions can therefore tell us much about the learner, compared to only focusing on the answers learners provide to the questions we ourselves pose as educators. The following section explores questioning in the classroom and what it might reveal about learners. The chapter then turns to questions asked when learning outside the classroom, in places such as online Ask-A-Scientist sites, and in museums. The chapter concludes by discussing a study into question-asking at the Natural History Museum, London.

Questions in the Classroom

The idea of a ‘question-driven classroom’ was championed by Shodell (1995), triggering a new wave of interest in student questions. Although researchers have raised concerns about the low number of questions asked by students in the classroom (Dillon 1988), new movements in science education have focused on using questions to drive students’ learning. Early work from the University of Waikato recognised the value of children’s questions to teachers and explored how students’ ideas and questions could play a significant role in their science education (Biddulph et al. 1986). In particular, students have been encouraged to answer their own questions through open-ended learning activities, inquiry-based learning and problem-based approaches (Abrandt Dahlgren and Öberg 2001).

Abrandt Dahlgren and Öberg (2001) studied the questions generated by undergraduate students during a ten-week problem-based introductory course at a Swedish university. Within this programme, a problem-based approach was defined as involving “formulating important questions surrounding a concrete environmental problem” (p. 266). This quotation highlights the prominence of question-asking in problem-based approaches in science education. The researchers analysed diary notes written by the students, looking at the structure and content of the questions asked. Students moved between the five identified types of questions, including encyclopaedic, meaning-orientated, relational, value-orientated, and solution-orientated. Switching between question types suggests that the students may be undertaking a meaningful, deep approach to learning (as defined by

Bowden and Marton 1998), rather than a surface approach to learning which may only make use of encyclopaedic questions to gain factual information.

The presence of deep and meaningful learning in questioning is encouraging, as it is deep levels of learning that are often sought in educational interventions. Such ‘deep learning’ is where students try to make sense of and grasp the phenomenon as a whole, make connections between different aspects and concepts, challenging and relating new information to previous knowledge. This type of learning is long-lasting and connects with other experiences and information (Chin and Brown 2000). Surface approaches to learning, in contrast, do not include such strong links to other information and ideas, and therefore knowledge is less likely to be integrated and memorable. Question-asking within problem-based approaches may therefore provide an opportunity for a deep and meaningful type of learning.

Christine Chin and colleagues also investigated student-generated questions and their relationships to deep or surface approaches to learning. Their study involved six students aged 13–14 as case studies, and over the course of a nine-week chemistry module, observations, field-notes, interviews and learning journals were used to study the types of questions asked, and how these related to learning (Chin et al. 2002). There were relatively fewer ‘wonderment’ (high-level) questions asked (14 % of total questions), compared to basic (low-level) questions. Wonderment questions supported deep learning as they led to discussion, prediction and hypothesising, whereas basic questioning gave little opportunity for discussion. The findings of Chin et al. suggest that teacher-directed activities provided fewer opportunities for deep-level wonderment questions, compared to activities where students worked through problems and where inquiry was encouraged.

In a later study, Chin and Chia (2004) used question-driven problem-based learning to investigate the types of questions 13–14-year-old students were asking during problem-based work in biology classes. They focused on the inspirations behind students’ questions, the types of questions students asked when in groups and individually, and the implications for knowledge construction. Additionally, they looked at the evolution of questions and how questions may show progress in students’ thinking. Four sources of inspiration for questions were identified: cultural beliefs and folklore, advertisements and the media, curiosity from personal encounters or observations, and issues from previous lessons at school. Studying the inspiration for questions allows us to see the possible sources of any preconceptions or misconceptions, which might affect the questions asked. Sources of questions also highlight where connections may be made to previous knowledge and, therefore, where deep learning might be encouraged. In this way, questions are a valuable source of information for teachers and educators.

Earlier work investigating student-generated questioning was carried out by Alison King. One study with undergraduates looked at the effect of training students in asking questions, and the role of guides for questioning, on students’ achievement and knowledge construction. It was found that students who had been trained in using guided questions during a reciprocal questioning exercise asked more high-level, critical thinking questions, gave more elaborate responses, and demonstrated higher achievement in a post-test compared to students in control groups who had unguided or no question training (King 1990). In work involving younger students, King (1994) compared students' interactions and post-test knowledge maps of those trained in two types of questioning. The first group, trained to ask questions not only about the content of the lesson they had just received but also to relate this to prior knowledge and experience, drew more complex and advanced knowledge maps, compared with the second group who were trained only in question-asking about the lesson. Further, both the groups trained in questioning asked more higher-level questions (including integration and comprehension) compared to a control group with no question training. Similar findings were reached in a later study with students (King 2002), showing that higher-level question prompts could encourage higher-level cognitive processing, that is, making inferences, conclusions, generating hypotheses, comparing and evaluating.

Research on student questioning in science education therefore shows that encouragement and training in question-asking can lead to deeper learning. Questions have also been used to provide information on the source of student inspiration, and therefore motivation for learning, as well as pointing to potential sources of misinformation and misconceptions. While some of this work predominantly focused on the level of students' explanations and the knowledge construction taking place, student-generated questions were a prerequisite of the explanations given and the type or level of questions were shown to affect the explanations given and the learning taking place. Therefore, studies have shown that a focus on questions, rather than explanations alone, might have promise for understanding students' learning and encouraging deeper engagement, as well as pinpointing areas of interest for students and potential misconceptions. The chapter now moves to focus on questions that learners might ask outside the classroom, exploring how these questions might reveal how individuals are developing their understandings and identifying differences in their areas of interest.

Questions Outside the Classroom

Research in science education has provided much insight into why student questions might be important and useful. However, we don't only ask questions when we are at school. The majority of questions asked will be asked outside school, throughout our lives. With Internet search engines at the tips of our fingers and with us all the time on our mobile devices, questions are 'googled' constantly. The word 'googleable' has even made it into the Oxford English Dictionary. It is increasingly easy and common to ask questions about things we encounter through our daily lives and gain instant information or feedback. Other examples of where learners are able to ask questions and participate in inquiry around science outside of school are discussed by Selwyn and Cooper (this volume).

Learners have an increasing number of opportunities to voice their own questions in science learning environments outside the classroom. Here I will cover two contexts in particular—museums . and Ask-A-Scientist websites—but these are just two examples of a whole suite of learning opportunities available to us as we engage with science throughout our lives. Many of the assumptions on which the work in formal education is based are also relevant to museums and out-of-classroom settings, and the pedagogies and learning opportunities have been studied (Stocklmayer et al. 2010), highlighting the relevance and overlap work in these two fields may have, and ways in which they can be integrated. Investigating question-asking outside the classroom in a similar way to how it has been investigated within schooling may give further opportunities to link classroom activities to field visits, for example, and promote integrated holistic learning, as opposed to visits to museums being one-off, dislocated experiences. Finally, as the majority of the research into learner-generated questions has been focused within schools, looking at contexts such as museums allows us to study questions asked by adults, who, of course, are not still at school but are very much still learning.

Following a period of concern about public attitudes towards science and scientists, the way in which science was presented to the public was re-examined, leading to an influential report by the UK House of Lords Science and Technology Select Committee entitled *Science and Society* (2000). This report called for public engagement with science using a more active and two-way model of science communication than had been the case before. Learning science outside school therefore became much more focused on the learners, who became active participants in their own learning rather than submissive vessels to be filled with knowledge. Part of this vision was to create active learners who engage with science, including asking questions of science and scientists, and taking part in dialogue and debate around scientific issues. Questions became important in the world of public engagement with science and learning outside the classroom and, subsequently, research focused on the nature and topic of those questions.

Ask-A-Scientist Websites

In line with the expansion of online learning environments, websites have emerged enabling students to ask questions to scientists or other experts. These websites are one way in which information and communications technologies (ICTs) are playing a part in science education, connecting students with scientists and scientific research and enabling learners to develop media literacy (see Shanahan, this volume). For example, 'I'm a scientist get me out of here' in the UK (imascientist.org.uk) has been running annually since 2008. It is an online event supported by the Wellcome Trust where students can chat to scientists online, ask them questions, and vote for the scientist they would most like to win a prize of £500 to communicate their science. These types of websites are useful fora to study learner-generated questions—questions are posed to experts in a relatively anonymous and free-choice way.

Questions asked by 9–18-years-old school students on another Ask-A-Scientist site (MadSci) were analysed in order to uncover student interests within different science topics (Baram-Tsabari et al. 2006). The researchers found significant differences between girls' and boys' interests in different topics. Girls asked more school-related questions than boys, that is, questions that were sparked by something the students had covered at school. In addition, the frequency of asking school-related questions increased with age (Baram-Tsabari et al. 2006).

A further study on the same Ask-A-Scientist site revealed gender and age differences in student interests, using question data collected over a decade (Baram-Tsabari et al. 2009). Female students asked more questions than male students although the gap decreased with age. The boys and girls showed different levels of interest in different scientific topics, providing more evidence that boys prefer physics-related subjects and girls show more of an interest in biology-related topics. Comparisons between different countries showed that female participation in asking questions on this site was found to be correlated with the difference between girls' and boys' achievement in science, but not correlated to levels of gender equity within the participating countries.

This finding demonstrates how student question-asking outside the classroom could be a valuable tool for investigating interests and attitudes around science over a long period of time, and over a wide geographical area. The Relevance of Science Education (ROSE) project, for example, compared interest in different scientific subjects of students aged 15 from 40 different countries. Students from countries who were classed as less economically-developed were more interested in a wider range of science subjects than those students in more economically-developed countries (Sjoberg and Schreiner 2010). The challenge is, therefore, how to create a context in which learners are stimulated, interested and able to ask questions about science. Questions asked by students could therefore be a useful resource for teachers aiming to gauge attitudes to a new subject, or for educators developing new programmes for museums, science centres and other events such as science festivals.

Museums

Museums aim to make their visitors think, wonder and ask questions, and exhibits and text are designed to challenge and engage visitors. Researchers have suggested that activities that focus on the learner and the questions they arrive with, and that encourage them to ask more questions as a result of their experiences, may increase the levels of engagement and learning on museum visits (Griffin and Symington 1997). However, despite some work into visitor engagement with thought-provoking text labels or displays, there has been little work into what questions visitors ask at museums, and particularly how museum staff and experts could support the generation of visitor questions. There has been research into learning conversations in museums, and within these conversations there will almost certainly be some learner-generated questions (such work includes Ash 2003; Leinhardt et al. 2002; Sanford 2010; Zimmerman et al. 2010). The work on museum visitor conversations follows the shift from constructivist approaches in museum learning to socio-cultural perspectives, where learners are studied as part of a social context, constructing knowledge together rather than as individuals. The vast majority of museum visitors come to the museum with at least one other person, often in groups, and therefore conversations, including questions, and social contexts will be relevant in most museum experiences.

Exhibits and museum displays are designed to engage visitors with the concepts presented, prompt questions, and challenge thinking around the content. One of the ways in which museums . might support this kind of behaviour is by using thought-provoking exhibit labels that prompt visitors to think about the exhibit and talk amongst their accompanying group. Hohenstein and Tran (2007) investigated the impact of adding a thought-provoking question to science museum exhibit labels on the conversations of groups of visitors. They found that for some exhibits, adding a question to the existing label prompted more questions and explanatory talk in visitor conversations. This finding suggests that with the right prompting in the form of questions on exhibit labelling, visitors can potentially generate questions and explanatory talk about exhibits, both of which are important components of inquiry and learning conversations.

Elsewhere, researchers in San Francisco were also investigating how to prompt inquiry behaviour amongst exhibition visitors. Josh Gutwill and Sue Allen at the Exploratorium attempted to devise a programme whereby visitors could develop their questioning, exploration and investigative skills through ‘inquiry games’, which were played by groups of visitors while engaging with museum exhibits (Allen and Gutwill 2009; Gutwill and Allen 2010). By identifying inquiry skills from the literature and developing a programme designed to support families using these skills while interacting with the exhibits, greater inquiry behaviour was observed among the groups compared to control groups. Inquiry behaviour included time spent engaging with the exhibit, the numbers and durations of questions or statements, and interpretive talk, both individual and collaborative. Although other measures of inquiry behaviour increased following training in the inquiry games, the number of proposing actions did not show any significant change. This finding indicates that families did not ask any more questions after inquiry training compared to before. However, the duration of proposing actions and coherence of investigations increased after participation in the games, suggesting that families formulated more sophisticated or complex questions that were related to prior and future investigations. Thus a focus on the actual questions visitors are asking at exhibits is crucial to understand any impacts on their learning—just looking at numbers of questions gives a limited picture of what is going on. Through studying what learners actually ask, we can start to explore some of their attitudes, understandings and interests, and use this information to shape the development of future learning experiences.

Questions as Interest

Arguments for a focus on learner questions have been outlined above, including the potential to provide a useful insight into learners' interests, motivations and knowledge construction, and into the impacts of a given intervention. Support for this argument can be drawn from work in educational psychology that looks at what constitutes interest and how it is related to learning and motivation (Krapp 1999; Renninger et al. 1992). Interest is "a content-specific motivational variable that can be investigated and theoretically reconstructed" (Krapp 2007, p. 5). Interests are content-specific, that is to say, explicitly tied to one 'object of interest', an experience, concrete object, area of information or idea. Interests are linked to motivations, drivers of future behaviour or thoughts, usually to find out further information about the object of interest (Krapp 2007). Interests are outcomes of interactions between the person and the object of interest, in a suitable environment or context (Hidi and Renninger 2006). Therefore, interests are strongly linked to motivations, positive emotions and knowledge about the interest object, and drive questions as the individual strives to find out more:

> a person who is interested in a certain subject area is not content with his or her current level of knowledge or abilities in that interest domain. Rather there is a high readiness to acquire new information, to assume new knowledge and to enlarge the competencies related to this domain. (Krapp 2007, p. 10)

Looking at questions as predictors or outcomes of the appearance or growth of interests not only requires an explanation of what constitutes an interest, but also an exploration of interest development. Krapp (2007) discusses a three-stage model of interest development in his person-object theory of interest. He argues that initially situational interests are triggered by external stimuli, following which they then may last during a phase of learning. If they are significantly engaging, the situational interest then becomes an individual interest, which is enduring and incorporated into the person's beliefs, goals and actions by a process of internalisation. The four-phase model of interest development, posed by Hidi and Renninger (2006), builds on Krapp's earlier work. The four phases identified were: triggered situational interest, maintained situational interest, emerging individual interest, and finally well-developed individual interest. The additional emerging individual interest stage is particularly relevant to this work as it is argues that this is the phase in which learners begin to formulate their own curiosity questions about the interest. In their paper describing the four-phase model, Hidi and Renninger (2006) emphasise the importance of external support in the development of the early stages of interest. This emphasis on external support highlights the potential that other people, such as teachers, parents and museum staff, may have in supporting interest development in visitors. Questions may be more numerous or complex in some phases of interest development compared to others but will still provide clues as to which interests are present and what stage the development of interests has reached.

France and Bay (2010) looked at student questions as an indicator of interest. The questions of 399 Year 13 students (aged 16–18) in New Zealand were collected using questionnaires in order to explore the interests of the students and their reflections on a day at a biomedical research centre. Students took part in a number of activities as part of their visit, including three practical workshop sessions and a small group discussion with two research scientists. Through two questionnaires, one administered before and one after the visit, France and Bay were able to compare the questions students intended to ask the scientists they met with the questions they considered the most interesting or useful that they had heard asked during the day. This comparison gave an insight into the views of students on science and scientists, and also their reflections of the day. The predominant finding of the study was that students showed an interest in the scientists themselves, asking more personal questions about their life and experiences, than would have been expected from the pre-visit questions. Students also made personal connections to the scientists they met, asking questions about the scientists' career histories and attitudes towards their jobs, as they themselves tried to explore their own science identities and consider their own futures. France and Bay argue that such questions are a tool students can use for cultural border crossing: through exploring their interests they can broaden their science literacy and explore the scientific research culture at the biomedical centre.

The argument for using questions as indicators of interest is not without its limitations. Without following up data collected on questions asked, researchers cannot be sure that these truly reflect the interests of the individual learner. A study of an online environment attempted to control for some of these problems by separating school-motivated questions from spontaneous questions, arguably those prompted by the students' own personal interests (Baram-Tsabari et al. 2006). However it is still not known whether these spontaneous questions are rooted in a long-term, genuine and sustained interest of the individual or, perhaps. the result of hearing something on television or from conversations with friends, sparking a more immediate, short-term, topical interest. Situational interests are primarily caused by external factors—a work or social situation, for example. Individual interests emerge from situational interests and are long-lasting, stable interests in which motivations to find out more about the object of interest are related to the object itself or its associated knowledge domain, as opposed to work- or context-specific motivations. In the study above, school-motivated questions might be classed as indicating situational interests, whereas spontaneous questions could be outcomes of individual interests. Both types of questions are, therefore, important, as those indicating situational interests may indeed form the basis for individual interests in the future. Therefore, a study into questions holds promise for revealing interest development as well as areas of interest.

Questions in the Natural History Museum, London

Museums aspire to be inspirational places, often full of new, exciting and rare objects, and as such are places where questions are sparked, asked and answered. Museums, therefore, are fruitful places to study questions, exploring visitors' learning, investigating what grasps their interests, and gaining indicators of impacts of museum experiences. Research at the Natural History Museum, London, undertaken by the author (Seakins 2014) used visitor-generated questions as part of a study into the impacts of interactions between visitors and scientists from the visitor's perspective. The questions formulated by visitors to ask scientists were studied in order to explore any impacts of the session on areas of visitor interest, and in particular their interest in, and therefore connection to, the scientists themselves. In this study, the learners were a diverse group of people—adult visitors and A-level biology students aged 16–18.

Studying Visitor Questions

Two elements of the Natural History Museum's educational programme enable visitors to meet some of the museum's scientists and were sites of data collection:

- Nature Live events: daily half-hour sessions where one museum scientist, accompanied by a science communicator ('host'), discusses their research with visitors.
- A-Level days: A-level biology students (aged 16–18) attend a behind-the-scenes tour with a museum scientist, followed by a Nature Live event.

Nature Live events are half hour events scheduled every afternoon and involve museum scientists speaking about their areas of research, recent projects or field visits, or areas of the collections in an informal discussion format. Events are hosted by one of a team of five Nature Live facilitators, all of whom have degrees in science communication. Scientists often bring along specimens from the collection or research equipment, show photographs and diagrams, videos from their fieldwork or even bring along samples for the audience to taste, such as edible insects or chocolate. The audience is encouraged to get involved in the session, ask questions, make comments, answer questions, handle specimens, and vote when given options by the host or scientist. A-level behind-the-scenes days are programmed especially for biology students (aged 16–18), including a behind-the-scenes tour with a scientist into laboratory, collections or research spaces, where the scientist discusses their research with the students. The A-level day also includes a special Nature Live session and a workshop on taxonomy.

The study involved a pre-and-post interview research design. Visitors were interviewed before and directly after the session, and then again six to eight weeks later. One or two visitors, depending on whether they were visiting alone or in a pair, were recruited for data collection for each Nature Live event. In total, 81 visitors from 52 events spread over 6 months were interviewed. Groups of four students were recruited for each A-level day. In total, 38 students from nine A-level days took part in the study (extra students were recruited as some were absent on days of follow-up interviews). Semi-structured interviews established what visitors felt they learnt or got out of the session, what had surprised them, and what

Table 1 Summary of data collection methods for visitor question data

Time period	Data collection method
Pre-session	Pre-session interview question: "What questions would you like to ask the scientist, or what things would you like them to speak about?"
	Data from study participants only
In-session	All questions asked by all audience members were recorded in field notes and checked against filmed recording of the session
	Study participants were asked in post-session interview: "Did you ask any questions? What did you ask about?"
	Data from audience in general and study participants
Post-session	Post-session interview question
	"If [scientist's name] were to come and sit down with us now, what questions would you like to ask them, or what more would you want them to talk about?"
	Data from study participants only
Post-visit	Post-visit interview question: "Have you thought of any other questions you might like to ask the scientist you met, if you were to meet them again, or anything more you might like to hear about?"
	Data from study participants only

questions they might like to ask, or would have liked to ask, the scientist. Table 1 indicates where and how data on visitor questions were gathered. As is evident from the table, study participants were asked about their questions in interviews, whereas the questions of the audience in general were recorded during the session.

Interview transcripts were analysed using a thematic coding strategy searching the transcript for the key themes which were then coded and arranged in a frame. This qualitative analysis provided the basis of the majority of a larger study (Seakins 2014). Further analysis focused on the questions visitors formulated to ask the scientist before the session, during the session and afterwards. Some visitors and students asked more than one question and some could not think of a question, explaining the differences in frequencies of questions asked. Questions from interviewees only were collected from the pre-session, post-session and post-visit interviews, whereas questions from the entire audience were included in data collected during the session.

Analysis of the topics of visitor questions points to areas of interest and curiosity held by the visitors. Changes in these topics from before to after the sessions indicate an impact on interest as a result of meeting a scientist. Question topics were coded based on the approach used in the study mentioned earlier by France and Bay (2010). Categories included those about scientific processes, science content, the scientist themselves and their career history, and social and ethical decisions in science (see Table 2). Questions were identified in interview transcripts and field-notes taken during the session itself. Questions were defined as an expression of interest to find out more information, for example, preceded by 'I'd like to hear more about…' or 'I would have been keen to ask…' Each question was coded under one category only—the category most applicable to the question—although it

Table 2 Question topic categories

Category	Description	Examples	Total occurrence
Personal	Questions about the scientist themselves, their career history and life as a scientist. Asking for information on what scientists might do day-to-day, how the scientist chose and got to their job in terms of studying, about the individual scientist and what they think about different aspects of their job	And what kind of things did they, like, study? And when did they make the decision that that was something they wanted to like specialise in? Also how did you become, go from a scientist to, like, when did you decide to work in the museum? And not just in a lab?	163
Science information	Questions about scientific concepts, facts and phenomena. This is usually related to the topic of the meet-the-scientist session, so the area of expertise of the scientist. About factual scientific content or concepts	What kind of algae is there—it all looks pretty algae-y to me, but is there colourful algae, living, like algae that eats things? Can you notice, have the ostracods changed at all over [time], from the fossils to the present day?	407
Science process	Questions about scientific research, how science is carried out and techniques and methods. May be to do with accuracy, taking samples, using equipment or techniques, or about the process of publishing or gaining consensus about scientific findings. Anything about the process or procedures in science	I would like to hear how people classify new animals/organisms, and the criteria for doing so. I have one question, that's could you ever find out how much a dinosaur fought from its bones?	110
Social and ethical issues	Questions about broader issues in science and scientific research relating to science and society, the future and potential implications, culture and moral and ethical dilemmas. Often about the wider implications of research, how it relates to society and culture, relating to funding, differences in opinion, opposition to science, or societal or political decisions which must be made in relation to research	Is there any opposition to the work that you are doing, you know, if someone wanted to build on the site of a plant which was at risk? And why it was important for us to actually know, well what's going to be the future, what's going to happen as a result of this. Are we going to try to create, is it all to do with trying to create life?	48

is recognised that often questions might fit into two or more categories. The proportions of questions asked on each topic were compared; in particular the changes in the proportion of questions that were about the scientist, their work and career history, were investigated, to examine whether visitors and students were identifying more closely with the scientist as a result of the interaction.

Following a pilot study, the categorisation used by France and Bay (2010) was adapted and adjusted for the Natural History Museum context, removing 'Nature of Science' as no questions were asked in this category. The absence of questions about the nature of science is interesting and may have been due to the differences in activities around which questions were generated. In the France and Bay study, for example, students took part in experiments and workshops alongside talking with the scientists. In the Nature Live events studied at the Natural History Museum, visitors and students took part in a talk/discussion rather than doing any experimentation themselves. The difference between the two studies suggests that the type of activity may have implications for the questions asked and, therefore, the interests that develop.

The coding is detailed in Table 2. Categories were added or adapted as more questions were coded, to ensure that they accurately reflected the types of questions that were being asked. Two second coders recoded all questions (half each), using the category descriptions and framework in Table 2. The percentage agreement achieved between coders for initial coding was 85.1 % for the A-level student question data, and 83.1 % for the adult Nature Live question data. Coders discussed any questions they had categorized differently, and reached an agreement on one code through discussion.

Trends in Visitor Questions

The proportion of questions on each topic was calculated for each time slot so that the relative proportions of questions on each topic could be compared over time. This strategy allowed for the trends in relative interest in each topic to be explored. Data from adults attending Nature Live events are shown in Fig. 1, and for A-level students in Fig. 2. To illustrate where the most questions were asked, the total number of questions is provided for each data collection point (pre-session interview, in-session, post-session interview and post-visit interview).

Taking the adult questions first (Fig. 1) two key trends can be observed. First, although interest in science .information, the conceptual and factual subject of the session, peaks during the session itself, relative interest in the scientific topic decreases following the session. In contrast, relative interest in the scientist and personal aspects about their career and job increases as a result of the session and over time. Two months after the museum visit, visitors are asking the same proportion of questions about the scientist as the scientific topic, whereas before the session, questions about the latter had been much more abundant. These trends

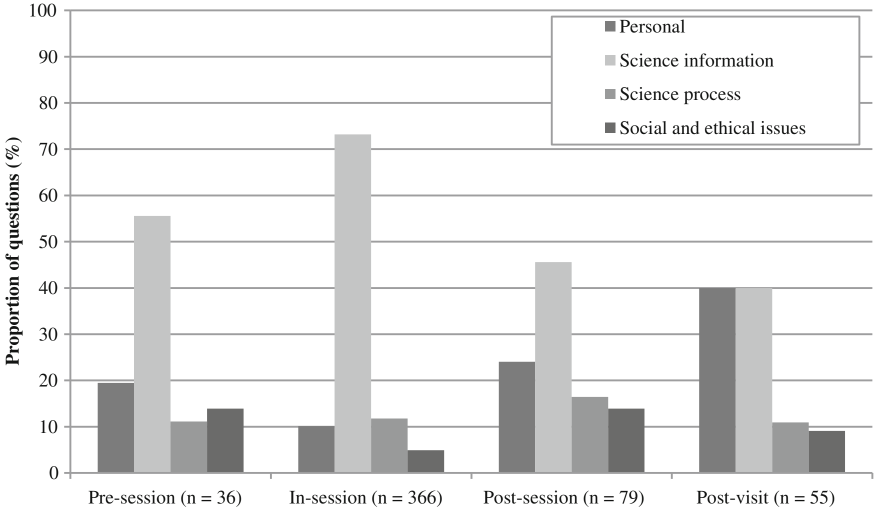

Fig. 1 Questions asked by adults in Nature Live events (n = 536)

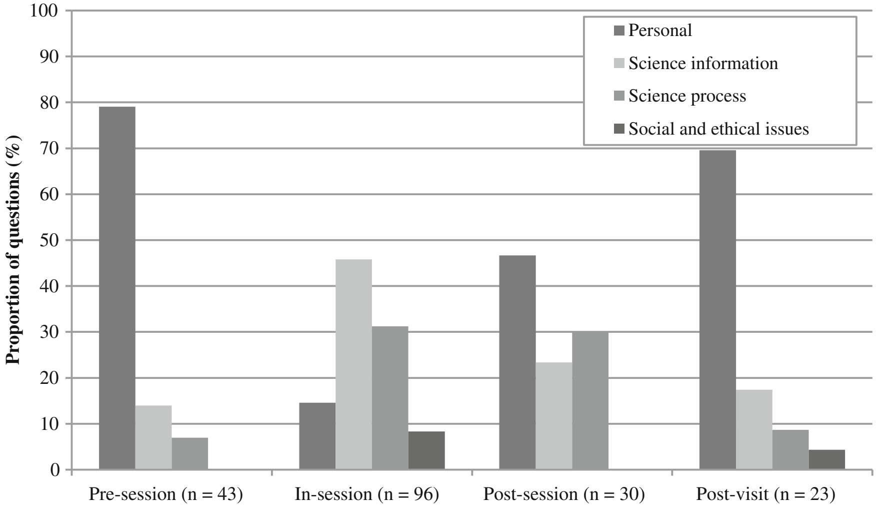

Fig. 2 Questions asked by students attending A-Level days (n = 192)

therefore suggest a long-lasting impact on interests of the visitors, with the scientists themselves becoming relatively more interesting than before.

A-level students also demonstrate changes in their interest profile over the period of the study (Fig. 2). Students entered the session with a high level of interest in the scientist themselves; they were focused on asking many questions about the life of the scientist and their career path. This finding is not surprising given the age of the students, who are themselves soon to be making decisions about university courses and future jobs. The event they were due to attend at the museum is called ‘a day in the life of a scientist’, and therefore they are expecting, and likely hoping, to hear about the work and career of a scientist. Interestingly, within the session, the interest profile was very different to that predicted by the pre-session interview data. Students asked more questions during the session about the scientific information and the processes involved in the science research than might be expected given the questions they arrived with. There were relatively few questions asked about the scientists themselves. Immediately after the session the number of questions about the scientist increases once more, with proportions of questions on each topic returning towards the pre-session profile by the time of the post-visit interview 2 months after.

Issues and Implications

An examination of the questions visitors generate to ask scientists has revealed trends about the audiences, their interests, and the impacts of the session on the learners. The differences between the adults and the A-level students in the proportions of questions asked in the pre-session interviews on different topics indicate that the two types of visitor studied begin with very different interests. This is useful information for the museum’s programme developers to be aware of, and will aid targeting of session content to the needs of the different audiences. It also seems that within the sessions themselves audiences are not asking the original questions they came with, perhaps due to the set-up or format of the session or because something else sparked their interest during the event itself. An awareness of the interests of the audiences before they enter the event will enable hosts to allow for any pre-existing interests to be nurtured, as well as sparking new directions of interest. A comparison of the differences between the pre-session and post-visit questions for both adults and students suggests that the meet-the-scientist sessions at the museum are more impactful in terms of interest for adults than students. An alternative explanation might be that adults are more dynamic and changeable in their areas of interest than students aged 16–18. The differences in the proportions of questions are greater when comparing adults’ pre-session and post-visit data than for students, which suggests that adults have changed the areas they are interested in as a result of meeting the scientist.

Looking at question-asking over time indicates that the adults attending Nature Live events experienced the sparking of situational short-term interest by meeting the scientists, and that they had maintained these interests beyond the immediate experience and, therefore, may be developing a longer-term personal interest in the people behind the science. Following work in educational psychology into interest development (Hidi and Renninger 2006; Krapp and Prenzel 2011) it could be suggested, therefore, that the questions posed in post-visit interviews are evidence that the adults have developed a sustained interest in the scientists as well as the scientific information they heard about, and that this interest may be something they continue to pursue in future. This would be a very promising impact of the museum's education programme. Questions reveal areas of interest and troublesome points in the mind of the learner, but also indicate the progression of learning as well as interest development.

Using the analytic frame originally developed by France and Bay (2010) enabled the questions to be coded according to topic of interest. The framework was adapted slightly for the purpose of the museum study to account for differences in the experiences of the learners, in this case the adult visitors and A-level students attending meet-the-scientist sessions. The analytic framework proved to be a useful tool to code the questions of the learners and could be adapted for use in classrooms and other learning environments. Questions could play a role in assessment, revealing how learners are developing interest throughout their education and indicating areas of misconception or misunderstanding. Coding of questions over a period of time could enable tracking of the progression of students over the course of a term or year, for example. I believe there is much potential in the incorporation of the analysis of questions into current education practice.

Looking at the questions learners ask might provide clues as to how to set the scene for stimulating question-asking within classrooms, museums, . websites, and other learning environments. How might education contexts and activities promote curiosity so that learners ask questions of the information they encounter? Could training students in question-asking extend learning experiences further in settings such as classrooms and museums, as seen in the work of King (1990, 1994)? Facilitating and encouraging learner questions may be a way in which educators might stimulate student engagement with science, and a way of keeping track of, and up to speed with, changing and developing interests (see Simon and Davies, this volume). Further areas that would be useful to research are levels of questioning in out-of-school contexts, for example, to examine where museum exhibitions might play a part in stimulating deep-level learning and to study how long that learning might last. The study presented here from the Natural History Museum suggests that audiences of Nature Live events are diverse and arrive with many different areas of interest and, therefore, questions. More detailed exploration of the differences between individuals' questions would be useful in pinpointing differences between cultures, gender, ages and backgrounds. Understanding this diversity in more depth would be of value to educators who have the difficult task of creating stimulating environments for a broad range of learners to ask their questions and develop curiosity, while managing expectations and hopes in situations when not all questions might be answered immediately.

Conclusions

I have argued that a focus on the questions learners are asking reveals much about their prior conceptions, interests, inspiration, motivations and development, and could be utilised more within education. Consideration of 'what's in it for the learner' requires attention to what the learner is motivated by and interested in finding out, which affects the questions they formulate. What are students asking their friends as they leave the lesson? What are visitors to a museum googling on their phone on the train journey home? What are children asking their parents when they get home from school? What are university students wondering as they catch the bus back home from the campus?

Research in the Natural History Museum, London, has demonstrated how visitor-generated questions can reveal much about the interests of visitors and the impacts of events and experiences on those interests. Building on the work into student questioning from science education, and interest development from educational psychology, the study of questions might just give us new insights into the minds of our students and learners.

> Learn from yesterday, live for today, hope for tomorrow. The important thing is not to stop questioning. (Albert Einstein)

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The Potential of Digital Technology for Science Learning and Teaching—The Learners' Perspective

Neil Selwyn and Rebecca Cooper

Introduction

Digital technologies are now an integral part of education. Students and their teachers have unprecedented access to information and communications through a variety of digital devices. Classrooms and other learning spaces are awash with digital resources, and a growing amount of learning and teaching is conducted on a 'virtual' basis. Having adapted to computers and the internet throughout the 1990s and 2000s, schools in the 2010s are facing 'new' technologies in the form of social media, wireless connectivity, cloud data storage, and (not least) personalised and portable computing devices such as smartphones and tablets. Education debates are replete with slogans such as 'twenty-first century skills', 'flipped classrooms', 'personal learning networks', 'massive open online courses' or 'MOOCs', 'bring your own device' or 'BYOD', an 'iPad for every child' and so on. It is difficult to talk about contemporary education without *some* reference to digital devices and digital practices.

Much of the imperative for this 'digital turn' within education is seen to derive from the changing nature of students themselves. The popular (but crude) notion of the 'digital native' reflects the changing nature of current generations of students and their technology-saturated lifestyles (see Thomas 2011). With many primary school pupils having been born into a world of touchscreen tablets and 'Wi-Fi', the need for educators to make more extensive and more efficient use of digital technology is rarely questioned. As Whitby (2013, p. 65) argues, "for today's young people technology is more than simply something you use for fun or novelty, it is an integral and natural part of life". As such, it is increasingly assumed that digital technologies are a fundamental element of schools and schooling. As Whitby concludes unequivocally, "technology can't be seen as an add-on or a 'nice to have'—it is essential, like school buildings, electricity and water" (p. 133).

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Despite this rhetoric, the realities of digital technology use in schools have remained inconsistent over the past 30 years or so. Indeed, it could be concluded that while digital technologies have promised much in the way of educational improvement and innovation, they have—to date—delivered much less (Cuban 2001, 2013). Levels of digital technology use continue to vary considerably between and within schools, with examples of 'cutting-edge' innovation and 'best practice' obscuring the routine 'implementation' of mundane digital practices and pedagogies. The perennial 'problem' when making sense of the relentless hyperbole surrounding educational technology is that there are few tangible indications that significant technological shifts are *actually* taking place on a substantiated system-wide basis. All in all, the use of digital technologies in education is often portrayed as a case of technology-fuelled optimism failing to be realised 'on the ground'. It therefore makes sense for us to approach the potential of digital technology for science learning and teaching in cautiously optimistic—if not circumspect—terms.

This chapter therefore offers a suitably tentative overview of the impact of digital technology on science learning and teaching. While there is an extensive literature on schools and digital technology, there are a number of issues and arguments specific to science education that merit further consideration. This chapter considers the specific nature of science education as a site for technology-based learning and teaching. As such it considers the following questions:

- Just how is it that digital technologies are seen to offer a possible means of addressing the problems and issues associated with contemporary science education?
- How does this potential correspond with the realities of learners' uses of digital technology to learn science?
- Most importantly, what needs to be done to better fulfil the undoubted potential of digital technology for the learning and teaching of science?

Science Learning and Teaching: Issues and Problems

So what are the main 'issues' and perceived 'problems' facing contemporary science education that may be addressed by digital technologies? Key here is the long-standing apparent disengagement of students from 'traditional' science teaching and STEM (Science, Technology, Engineering and Mathematics) subjects as they progress through the school system. Numerous studies around the world provide evidence of the decline of student interest in the academic study of science. For example, Bennett and Hogarth (2009) report steadily decreasing proportions of US high school aged students identifying with, or having any interest in, pursuing science. Another US study reported 43 % of eighth grade students expressing no desire to continue with science (Gonzales et al. 2008). Similarly, many Australian students perceive the science they are taught to be of little interest or relevance to them, while also finding teaching methods offer little opportunity for challenge or engagement (Goodrum et al. 2001). With fewer students all over the world—especially girls—expressing an interest in pursuing careers in science (Sjøberg and Schreiner 2012) and strong indications that "most students tend not to learn science content meaningfully (i.e., do not integrate it into their everyday thinking)" (Aikenhead 2006, p. 27), science educators are now acknowledging the need to reconceptualise 'science education', and to explore factors that positively impact children and young peoples' engagement with science (see Osborne and Dillon 2008).

These reconceptualisations have tended to focus on fundamental questions of what science education is, what science education is for, and how science education should take place. The response is multi-pronged. First there have been widespread calls for a shift away from science education solely as preparation for higher levels of science scholarship and/or eventual entry into science-related careers. Instead, it is increasingly being argued that science education should place greater emphasis on assisting students to develop 'scientific literacy'. This reflects the acknowledgement that not everyone is going to pursue a career in science, but that the goal of a society of scientifically literate, interested citizens is worth pursuing. If this aim is to be achieved then making science education more attractive to students is important, particularly in terms of those who show little interest in science. Yet, even with this generally well-accepted aim, it has been argued that science education continues to be taught in a manner that leads to the promotion of a view of science as fragmented, discrete pieces of knowledge that do not have any relevance to students or their world.

Second is consideration of the contrasting enthusiasm for informal science learning amongst many young people, especially when located within 'outside school' contexts such as families, museums and broadcast media. Indeed, research suggests that students are more excited about learning science when they are provided with opportunities to learn in different ways in both formal and informal environments. As Dierking and Falk (2010) contend, "the best informed and most science-literate citizens are those who enjoy maximal benefits from both in- and out-of-school science learning opportunities" (p. 493). Science educators have identified a variety of ways to promote and support more 'informal' science learning within the school context that include social interactions, community contributions, representations, argumentation and debate, practical or fieldwork and exploring socio-scientific issues. The work of Rennie and Cowie and Khoo (this volume) emphasises the significance of community contributions that can come from several sources including families, friends, institutions, community and government organisations and media. Here too, however, the criticism persists that these forms and styles of science education are not easily replicated across the school system.

Third, there is an acknowledged need to make science learning a more active and socialised process that is based around principles of problem-solving and discovery. This reflects the widely-accepted shift in the nature of science from factual knowledge to being more about the thought and skill processes involved in acquiring knowledge and skills of different types that are embedded in society (Grandy and Duschl 2005). This suggests, for example, learning science as a 'story' involving people, situations and actions, thereby offering students real world situations to engage with and posing focal questions that attract their interest (Fensham 2006). The work of Donovan and Bransford (2005) highlights three principles of learning that some science educators contend should be better integrated into science curricula and instruction:

- students have preconceptions about how the world works;
- students' competence in science requires factual knowledge and conceptual understanding; and
- students can learn to control their own learning through metacognitive strategies.

Again, there is little evidence of shifts towards these three principles being reflected in general classroom practice. Several researchers have found that there is a tendency for the teaching practices used in schools to continue to promote science as a fact-based endeavour where experiments are followed in a recipe-like manner (Goodrum et al. 2001; Ritchie et al. 2007) and "knowledge is seen as a commodity to be transmitted" (Osborne and Dillon 2008, p. 9). In this sense, students see science as something that they must acquire rather than do, and as historical knowledge rather than a current idea that is up for exploration and debate by humans (Johnston 2009). This leads to the common criticism that students' natural curiosity and ways of knowing and investigating are not often nurtured or valued in school science (Warren et al. 2001). More often then not, students' experiences of science suggest that it "ignore[s] the interests of students, which in turn eliminate[s] student motivation and natural curiosity while also developing more negative attitudes toward science and creativity" (Lee and Erdogan 2007, p. 1316).

In summary, then, science education in the 2010s is facing considerable pressure to alter in the face of the apparently changing nature, interests and needs of learners. The primary 'problem' facing the science education community is how best to stimulate a personalised and socialised science education within schools. How can learners engage with science education in ways that are contextualised, presented as an issue of personal and social relevance, and that involve working on open problems that learners can investigate using methods that they develop for themselves (Aikenhead 2006)? Of course, while each of these changes may appear straightforward enough to achieve in principle, realising them in practice—and simultaneously—has proven to be difficult. Re-orientating the culture, content, and underpinning philosophies of science education along these lines is no small task.

Digital Technology as a Possible Solution?

In light of the concerns raised above, increasing numbers of science educators are beginning to argue that digital technologies offer a ready means of addressing the challenge of supporting students to learn science that is relevant and of interest to them, while making effective use of contextualised, open problems that allow for community involvement and student investigation. As Gupta and Fisher (2012) contend:

> not only has the use of technology increased to make the process of [science] teaching and learning in the classroom more effective, learner-centred and outcome-focused, but it has also given an impetus to teachers to use it as a tool to bridge the gap between traditional learning and modern educational requirements for the overall development of the learner (p. 196)

In theory, at least, digital technologies are seen to offer a means of addressing many of the issues just described as facing science education. First and foremost, digital technologies are popularly seen as being able to infuse school education with the individually-centred, connected, fluid, creative qualities of the 'digital age'. Here the broad understanding is of digital technology breaking down barriers between and within school settings, facilitating new ways of participating and interacting, as well as allowing participants to 'bring in' their own vernacular practices. Digital technologies are therefore seen to break down traditional educational barriers between time/space, experts/novices, production/consumption, single/simultaneous acts, and synchronous/asynchronous communications. In terms of what takes place within the science classroom and the science curriculum, digital technologies are therefore seen to be able to support a range of notably different learning practices and altered social relations.

Returning to the issues facing science education outlined above, there are three main strands to the potential of digital technologies. First is their potential to provide individual students an enhanced freedom from the physical constraints of the 'real world'. This is often expressed in terms of overcoming barriers of place, space, time and geography, with individuals able to access high quality educational provision regardless of their local proximity. This increased access to high quality education is especially the case with computer-based simulations, including 'conceptual' simulations (such as those that offer models of complex processes in physics) that support the learning of abstract principles, concepts and facts related to systems being simulated. When using simulation software, for instance, students are seen to be able to experience otherwise inaccessible locations, experiences and system interactions. Here digital technology is used to present dynamic models of real-life systems and processes that would be too expensive, dangerous, time-consuming or microscopic to experience in real life. The ability of computers to repeat these simulations on multiple occasions allows for discovery-based learning and the refinement of conceptual understandings (Rutten et al. 2012).

Continuing this theme, simulations are seen to epitomise the ability of many forms of so-called 'virtual' technologies to offer individuals an increased social and psychological freedom from their real-life circumstances. Enthusiasts argue that virtual technologies have profound implications for the ways that students and teachers can communicate and interact with each other, with people no longer constricted by distance, time or physical attributes such as location or body. In this sense, it is argued that users will be able to construct diverse 'virtual identities' and digital forms of embodiment through which they can experience these 'virtual' worlds. The key advantage here is that the individual user has control over both their environment and their presentation of self. These issues all feed into the wider contention that virtual technologies can support 'freer' and 'fairer' interactions and experiences—reflecting “an impression of digital space as a radically democratic zone of infinite connectivity” (Murphy 2012, p. 122).

Second, enthusiasm about digital technologies among many educators is supported by a strong belief in digital technology as a potential means of supporting socially-contextualised forms of learning. This view is based on an assumption that learning is a profoundly social and cultural process emphasising the influence of the social environments that surround an individual’s learning and cognitive development. Seen along the lines of socio-cultural theories of learning—particularly the (post-) Vygotskian tradition—digital technologies act as powerful social resources within an individual’s learning context (see Luckin 2010). In particular, digital technology can be seen as a key means of providing learners with enhanced access to sources of knowledge and expertise that exist outside of their immediate (classroom) environment. There is now considerable interest, for example, in the field of ‘computer supported collaborative learning’)where individuals collaborate and learn at a distance via digital tools. Similarly, there is much enthusiasm for the ability of digital technology to support social-cultural forms of ‘situated learning’ and the associated notion of ‘communities of practice’. Key here is the increased use of social media tools to allow learners to interact, collaborate and participate along ‘mass socialised lines’ (Davies and Merchant 2009). In such a context, science education is considered to best take place in the form of ‘real-world’ activities and interactions between people and their social environments.

Finally, and perhaps most significantly, is the potential for digital technology to present many opportunities to support quality learning in science education, such as options to reinforce or take the place of practical work—not least improving access to current and accurate data for analysis and the opportunity to view phenomena in real time (McFarlane and Sakellariou 2002). More generally, Webb (2005) describes three main effects of using digital technologies to support learning and teaching in science classrooms: enabling a wider range of experiences so that students can relate science to their own and other real-world experiences; increasing students’ self-management; and facilitating data collection and presentation. In all these senses, then, digital technologies offer assistance to students in making sense of data, thus providing them with further opportunities for the development of conceptual understanding.

Examples of Digitally-Based Science Learning and Teaching

Of course, optimistic claims and enthusiasms such as these have long been made for digital technologies and education—yet it can be reasonably argued that technologies now exist and are in mainstream use to realise these potentials. Indeed, there is a range of tangible examples of such technology-based forms of science education. Take, for instance, the growing use of so-called ‘virtual classrooms’—usually spatial representations of a classroom or lecture theatre that can be ‘inhabited’ by learners and teachers. Often these virtual spaces will support synchronous forms of 'live' instruction and feedback, with learners able to listen to lectures, view videos and visual presentations, while also interacting with other learners via text and voice. Other asynchronous forms of virtual classroom exist as digital spaces where resources can be accessed and shared, such as audio-recordings and text transcripts of lectures, supplementary readings and discussion forums.

From a science education perspective, an integral component of the virtual classroom is the 'virtual lab', offering complex simulations of practical science work. Virtual classroom and virtual lab technologies are now available in a variety of forms. One notable trend is the virtual labs provided by professional science organisations as a form of public outreach. The UK's Medical Research Council (MRC), for example, ran a 'Virtual Lab' project at the beginning of the 2010s allowing schools to engage in interactive web-based experiments showcasing the MRC's contemporary medical research, and thereby engaging school students with 'real-life' science.

Virtual classroom and virtual lab technologies can be combined to support complex learning arrangements over time and space. One example is the Australian 'National Virtual School of Emerging Science' (NVSES, see Lancaster et al. this volume). One of the aims of NVSES is to provide access to science content based on aspects of emerging science, such as nanotechnology and quantum physics, which are not specifically taught in the standard secondary school science curriculum. NVSES can be accessed by students from all over Australia through lessons taught using a virtual meeting and collaboration platform alongside a learning management system. The NVSES has been designed to make good use of virtual experiments, allowing students the chance to manipulate equipment (albeit virtually), engaging in the process rather than simply observing, and to then explore the application of science in a context that they may relate to. In addition to these digital affordances, NVSES also uses technology to offer students connections to real-world situations and people who can share stories related to their work in emerging fields of science. For instance, each unit includes at least one lesson that connects with an expert in the field being studied and students interact with this person using online collaboration tools. The NVSES therefore aims to locate students' science education within a sense of science as a collective endeavor rather than a purely individual activity.

Another form of online community learning is in the 'online lab' model of dispersed groups of learners participating in sustained experimental learning—much along the lines of virtual professional scientific work over the past 20 years or so. One such example is the on-going EC-funded project 'Go-Lab: Global Online Science Labs for Inquiry Learning at School'. Here, internet technologies have been used to open up remote science laboratories, their data archives and virtual models ('online labs') for large-scale use in education in order to enable inquiry-based science learning that promotes acquisition of deep conceptual domain knowledge and inquiry skills and directs students to careers in science.

Whereas virtual schools and virtual labs make use of digital technology to replicate formal education processes, a range of technologies have also been developed to support informal science learning. In particular, science education has seen a recent rise in games-based learning (see Evans and Biedler 2012). These games are developed by all manner of organisations seeking to support science learning. For example, ‘Game For Science’ is an extensive multi-player virtual world developed by CREO Inc. based around science learning. Similarly, ‘ImmuneAttack’ is a game developed by the Federation of American Scientists, requiring players to navigate a Nanobot through blood vessels and connective tissue in an attempt to save a dying patient by retraining her non-functional immune cells. More prestigiously still, the Nobel Prize organisation offers a range of free games based on Nobel Prize-awarded achievements. These games aim to teach and inspire science learning and range from games concerning ‘DNA and the double helix’ to ‘control of the cell cycle’. Similarly, organisations such as NASA, the Smithsonian Institute and the UK’s Science Museum have all produced a range of science education games.

Many commentators argue that science games of this kind have considerable educational merit, both in terms of the science-related content and knowledge and a range of ‘higher order’ domains of learning. According to Gee (2003), for example, digital games usually demand that players actively and critically engage with the design principles of the game. Gee also sees players as learning from being required to engage with the multiple ways that meanings are signified and conveyed within games, such as images, words, actions, symbols, abstract design and other artefacts. In this sense, much games-based learning can be seen as semiotic and ‘multimodal’ in nature. Within the context of the game, Gee describes learning as taking place through discovery and interaction with other agents within the game, be it other players (in the case of multiplayer games) or computer-generated characters. As such, meaning and knowledge can be seen as distributed across the learner, objects, tools, symbols, technologies and ‘material objects’ within the game environment. Gee also suggests that the requirement within the design of many games that players take on and play with a number of new identities leads to learning taking place.

Another prominent digital innovation with informal as well as formal science education applications are the ‘Open Courseware’ and ‘Open Educational Resource’ movements, which are concerned with making professionally-developed educational materials available online for no cost. For example, it is reckoned that content from almost 80 % of courses at the Massachusetts Institute of Technology is available in this free-to-use manner. Similar commitments can be found in institutions ranging from world-class universities such as Oxford and Yale to local community colleges. In all these cases, course materials such as seminar notes, podcasts and videos of lectures are shared online with a general population of learners who could otherwise not attend. Often the emphasis of Open Educational Resources is not simply on allowing teachers and learners to use materials as provided, but encouraging users to alter and add to these resources as required. For example, the UK Open University’s ‘OpenLearn’ project provides free access to all of the institution’s curriculum materials (including a wealth of science material) with an invitation for teachers *and* learners to adapt them as they see fit.

Other digital content sharing ventures rely on educational content that is created by individuals as well as institutions. For example, the ‘YouTube.Edu’ service concentrates on providing educational videos produced by individuals and institutions alike. On a more commercial basis, Apple Computers' collection of educational media—iTunes-U—is seen to allow learners to circumvent traditional educational lectures and classes in favour of on-demand free mobile learning (McKinney et al. 2009). Describing itself as "possibly the world's greatest collection of free educational media available to students, teachers, and lifelong learners", iTunes-U offers free access to over 200,000 educational audio and video podcast files to learners and teachers. More recently, the Khan Academy has put over 4,200 videos online alongside interactive quizzes and assessments covering K-12 biology, chemistry and physics, allowing learners to learn at their own pace and to revisit material on a repeated basis. Their so-called 'flipped classroom' model is intended to allow students to engage with instructional elements of learning *before* entering the classroom. Face-to-face classroom time can be then be devoted to the practical application of the knowledge through problem solving, discovery work, project-based learning and experiments.

More radical still has been the development of 'Massive Open Online Courses' (MOOCs) over the past 5 years or so. Now, most notably through the development of large-scale programmes such as Coursera and Ed-X, these are large-scale ventures concerned with delivering university courses on a free-at-the-point-of-contact basis to mass audiences. The MOOC model is based on the idea of individuals being encouraged to learn through their own choice of digital tools—what has been termed 'personal learning networks'—the collective results of which can be aggregated by the course coordinators and shared with other learners. This focus on individually-directed discovery learning has proved especially relevant to science education (see Waldrop 2013) and it is possible for learners of all ages to participate in MOOCs run by professors from institutions such as Stanford, MIT and Harvard in science subjects ranging from MIT's 'Mechanics ReView' to Harvard's 'Fundamentals of Neuroscience, Part 1: The Electrical Properties of the Neuron'.

The Need for Caution: Possible Limitations to the Technological Transformation of Science Education

As all these examples suggest, there are many ways in which digital technology *can* support forms of science learning and teaching that are more learner-centred, learner-driven, discovery-based, intrinsically motivating and participatory. However, as we pointed out at the beginning of this chapter, the application of technology to education—especially school education—is not straightforward. In this sense, it is important to balance our enthusiasms for the potential of technology with a number of caveats concerning the realities of education and digital technology. So why might the potential of digital technology for science learning and teaching *not* be realised?

First, it is important to consider seriously the perspective of the learners themselves. For instance, it is important to recognise that all of the potential applications just discussed should not be assumed as inevitably and intrinsically appealing to all young people. In contrast to much of the ‘digital native’ commentary, children and young people’s uses of new technologies is a rather more complex and compromised affair. At a rudimentary level, for example, the idea that all young people are immersed in a state of constant access to technology is an obvious oversimplification—especially in light of the continued digital divides that exist between and within different countries around the world. Instead, research suggests that the ability of young people to engage with digital technologies remains patterned strongly along lines of socioeconomic status and social class. Clear differences are also apparent in terms of gender, geography and the many other entrenched ‘social fault lines’ that remain prominent in early twenty-first-century society. Indeed, some social groups of young people appear to be as ‘digitally excluded’ as older generations, albeit in ways which are less apparent to adult commentators (see Selwyn and Facer 2009).

Aside from inequalities in access and engagement, there is growing evidence that many young people’s actual uses of digital technologies remain rather more limited in scope than descriptions of the empowered digital native suggest. Surveys of adolescent technology use, for example, show a predominance of game playing, retrieval of online content, text-messaging and communication via social networking sites—and increasingly on mobile smartphones rather than computers (Madden et al. 2013). The most popular technology practices of younger children are often relatively simple and repetitive, centred on writing and image creation, as well as game playing and video watching (Selwyn et al. 2010). These core interests and activities are understandable, yet often belie the supposedly creative, communicative, social, participatory nature of digital technology use. Instead, it would seem that the majority of young people are perhaps best termed as ‘non-active users’ of digital technologies—passively downloading content rather than engaging in any meaningful acts of creation or sharing (Brandtzæg 2008). Further, a growing body of empirical studies highlights a lack of ‘sophisticated’ or ‘advanced’ use of social media services and applications among populations of users at all ages and stages of life. As Donna Chu’s (2010) detailed study of well-educated teenagers in Hong Kong concluded: “contrary to popular rhetoric, young people are far from active users or prosumers in the new media age”.

The passive, receptive nature of young people’s use of digital technology is especially the case in terms of learning with digital technology. Studies of informal technology-based learning often find digital technology use that leads, at best, to what Charles Crook (2008) termed a “low bandwidth exchange” of information and knowledge, with most instances of technology-based collaboration between groups of learners described more accurately in terms of co-operation or co-ordination between individuals. Similarly, use of digital technologies for information gathering can be described more accurately as passive information retrieval rather than active inquiry (Rowlands et al. 2008).

Even when learners make use of digital technologies in more ‘active’ and generative ways, it seems to be nigh on impossible to ‘prove’ any discernible ‘contribution’ or ‘effect’ on learning. Put simply, credible evidence of the assumed educational benefits associated with virtual classrooms, digital games and the like is hard to come by. Further, for every study that claims "a statistically significant improvement for knowledge acquisition" (Ras and Recha 2009, p. 553), there is counter-evidence reporting that digital applications "over-simplify" education and "diminish learning abilities" (Ben-David 2011, p. 1384). As with previous incarnations of educational technology, pinpointing the actual educational benefits and learning 'gains' associated with current forms of digital technology use remains as much a matter of faith as it is a matter of fact.

Aside from the questionable outcomes of technology-based science education, we also need to be circumspect about the innate expectation or even desire among learners to be constantly using digital technologies in education. Instead, research studies suggest that young people are rather more discerning in their desire to use (and not use) digital technologies. For example, there is a growing body of evidence of young people's ability to self-regulate their use of digital technologies. This was evident, for example, in Davies and Eynon's (2013) study of digital technology use among UK teenagers. As well as documenting the activities of regular technology users, the study also highlighted "variations around the mainstream"—highlighting ambivalence and sometimes rejection of technology use by some young people at different stages of their lives. In a science education context, therefore, there is little reason to presume that the increased use of digital technology (whether in the form of games, virtual worlds or simulations) will be motivating factors in and of themselves. If students are not motivated and engaged by the subject and content itself, then the mode of delivery is unlikely to make a profound difference. To reverse Marshall McLuhan's maxim, it is the nature of 'the message' rather than 'the medium' that will likely make most difference to the appeal of science education amongst young people.

Indeed, it could be argued (albeit contentiously) that the epistemological nature and form of science education perhaps makes it less applicable to many of the 'virtual' forms of technology-based learning outlined in this chapter. It *could* be argued that formal classrooms, face-to-face and 'hands-on' instruction, fixed curricula and assessments are the best technologies for supporting science learning. From a practical point of view, for example, 'hands-on' experiences could be seen as essential to many different areas of science education. As Klahr et al. (2007) observe,

> physical materials are likely to have an advantage in domains requiring physical manipulation and tactile senses such as pouring and mixing of chemicals, and there may be domains—such as the life sciences—where having learner's hands on 'the real thing' may have important effects on learning. (p. 198)

Similarly, some of the most important 'experimental' aspects of science education follow an apprenticeship rather than discovery model. In most school science laboratories, for example, experiments are performed with the overall purpose of generating data that already exists, using established processes that have already been tried and tested. While less social or participatory, this *could* be seen as a necessary precursor to the professional science 'work' of trialling and testing ideas or being prepared to experiment with the sole intention of just seeing what happens.

More esoterically, it could also be argued that science subjects are forms of 'powerful knowledge' that are best suited to current forms of mass schooling. As Young (2009) contends, subjects such as physics comprise forms of knowledge that many children and young people cannot acquire easily at home or in the community. Crucially, this is often knowledge that can be almost inaccessible through informal education and so often can only be transmitted through the school. In the case of these forms of powerful knowledge, it could be argued that school plays a crucial enabling and supporting role. Indeed, formal science education could be seen as comprising things that learners cannot easily discover or explore for themselves—not least because learners "can't know what they don't know" (Young and Muller 2010, p. 16).

An appreciation of the value of science (and a motivation for engaging in science learning) is perhaps not something that can be spontaneously discovered and recognised by many students. Rather it could be argued that the supporting role of mediating experts (e.g., teachers) remains crucial in stimulating a desire to engage with science, and then determine what is worth learning. As Corrigan (2006) argues, "Science educators need to provide a bridge between science and science education if students are to appreciate what science can offer in a number of roles such as a scientific worker, a consumer and as a responsible citizen" (p. 51). As such, the knowledge domains of science education could be seen as requiring a balance between a 'time for telling' as well as a 'time for discovering' knowledge (cf. Schwartz and Bransford 1998). In this sense, formal face-to-face schooling might remain one of the most appropriate means of providing a place, as well as a time, for science learning to take place.

Conclusion

Whether we agree fully with these latter arguments or not, it is clear that the teaching and learning of science is not simply 'enhanced'—let alone transformed—through the addition of digital technology. It may well be that digital technology helps some learners to engage with science education in more convenient, engaging and useful ways—yet this is unlikely to be the case for everyone. Indeed, there is a well-worn tendency of technology to reinforce existing patterns of educational engagement—helping already engaged individuals to participate further, but doing little to widen participation or re-engage those who have previously disengaged. In particular, the latter discussions should remind us of the limitations of any 'technical fix' approach to understanding contemporary science education. Instead, it is likely that many of the 'problems' of science learning and teaching are primarily social/cultural in nature, and therefore require social/cultural responses that cannot solely be technological in nature.

Of course, all these conclusions need to be set against the future development of science *and* technology over the next decade or so. In terms of future technological developments, for example, we can be reasonably sure of the emergence of a number of ‘new’ new technologies that will come to bear on science education in the second half of the 2010s and into the 2020s. These include 3D printing and other fabrication technologies, augmented reality and the embedding of digital information into physical environments, holographic projection, robotics and, of course, the increasing significance of so-called ‘big data’ and learning analytics. All of these technologies offer new sets of promises about what change *might* take place in the arrangement, provision and processes of science education. However, given everything that this chapter has discussed in terms of the technologies of today, it would be foolhardy to predict a substantially different future driven by the nature of these emerging technologies alone.

Digital technologies will clearly be an important part of science learning and teaching in the near future, but the use of technology to make science education ‘better’ is a deeply complex matter that goes well beyond technical issues of how to present material to learners, or engage them in learning opportunities. The future of science education may well involve increased use of digital technology—but will certainly not be determined by it.

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Facilitating Change in Science Teachers' Perceptions About Learning and Teaching

John Loughran and Kathy Smith

The Science Teaching and Learning (STaL) project is an in-service teacher professional learning programme constructed around two important design principles aimed at enhancing student learning. The first principle is based on the value of intensive pedagogical learning experiences for teachers of science. Guided by this principle, the programme aims to build participants' capacity to be reflective practitioners (Schön 1983) who seek to transform approaches to learning and teaching in science within their schools. The second design principle is to focus on assisting participating teachers to explicate personal understandings of that which constitutes effective school-based science education leadership as a mechanism to enhance the overall quality of science teaching and learning—with a clear expectation of impact on student learning (Lindsay 2013). These principles form the basis on which STaL is structured. In so doing, the programme genuinely supports a professional learning approach through which teacher participants are placed in the position of being learners of science and hopefully, then, initiators of change in their schools.

This chapter examines science teacher participants' developing knowledge of their students' learning about science as a consequence of changes in their practice catalyzed through the STaL programme. The data for that analysis is derived of the cases that participants write on the final day of the programme. Such cases are self-directed and driven by participants' needs, issues and concerns about their practice and their students' learning. As such, the cases document the pedagogical reasoning, actions and evidential base that matter for them in further developing their approaches to, and knowledge of, science teaching and learning.

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STaL Program Structure

STaL is a 5 day (2 + 2 + 1) intensive, residential course spaced across the school year with two explicit forms of support. The first is in terms of the residential programme itself (teaching and programme facilitation), in which a constant focus on facilitators' pedagogical purpose is explicitly linked to the learning approaches encouraged and teaching procedures adopted. The second is that of ongoing in-school support from a 'critical friend' (the second author of this chapter). The critical friend visits all schools (between 10 and 15 schools a year) at least three times throughout the programme. In these school-based meetings, discussions promote reflective thinking and support the trialing of alternative approaches to science teaching and learning. This ongoing contact ensures a supportive relationship is established which is important in encouraging and assisting participants throughout the programme, and, in particular, supporting them to better conceptualise problems of practice specific to their teaching and learning context.

The programme involves both primary and secondary teachers. There is an expectation that more than one teacher from each participating school attends with the intention that, through a shared experience of professional learning, participants might better be able to build on their learning experiences and support one another in meaningful ways in their school-based endeavours.

The formal outcome of the programme is that all participating teachers produce a written case (Barnett and Tyson 1999; Shulman 1992) capturing their professional learning as a result of their STaL experience. The cases are compiled, edited and formally published each year, producing a separate volume of work (e.g., Keast and Berry 2009). These cases explore a range of teaching and learning issues in science education and have provided useful insights into teacher thinking and a valuable set of data for analysis in relation to the impact of the programme. Each year the book is launched at a public event involving the teacher participants and celebrating their achievement as authors.

STaL was initiated in 2005 and in the seven times it has been conducted up to 2012, it has developed and been refined in accord with the expectations of the underlying design principles. All science teacher participants (N = 226) have been volunteers with annual cohorts of approximately 30. The purpose of the programme is to explore teachers' existing understandings of their practice and to introduce them to alternative ways of framing problems and reflecting on their science teaching and their students' learning of science—which is ultimately documented through their case writing.

The role of the critical friend has become a crucial part of the overall professional learning experience for all teachers participating in STaL. In the school-based meetings the critical friend encourages teachers to revisit their STaL programme experiences as a prompt for 'noticing' their teaching in new and different ways. Although, by design, these meetings are unscripted and informal, the discussions aim to purposefully promote critical reflection. Teachers are encouraged to take time to explore those moments in their teaching in which their routine thinking has been interrupted or unexpectedly challenged. The critical friend listens, withholds judgment and responds to these teacher stories and concerns with the intention of drawing attention to aspects of these experiences that may have been overlooked, or to focus on particular reactions or responses to events in order to facilitate reflection. In this way the critical friend is actively developing teacher talk that goes beyond science content and teaching activities in order to encourage consideration of their personal perceptions of quality teaching and learning and their enacted role as a science teacher. In a similar manner, these discussions also create ways to explore students' perceived and enacted roles as learners.

The meetings are driven by issues that matter to teachers and it is through the lens of personal experience that they are encouraged to explore meaning and develop insights. The critical friend enables teachers to: comfortably discuss ideas about students' learning needs, identify that which is problematic in practice, and prepare to confront the challenges associated with considering and constructing new approaches to pedagogy. As a result, teachers begin to notice and attend to how their personal professional understandings shape and determine the ways in which they work and the nature of classroom events. This reflective thinking creates opportunities for teachers to begin to develop ways of focusing on experiences that (at the end of STaL) help to shape their case writing.

Each of the 2-day components of the programme explores different approaches to science teaching and learning and places participants in the role of science learner. It is also in these workshops that participants are introduced to case writing as one way of conceptualising, documenting, sharing and learning about practice. The final day of the programme is a writing day in which participants develop drafts and share these with colleagues (STaL team members and participant teachers) in order to refine their ideas and writing, and to reflect further on their learning about science teaching and learning. Most participants report that the writing day offers, for the first time in their teaching careers, an organised and structured space outside of their teaching to write about their practice.

Spacing the programme across school terms 2–4 enables teachers to access new ideas and trial these in their school context and then to return to the programme and discuss their experiences further, and access the experiences and ideas of other participants in order to enhance their own thinking and practice. This format helps to diminish the 'one-off programme' view (that can easily dominate professional development (PD)) and purposefully aims to build relationships. Importantly, the programme is conducted in a non-school context (a city hotel, which comes at a high economic cost) but through that residential environment, the programme reflects STaL and the funding agency's (Catholic Education Office, Melbourne) concern to treat teachers as professionals and value their involvement in ways not common in more traditional PD programmes.

The STaL project is a vehicle for challenging existing science teaching and learning practices and encouraging the development of new knowledge of practice through experimenting with and sharing practice. The case writing acts as a formalised approach to reflection and knowledge development and dissemination. In essence then, teacher participants are positioned as "producers, not just users, of sophisticated knowledge of teaching and learning" (Loughran et al. 2006, p. 15).

STaL sessions are designed to explore a number of specific areas of science education, in particular, exploring students' existing ideas and alternative conceptions, promoting rich discussion among teachers themselves about purposeful learning, unpacking student thinking to better access student understanding, the role of effective assessment, the role of personal values in science education, and scientific literacy.

Central to STaL is a re-imagining of traditional notions of PD as the supply of pre-packaged knowledge that is distributed to teachers in 'easily digestible pieces' (most commonly, mandated changes in policy and practices directed by education authorities), to a genuine focus on professional learning (PL), whereby teachers actively explore their individual experiences and contexts and become articulate about what they have learnt (Lieberman 1995). Conceptualised in this way, PL involves the sharing of insights about teaching and learning between teachers in order to gain a sense of professional control and ownership over their learning and, concomitantly, a responsibility for the learning and teaching environment that they actively create in their classes (Berry et al. 2009).

Cases as Data

Cases are a vehicle for eliciting teachers' knowledge of practice in ways that help to make the tacit explicit. The cases, which have been published as an outcome of each STaL programme, capture, portray and share participants' knowledge of practice and insights about science teaching and learning. The format is one in which teachers are encouraged to portray in rich detail the dilemmas, issues and concerns they face in their classrooms, resulting in a sense of credibility that tends to resonate easily with other teachers.

As the cases are written by teachers, the ways in which they choose to report their new understandings are idiosyncratic and are certainly not scripted to adhere to any particular or prescribed theme. Hence, links between teaching and learning are reported from participants' perspectives and reflect participants' new understandings.

The cases suggest that as a result of programme experiences teachers begin to think differently about their science teaching and trial alternative approaches to planning and teaching in an attempt to enhance student learning in science (the following brief extract from a case illustrates this point from a participant's perspective.)

> During my time in STaL I came to the conclusion that I really wasn't that great a teacher. On Day 1, we were presented with a teaching model that I loved and wanted to learn more about. The model (comprising ideas about prior knowledge, processing, translation, synthesis, etc.) made me realize that even though I teach content and throw in lots of hands-on

> (dare I say 'fun') activities, I am not always conscious of the entire learning process and what experiences my students (the learners) are going through.
>
> "I teach therefore they learn. Yeah right!"
>
> Being a learner again for 5 days was a real eye-opener. The strongest learning experience I had was when we spent 2 h creating our own Slowmations[1] … I was caught up in the process because creating a Slowmation was new for me; I already knew the scientific content knowledge. Because I had to get my head around the idea of creating a Slowmation I put all of my learning efforts into that. I couldn't give both tasks the same level of mental effort so I concentrated on one. It's like when you learn how to drive for the first time and you need to put all your effort into the clutch, gears and accelerator. However, as your learning progresses and you become more experienced, those separate tasks combine, become automatic and then you start to pay attention to the other things.
>
> As a result of my learning experiences I recognized that I needed to plan units of work more sequentially. This could be done using the ideas from the model from the first session, but I needed to think about separate learning tasks and activities so that students are not bombarded with too much new information all at once. This way my students will hopefully experience learning at a deeper level. It is also important to recognize the difference between content knowledge and the processes or skills that students need to learn those things.
>
> STaL enabled me to take a step back and become a learner again. That was the most powerful learning for me and has enabled me to shift my focus from, "What am I teaching?" to, "What are they learning?" (Speakman 2012, pp. 18–19)

Over the life of the programme more than 200 cases have been published. These cases have been analysed and categorised to develop an understanding of:

- the range of issues that are prominent among teachers,
- the prevalence of these issues across various cohorts of participants, and
- changes in teacher thinking about these issues as a result of experiences in STaL.

Using the cases as a rich data set for secondary analysis has revealed evidence that STaL impacts teacher thinking and practice in three broad areas: the nature of science teaching, pedagogy and assessment. In the remainder of this chapter, indicative case quotations are used as data sources to illustrate the themes, issues and concerns being discussed. (The reference following each quote refers to the teacher author and the source from the appropriate case book from which the quote has been extracted.)

As cases are written from a teacher's perspective, they provide a way of seeing into the relationship between teachers' actions and students' learning behaviours. The analysis that follows highlights how the STaL cases illustrate ways in which the teacher participants think about student learning and how their teaching shifts in response to their insights. Importantly, the analysis revealed that as teachers begin to see their students' learning differently, it encourages them to continue to refine

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[1] Slowmation is a simple form of digital animation used to create a 'slow-animation' (hence Slowmation) of a particular, theme, issue, concept or process which has great value in science teaching. For further details see Hoban et al. (2011).

their teaching. Therefore, as student learning develops it further reinforces the value of change in their teaching practice.

Student Learning

Concerns about students' learning in school science have been well documented, with issues of lack of interest and disengagement continually coming to the fore (Goodrum et al. 2000; Rennie et al. 2001). In response to these concerns, the STaL programme intentionally attempts to expose participants to teaching practices and curriculum designed to build on student interest, respond to student curiosity and questions, and make links to relevant real-life situations (for students).

During STaL, specific sessions explore ways to effectively develop understanding of content through student questions and open-ended discussions, and these sessions encourage teachers to think about their teaching differently, undertake new planning and teaching approaches, explore these in the classroom and share their experiences of science teaching and meaningful student learning. How these learnings are translated into teachers' practice and how those changes relate to perceptions of student learning can be explained through the idea of noticing.

Mason (2002, 2009) used the term 'noticing' to signal the need for teachers to see beyond that which is immediately obvious in their practice. He considered noticing to be integral to helping teachers approach teaching in a disciplined manner, with inquiry at the heart of practice. Mason argued that teachers cannot really understand practice if they cannot see it with fresh eyes and from alternative perspectives—something similar to that which Schön (1983, 1987) described as reframing. Therefore, in order for teachers to grasp the reality of students' learning experiences, there is a need to inquire into practice in order to better appreciate the relationship between teaching and learning. In so doing, a "teacher learns with and from the students about the ways in which teaching impacts their students' learning and how that learning helps further refine practice" (Loughran 2009, p. 12).

A number of cases captured the struggle that teachers experienced as they began to realise that their prevailing science teaching may not assist in the development of students' curiosity, skepticism and critical thinking skills. Rather, they saw that they may have been perpetuating a perception of science as a rigid body of absolute unchanging truths, consisting of isolated facts, and devoid of human imaginations and logical reasoning. Some participants saw a connection between the nature of school science and student disengagement; they began to notice different things in their daily practice:

> I saw that the students were almost drowning in class notes, and found myself drowning with them. I didn't see that I had a choice, but to get out there and try something different. What would have happened if the activity hadn't worked? No worse than could have happened if I didn't try the activity in the first place. (Solomon 2006, p. 22)

> But, good teaching requires us to promote thinking in our students, and this can only be done when staff are prepared to engage in reflecting about how they are teaching. Our

> profession is in a special situation where we are required to engage and help students to be ready to be involved in the workforce … [yet] many teachers have never worked outside an educational setting. The demands of a changing society in many ways require very different approaches than the schooling we experienced as teachers, including the ways we were taught to teach. (Goodridge-Kelly 2010, p. 82)

As the case extracts (above) illustrate, when teachers focus on student learning it has ramifications for their thinking about their own practice. In each of the sections that follow, case data is used to exemplify the theme under consideration in similar ways to that outlined above.

Challenging Assumptions

Seeking to find and challenge taken-for-granted assumptions (Brandenburg 2008; Brookfield 1995) in practice is one way in which the act of noticing can lead to new insights into student learning. A common assumption many teachers raised was related to the perceived importance of teacher control in relation to effective learning. The assumption that students learnt what a teacher prescribed was challenged and led to a recognition that disengagement and underachievement could not simply be blamed on the students themselves. Transmissive teaching (Barnes 1976) can too easily prevail as a default approach to school science. However, through their case writing, some participants noted the need for such approaches to teaching to be seriously confronted:

> A sense of disquiet was growing in me about my classes. It was not so much from the students—they seemed to be engaged in my lessons, enjoying the practical work and not complaining that they had a science lesson. It was something else. I was not happy. I was slowly coming to the realization that my teaching was gradually becoming monotonous. My method of 'getting the content across' involved standing at the front and reading the content to them, and occasionally picking on a student to read out loud; usually the one that had been talking. This was becoming my 'easy default' option. (McGrath 2008, p. 69)

> I was suddenly faced with the realization that my desire to impart scientific content and get them to absorb it may actually be the wrong approach. "How much of the knowledge we are exposed to at school do we retain and are able to use in our daily living?" I asked myself. I know that when I work something out for myself I understand it at a much deeper level than if I learn it "parrot fashion". There seems to be something missing when I do it that way. (Goodman 2008, p. 55)

As evidenced in the case extracts above, when teachers begin to question their approach to teaching, they see the classroom and their actions anew. In preparing for STaL, the critical friend (second author) visits all of the participants to discuss their existing practice and issues/ideas/challenges they might see for themselves and what they might hope to gain from the programme. She typically finds that prior to participating in STaL, many teachers describe predictable and familiar approaches to science teaching that reflect their own rather, than their students', understandings of science ideas. One outcome of STaL is that these views are challenged in productive ways by the teachers themselves as they see their practice and their students' learning differently. For example:

> I found creating ways for students to be independent learners changed my teaching and their learning. I had struggled to develop a conversation with this group all year and had found that just posing questions was not enough. These students needed visual cues. Through this approach to my science teaching I have consciously started to delay judgement and to refrain from simply praising students publicly. As a consequence, they appear much more confident to write what they think and to make contributions to discussions in ways that are new for me and much more meaningful for them. (Laba 2012, p. 4)

Passive Learning

The cases provide evidence that as a result of their learning experiences in STaL, participants began to question why they taught science in a particular way, that is, they controlled decisions about what content was to be learnt, and when and how students learnt best. They also began to question the value of the inevitably predictable classroom routines which flowed from these decisions—routines which failed to engage students intellectually. They started to confront the situation, recognising that they employed some approaches to teaching science that allowed students to disconnect from both the content and the rigours of learning. The data suggest that some teachers began to notice how their thinking and actions shaped what and how their students learned and that the teaching behaviours that made them feel in control and confident as 'good' science teachers, in reality, reinforced passive student learning behaviours.

Many instances of passive student learning were observed and cited in teachers' cases, all within a context of noticing their practice differently. The data suggest that students expected, and perhaps even relied on, teachers to maintain classroom conditions in such a way that learning was routine, familiar and comfortable. The following extracts demonstrate teachers' heightened awareness of the interconnectedness between teaching and learning, and in particular the impact of their teaching on student learning:

> "Miss, you actually have to teach us this stuff, we can't learn it by ourselves."
> "Can you please explain, like, the whole thing."
> "I'm dumb at chemistry, you need to teach me."
> "You weren't here to teach us yesterday so we didn't do anything."
> It was comments like these that made me realise that perhaps my class were too reliant on me teaching them new concepts.
> The problem I faced was thinking about what I might do to change this. For the next few weeks I reflected at the end of every lesson on what learning had occurred; something I hadn't done since teaching rounds. (Monds 2008, p. 88)

> It is a matter of concern, not just to me but several members of the Science staff that the students seem to be like sponges. They want to soak up facts presented by their teachers but don't really seek to be active in their own learning and all they care about is the mark they get at the end. (Bliss 2007, p. 63)

Changing Conditions for Learning

In acknowledging passive learning, many teachers made a deliberate decision to attempt to change their students' learning behaviours—which ultimately meant changing the prevailing classroom conditions. Some of the cases captured teachers' reflections about what changing the learning conditions meant for their teaching, particularly in terms of the accepted approaches they used in the classroom and the skills and actions which they needed to reconsider. Changing the conditions meant there was a need to build respect and trust between themselves and their students. This was something that stood out as being crucial when taking risks and trialing alternative teaching approaches.

Across a range of cases, it was evident that making changes involved:

- giving students more opportunities for decision making;
- trusting students' judgements about their personal learning needs and interests;
- encouraging more flexible teaching and learning discussions and interactions;
- utilising real world events to exemplify and contextualise student learning;
- recognising the power of language in building meaningful understanding;
- the importance of attending to student interest and curiosity by valuing student questions; and
- actively debriefing with students and promoting student reflection on their own learning.

The following extract illustrates one teacher's thinking about these types of changes and the challenges such changes present.

> I looked at the teaching in my Science classes. One of the most challenging and enlightening realizations that I learnt through the Science Teaching and Learning Teacher Research project was just how powerful the relationship between the teacher and their own class of students is.
>
> I realized that I needed to know my students much better if I was to teach them well. However, that is some challenge when I regularly see 170 students each week.
>
> I decided to see every Year 9 Science student at the Parent-Teacher-Student interviews and to discuss their learning instead of talking about marks and behaviour. I also began to recognize the importance of helping students to make a real connection with their own world. I also wondered whether that was really possible to achieve. I have started to do this by asking students questions about what they have previously covered in science and other subjects and how that connects with their everyday life. In making changes to my practice, my greatest fear has been to lose control of both my students' learning and behaviour. I was also worried about what my colleagues or parents might say.
>
> "What would students think of me when I showed doubt, confusion and mistakes in trying out new approaches that I wasn't yet expert in?" That's hard; the first couple of times anyway.
>
> It has been hard going. There is so much preparation necessary because of the various changes that have to be done: rearranging the classes; giving different explanations; spending the entire class wandering around and dealing with more questions than in the past; and, dealing with students who are stuck and just want to be told what to do.
>
> Often I reach the end of the class that I think has been engaging for my students but am not sure what to do next:

> "How will I follow through in the next lesson to build on the learning?"
> These are all challenges that I am now learning to deal with.
> "So where to from here?"
> Well, I can honestly say that now I feel more confident to start to offer a range of learning approaches, to talk with each student to say for example:
> "Do you like this method John?"
> "What have you learnt today?"
> "What can we do together to improve learning?"
> I found it useful to regularly conduct a review of my own and my students' progress. In this way I am beginning to see that the effort is worth it and the gains, although slow, are real. I am enjoying my teaching more and now I feel as though I can see how my students are learning. It's hard work, but it's worth it. (Butler 2007, pp. 106–107)

As teachers elected to change their teaching, students found themselves in unfamiliar territory in their science classes. What had previously been predictable landmarks and signposts had shifted. No longer were they encouraged to sit passively and listen; the teacher wasn't telling them what they needed to know. There was more to science than doing experiments, responding to closed questions and completing standard written reports.

These changes had a significant impact on teacher expectations of students' learning and behaviour. Teachers were more accepting of students' thoughts and ideas and encouraged them to take part in open discussions. In response, students were expected to take risks and share a variety of ideas. This, in the students' eyes, meant that there were fewer cues to what might be 'right', and more opportunity to be seen publically as being 'wrong'. Learning was not defined by the expected routines and students were now being required to play an active part in decision making, to see how ideas linked together, to take responsibility for finding ways to demonstrate their understandings and to pay attention to how they were thinking and learning. This is exemplified in the following extract:

> "Why haven't you started, girls?" I asked.
> "We don't know what to do," Sally replied.
> "What questions are you investigating?" I inquired.
> "Does looking at an eclipse really send you blind and what effect would it have on eclipses if the moon were a different distance from the Earth?" she answered.
> "Well how do you think you could find that out?" I asked, trying my best to push them forward in a positive way.
> "Can't you just tell us the answer?" Michelle retorted.
> "Are you going to mark us on this?" Sally added.
> "No, I can't just tell you the answer and no I am not going to mark you on this," I said with a hint of frustration.
> "Well, will it be on the test at the end?" Sally asked.
> I must admit that at this stage I was feeling rather frustrated. I was trying to create this wonderful learning experience and all they were interested in was how I was going to mark them …
> By now Sally, probably the academically weakest student in the group, seemed to be getting the idea but Michelle, who regularly achieved high marks on the tests, still seemed dubious.
> "Do you understand what you need to do Michelle?" I asked.
> "I think so but why can't you just tell us the answer?" she replied.

> I ignored the last question and left to check the group working in the computer pod. They had discovered what an eclipse looked like but had not had much luck with their second question. I suggested that it might be better if they found that out by doing an experiment. However, once again I found myself up against a culture of "Just tell me the answer!" If I don't tell them they will look on the internet to find someone who will.
>
> I shoo them out of the pod to get some equipment and see if they can work out for themselves what might happen if the moon was a different size.
>
> I visit each group to see what they are doing and how well they are getting on with answering their questions. As I move around I am asked, several times, variations of "Can't you just tell me the answer?", "Will we marked on this?" and, "Will this be on the test?" I can tell several of the students are annoyed or frustrated by my refusal to give what they consider to be satisfactory answers to these questions …
>
> On the whole I was happy with how this activity went but there were several hurdles to jump, most important of which seemed to be an entrenched mind set in the students.
>
> It seemed that some of the "brightest" students had struggled most with the task. These students are so focused on marks that an unmarked task seems to lack relevance to them …
>
> It is perhaps important to accept as a teacher that a single activity is unlikely to result in wholesale change in the mind set and attitudes of my students. Such changes of culture are going to take a long time and may be made more difficult by what is happening in other classes. Helping students learn for understanding is hard work. (Bliss 2007, pp. 64–66)

Changes in Learning

Because STaL is an ongoing programme over the course of a year, changes in both student learning behaviours and the quality of student learning were raised verbally on different workshop days and through the school visits with the critical friend, as well as being more formally reported through cases.

Case data provided evidence that some teachers could see that their students were asking questions and sharing personal thinking and ideas in new ways. Teachers drew attention to how students began to demonstrate high levels of personal interest through their willingness to:

- initiate research and personal investigations;
- engage in discussions;
- utilise a range of communication strategies;
- link science to real world experiences;
- talk together about science ideas; justify thinking;
- talk together about learning; and
- question and interrogate information.

In many of the cases it was noted how these changes began to emerge as students experienced a greater sense of trust and acceptance of their ideas. However, it was also clear that teachers had to work hard to consistently maintain high personal expectations of student learning and develop the skills and strategies to ensure a learning environment in which conditions for promoting interactive and personal learning were present. A major challenge appeared to be that this process of change was slow; it took time and was often inconsistent in terms of sustained student behaviour.

> "Will you give us proper notes for this stuff though?"
> "What? You've got good notes," I thought.
> Apparently if the notes are not from me they are not "proper notes".
> At this point I realised that some of the girls had missed the point. They were totally capable of taking control of their own learning. They had just been doing it. I had seen it for myself. These girls, and so many others like them at our school, are spoon fed information and don't think they have accomplished anything unless they have pages of writing to prove it.
> "Am I going to be able to change their thinking overnight?" I thought to myself. "No way."
> "Could I chip away at it using activities such as this one to try and make them see their learning from a different angle? Sure!" I told myself with a sense of satisfaction and confidence … However, I've demonstrated to myself that I am capable of 'letting go' and giving them a bit of freedom. And, on most accounts, it has been a worthwhile thing to do. Although the girls may not have seen the benefits immediately as I did, it had been a positive learning experience; for both myself and the girls.
> "Now to get them to see it more themselves. That's what I need to do. Yep, I'm not the only one who has to learn to let go." (Rowe 2008, pp. 94–95)

Science also seemed to be changing. The characteristic 'definitive answer' became less prevalent. Science was becoming more dynamic and open to conjecture (see also Fensham's chapter, this volume). Views of science learning were changing, albeit slowly.

> What their responses taught me was that for many of the students, science remains 'fuzzy' as they are in a state of review or reflection. They no longer think that science is just made up of experiments and are now coming to understand that science is a method of study and an opportunity for discovery. Although it was perhaps a small shift in their thinking, they made a giant leap towards where they can move in the future. (Walsh 2010, p. 91)

Overview

STaL appeared to function well as a genuine professional learning experience through the manner in which it actively encouraged and supported participating teachers to begin to recognise and respond to indicators of effective student engagement, the nature of teacher talk, the value of listening to students, and noticing and reflecting on critical incidents (Tripp 1993), often the trigger for their case writing. However, cases also demonstrated that many teachers were concerned about taking risks and letting go, responding to student thinking, linking science to real life contexts, and shifting students' perceptions of science learning.

The ongoing tension for teachers was that these challenges were interconnected with student perceptions about their own role in science classes, that is, students maintained persistent beliefs about that which constituted valuable learning and what teachers should be doing to support such learning. The evidence in the cases suggests that changing teaching approaches was not on its own a solution; students also had to find a reason for change and a motivation to accept an alternative role in school science.

What was clear was that through a focus on pedagogy, the essential conditions for building trust and interactive, respectful relationships led to valuing student thinking in different ways. As a consequence, a clear purpose for learning emerged which challenged transmissive views of practice in ways that supported more sustainable and achievable change in the longer term. This change was apparent not only in teachers working with their students, but also in teachers accepting a leadership role in working with colleagues.

> Simply because I have changed in how I think about my pedagogy does not mean that I should expect that all staff will, or should, be like me. Importantly, teachers, just like students, also need to have a reason to introduce new ways of working and to experience success with new strategies to gain the confidence to try further new things and to integrate these changes into their teaching. As a leader, I have also learnt that I need to have clear expectations, provide resources and engage my teachers at every opportunity over an extended period of time to allow them to have success and gradually change their practice. (Brasher 2010, p. 84)

Science teaching is often criticised for being preoccupied with knowledge acquisition rather than engaging and enabling students to become more effective learners of science. When teachers begin to notice the inconsistencies between what they say, what they value, and what they actually attend to in their practice, we have found that rich personal learning opportunities begin to emerge. We see STaL as encouraging us in our role as programme facilitators to effectively capitalise on these 'teachable moments'. Such teachable moments do not occur by simply immersing teachers in more science content. We have learnt that it is about building relationships from which supportive learning environments emerge.

Teachers need opportunities to construct their professional knowledge from purposeful interactions through both the uncertainty and empowerment of the learning process. This experience of learning supports and challenges teachers to strategise how they might better align their teaching intents with the learning outcomes they value for their students. As we trust this chapter illustrates, the evidence of such a learning process resides in participants' cases.

Conclusion

This chapter highlights that in order to enable substantive changes in the teaching and learning of school science, the nature of PD needs to be seriously reconsidered. As the cases data illustrate, when teachers are supported to contextualise their learning and write about it in a structured (but not restrictive) form, opportunities for individual learning are able to be capitalised on and shared in meaningful ways, which then supports teachers' professional learning.

As the data illustrate, STaL facilitated teachers' development of an articulable purpose and vision for their science teaching which was closely linked to their expectations for change in student learning. For those changes to be realised, it therefore seems reasonable to assert that professional learning must enable teachers to reconceptualise learning in science—and student engagement provides a powerful focus for this process. An interesting finding from the analysis of the cases has been that as teachers attempt to reframe their practice there is a 'flow-on' effect in relation to the role of students as learners.

The cases powerfully capture not only the complexity of the challenges teachers face as they attempt to reframe practice but also the challenges that students face as the science teaching and learning landscape is reconfigured. This flow-on effect suggests that students are confronted by a shift from a position of relative clarity about themselves as passive, dependent learners to a far more tentative position embodied by what it means to be more autonomous learners.

The well-documented concerns with school science that typically emerge in the research literature (e.g., that success is about having the 'right' answers, science is about note-taking, the teacher is the font of all science knowledge in the classroom, science as it is taught is often not relevant to everyday life, and so on) cannot simply be addressed by a change in teaching approach. Traditional PD is often characterised as a mandated system based on superficial views of change as linear and straightforward. This chapter suggests that teachers profit from professional learning opportunities that help them explore the conditions needed in their classrooms to influence students' perceptions of learning. When that situation prevails, students' learning of science is more likely to be substantive, real and long lasting.

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Index

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