Deborah Corrigan · Cathy Buntting
Angela Fitzgerald · Alister Jones *Editors*

Values in Science Education

The Shifting Sands

Springer

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ISBN 978-3-030-42171-7 ISBN 978-3-030-42172-4 (eBook)
https://doi.org/10.1007/978-3-030-42172-4

This Springer imprint is published by the registered company Springer Nature Switzerland AG.
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

This is the sixth book in a series initiated by Monash University-King's College London International Centre for Study of Science and Mathematics Curriculum, in partnership with the University of Waikato. The Monash-King's College Centre was established in 2002 with initial support from the Monash University Research Fund (new areas). The Centre for Science, Mathematics and Technology Education at Monash University and Waikato University's Technology, Environmental, Mathematics and Science (TEMS) Education Research Centre 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 and R. Gunstone [Eds.], 2007, Rotterdam: Sense), 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 in science education. At the time, the overwhelming experiences of those who were teaching science were in an environment that had seen the de-emphasis 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 Teaching* (D. Corrigan, J. Dillon and R. Gunstone [Eds.], 2011, Dordrecht: Springer), our intent was to explore what expert science education knowledge and practices may look like in the then slowly emerging "bigger picture" of the re-emergence of values, which we saw as a logical step from the first book's exploration of values. We noted in the Foreword to this book that the focus of the book 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 the third book, *Valuing Assessment in Science Education: Pedagogy, Curriculum, Policy* (D. Corrigan, R. Gunstone and A. Jones [Eds.], 2013, Dordrecht: Springer), we took what we considered to be another logical next step in the sequence of foci begun with our exploration of values: assessment. The reality of education is that it is assessment that is almost always the strongest force shaping teacher development and behaviour, the implemented curriculum, student approaches to learning, etc. Consequently, the third book considered the "big picture" of assessment in science education, from the strategic and policy level to that of classrooms. However, 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 rather than the impacts of assessment on students.

The fourth book, *The Future in Learning Science: What's in It for the Learner?* (D. Corrigan, C. Buntting, J. Dillon, A. Jones and R. Gunstone [Eds.], 2015, Dordrecht: Springer), considered the learning of science in contemporary education: the forms of science that 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 better take and how this learning happens. Of particular concern was 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 they are too commonly being positioned. Additionally, we sought to represent and value the perspective of the learner as an important overarching theme.

The fifth book, *Navigating the Changing Landscape of Formal and Informal Science Learning Opportunities* (D. Corrigan, C. Buntting, A. Jones and J. Loughran [Eds.], 2018, Cham: Springer), championed research involving learning opportunities that are afforded to learners of science when the focus is on linking the formal and informal science education sectors. We use the metaphor of a "landscape" to emphasise the range of possible movements within a landscape that is inclusive of formal, informal and free-choice science education opportunities, rather than the not uncommon formal sector assumption that the informal sector should somehow serve the formal, and that free choice is not part of education at all. In addition, the book explored opportunities for informing formal school science education via the perspectives and achievements of the informal and free-choice science education sectors.

This sixth book returns to an explicit focus on values, more than a decade after the first book in this series. In that first book, it was evident that different cultures have different traditions in relation to the place of values in their school science curriculum and that these traditions were being challenged. In this volume, we reflect back on how values are centrally associated with science and its teaching, as well as the wide range of factors that influence science education. These include sociocultural, philosophical and psychological influences; curriculum; the nature of science; formal and informal education settings; the relationship between science, technology, society and the environment; teaching and learning practices; assessment and evaluation; teacher education; and classroom climates. Our title, *Values in Science Education: The Shifting Sands*, seeks to capture the persistent but vulnerable nature of values in the face of forceful influences on the education landscape.

We used the same approach to the creation of this sixth book as we did with the previous five. In seeking to achieve a cohesive contribution to the literature while enabling the authors to assert their own voices without restrictive briefs from us as editors, we again hosted a 3-day workshop involving all the authors to facilitate a more interactive and formative writing process. A first draft of all chapters was distributed prior to the workshop, enabling 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 the group's feedback. As with the previous books, the workshop was scheduled around the European Science Education Research Association (ESERA) conference and took place at Trinity College, Dublin.

This writing process 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 (Eds.), 1994, *The Content of Science: A Constructivist Approach to Its Teaching and Learning*, and R. Millar, J. Leach & J. Osborne (Eds.), 2000, *Improving Science Education: The Contribution of Research*. More recently, the approach has been 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—formative, 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 and Waikato University and the commitment, openness and sharing of all participants in the workshop.

Clayton, Australia — Deborah Corrigan
Hamilton, New Zealand — Cathy Buntting
Hamilton, New Zealand — Alister Jones
Clayton, Australia — Angela Fitzgerald
September, 2019

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Joseph Roche is an Astrophysicist and Assistant Professor in Science Education at Trinity College Dublin, contributing to courses on Science Education, Communication and Society. He has worked for NASA and observed symbiotic stars using the Hubble Space Telescope. He is based in the School of Education but is seconded to Science Gallery Dublin for 50% of his time. His current research interests include informal science education, citizen science and evaluating public engagement in science.

Shirley Simon is Professor of Science Education at the UCL Institute of Education. She began her career as a chemistry teacher and taught in inner-city London schools before completing her doctorate. Her research has focused on science inquiry, cognitive acceleration, argumentation, teacher learning, students' attitudes towards science and students' career choice. She supervises doctoral students working in many aspects of science education.

Kathy Smith is a Senior Lecturer at Monash University. She has expertise in science education and a particular research interest in teacher professional learning and the conditions that build teacher capacity for self-directed learning. She began her career as a primary teacher and worked in the role for over 9 years. In more recent years, she has worked across education sectors in projects related to science education and teacher professional learning and assisted with the development and implementation of a sector-wide Science Education Strategy for Catholic Education Melbourne.

The Shifting Sands of Values in Science Education. An Introduction

Deborah Corrigan, Cathy Buntting, Alister Jones, and Angela Fitzgerald

In 2007, the Monash-Kings College London International Centre for the Study of Science and Mathematics Curriculum edited a book called *The Re-emergence of Values in Science Education*. In his review of this book, Derek Hodson (2008) stated, "The book is timely, in that it reflects a discernible shift in the science curriculum in many countries towards consideration of the ways in which socio-cultural, economic and political factors impact on science and technology" (p. 995).

At that time, the editors raised the question, "Why consider values and the science curriculum?" (Gunstone, Corrigan, & Dillon, 2007, p. 8) and argued that issues relating to values have always had a place in school science curriculum. However, what was evident from this original book was that different countries and cultures have had different traditions in relation to the place of values in their school science curriculum. What was also becoming obvious, at this time, was that science curricula across the globe were changing and challenging such traditions.

It has now been more than a decade since this original book and so it is timely to reflect back on how values have been considered, and particularly in terms of socio-cultural, economic and political factors that have impacted broadly on science, technology and society, and more specifically on informal and formal science curricula. Hence the title of this book has been framed as *Values in Science Education: The shifting sands.*

As in the first book, this collection focuses on values that are centrally associated with science and its teaching, and not the more general notion of values such as cooperation or teamwork that are also important values in current curricula. Again, we have adopted Halstead's (1996) broad definition of values: "the principles, fundamental convictions, ideals, standards, or life stances which act as general guides

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D. Corrigan et al. (eds.), *Values in Science Education*,
https://doi.org/10.1007/978-3-030-42172-4_1

or as points of reference in decision-making or the evaluation of beliefs or actions and which are closely connected to personal integrity and personal identity" (p. 5).

Such a broad definition of values allows consideration of a wide range of factors that influence science education, including socio-cultural, philosophical and psychological factors; the nature of science; in school and out of school science education aims and curricula; the relationship between science, technology, society and the environment; teaching and learning practices; assessment and evaluation; teacher education; learning contexts; and so on.

However, it also important to reconsider Allchin's (1998) comments regarding how values interact with science:

> Values intersect with science in three primary ways. First, there are values, particularly epistemic values, which guide scientific research itself. Second, because scientific enterprise is always embedded in some particular culture, values enter science through its individual practitioners, whether consciously or not. Finally, values emerge from science, both as a product and a process, and can be redistributed more broadly in the culture or society. (p. 1083)

From differing perspectives and to varying extents, each of the chapters in this volume considers one or more of these broad forms of values/science interactions.

This book has been structured into four sections. In the first section, *Values in Science*, some values that underpin science are considered, particularly in terms of how they can be applied through different practices. Such practices include the application of values in public education (Léonie Rennie), in professional learning that explores teachers' understanding of such values (Kathy Smith and Deborah Corrigan) and how values shift as you engage in career progression (Rebecca Cooper and John Loughran).

The second section focuses on *Values for Science Education*, with chapters exploring values that are important in framing up what is important in science education. As science education is called upon to develop scientific literacy – or even critical scientific literacy – for all students to prepare them for their citizenry in the twenty-first century, it becomes clear that traditional approaches to developing such values is no longer fit for purpose. In these three chapters contemporary examples are used to demonstrate how values positions can shift and that science education needs to address such shifts. Karen Marangio and Richard Gunstone focus on media and social media to examine how "fake news" has been misrepresenting science and what this means for science education. Joseph Roche and Colette Murphy consider how Science Gallery provides an effective vehicle to bring experts in science and art together with youth who have largely become disengaged with science in order to reignite their interest in and engagement with science. Cathy Buntting and Alister Jones explore how the complex context of biotechnology can help students develop values discourse as well as their ethics and futures thinking skills to assist them in navigating contemporary biotechnological controversies.

In the third section, the focus shifts to *Values of Science Education* practice. In this section the chapters explore how teachers can be supported to take ownership of what they value in science education. The chapters demonstrate how practitioners hold onto their values in changing environments and contexts for their practice. As a result, practitioners constantly need to re-examine their values for relevance in such dynamic contexts. For example, Shirley Simon and John Connolly discuss the importance of values congruence. Tetsui Isosaki examines one purpose of Japan's "Lesson Study" as being to push teachers to articulate their values and to take ownership of both their values and practices. Justin Dillon and Alan Reid revisit Minstead Study Centre 10 years after first writing about the values held by the educators at this residential environmental study centre to investigate how the values and practices have or haven't shifted.

In the final section of the book, the focus turns to the *Values of Science Education Systems*. In exploring the values supported by science education systems, the authors consider the historical, political, economic, cultural and social influences and examine whose values count most in such systems. Gillian Kidman and Peter Fensham take a historical perspective as to how values representation in science curriculum have changed and clearly highlight how decisions about what values are important have been made. Jennifer Mansfield and Michael Reiss revisit Michael's chapter from the first book where he explored the aims of science education. In this updated chapter, they situate their analysis in the contemporary global world, and in effect delve more deeply into curriculum after Kidman and Fensham's historical perspective. Taking a different perspective, Angela Fitzgerald and Diana Abouali use a world heritage site—Petra—as a case study for examining whose values count most in this fragile ecosystem.

Over the decade since *The re-emergence of values in science education* was published, values have indeed become more of a focus in science education. This may be a response to the changing global context, where technological changes have been rapid and accelerating. In such complex and risky environments, it is our guiding principles that become the important mainstays of our decisions and practices. In terms of science education, what is becoming clearer is that traditional content and traditional science and scientific methods are not enough for science and hence science education to meet such challenges. What we have noticed with this new volume is that all of the chapters, when mapped onto continua of traditional content versus scientific literacy and traditional science and scientific methods versus contemporary science and processes (see Fig. 1), focus more on the scientific literacy and contemporary science and processes.

It would be expected that Gillian Kidman and Peter Fensham's chapter is located in the middle of each of these continua given its historical perspective. Similarly, Tetsuo Isozaki's chapter on Japan's Lesson Study is focused on the middle of the content continuum and favours traditional science and scientific methods. Again, this is not unexpected given that this chapter focuses on working with teachers in their classroom and the rate of change is slow as it takes time to shift teacher thinking, values and practices. This is similar for the Smith and Corrigan and Simon and Connelly chapters, which again involve working with teachers. For those chapters using contexts outside of school classrooms, such as Marangio and Gunstone, Rennie, Dillon and Reid, Roche and Murphy and Fitzgerald and Abouali, the position extends more towards the contemporary science and processes and scientific literacy continua. Perhaps this is an indication of the structural impediments of schools that it is the out of school examples that have greater opportunity to realise more contemporary goals of science education. The fact that Mansfield and Reiss in

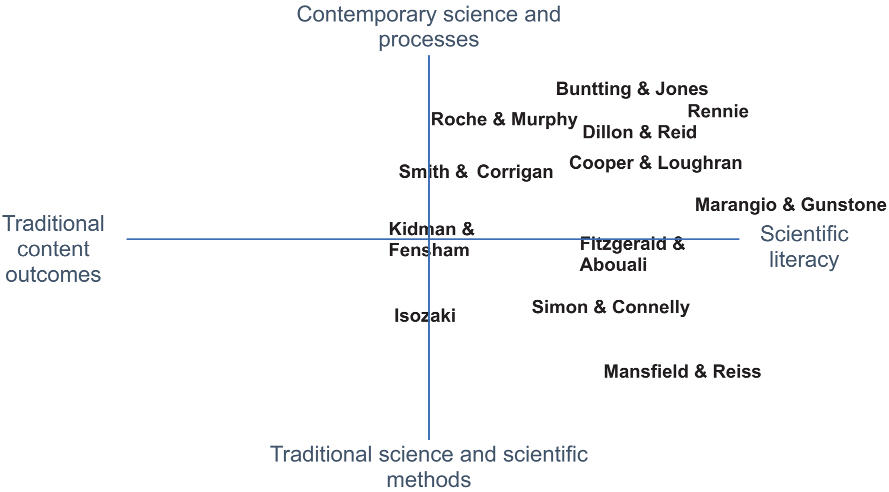

Fig. 1 Mapping the book's chapters onto content and process continua

their consideration of the aims of science education also have constraints in terms of traditional science and scientific methods reinforces this notion. However, the chapter on biotechnology by Buntting and Jones highlights opportunities for values learning within school contexts. Another exception is the chapter by Cooper and Loughran, which focuses on career progression from school science teacher to science educator. Does the transition to the non-school sector also provide greater opportunities for engaging in risk and complexity of modern life and education?

In 2007, *The re-emergence of values in science education* indicated a discernible shifting in the science curriculum. More than a decade later, these shifts continue, perhaps in more diverse ways than originally considered. However, tensions remain in curriculum development and implementation, as evidenced by the continued diversity of views about what and whose values matter most.

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Part I
Values in Science

Deborah Corrigan

The first section of this book comprises three chapters whose primary focus is on values in science and the ways they may be applied in different practices, such as in public education (Rennie), in teachers' professional learning that explores their understanding of such values (Corrigan & Smith) and how values in science can be viewed (and valued) differently by teachers as they progress through their careers (Cooper & Loughran). While each of these chapters are applying values in science in very different practices, there is no doubt about their common theme of the importance of considering such values and the impact such consideration can have on the practice concerned. As indicated by Cooper and Loughran, this is challenging work, but work essential to engage with. It is hoped that the examples in the chapters provide some insights into how such engagement might be fostered and supported.

Léonie Rennie expands on previous work she has done in out-of-school science learning and how communicating science is fundamental to science being understood by the public. In this chapter she explores how important epistemic values in science, such a fallibility, are often misrepresented or not understood in a scientific sense by the general public. In particular, the chapter focuses on certainty—and more importantly uncertainty—and how powerful uncertainty is to scientists as a measure of how well something is known as opposed to everyday thinking of uncertainty as not knowing. Throughout the chapter, Léonie distinguishes between some important values in science - science is reliable but not certain; there needs to be trust in science as it represents a rational perspective based on evidence - and cognitive attitudes such as certainty/uncertainty, trust/distrust and opinion/fact. These cognitive attitudes can easily be superimposed on values in science, particularly if the communication of science lacks purpose, or is not messaged to the audience in accessible ways that are clear and credible.

Kathy Smith and Deborah Corrigan take a different approach to exploring values in science. In their chapter, they explore teachers' personal values and beliefs about science and the relationship these perspectives have with their science teaching and learning. Such personal values and beliefs often remain implicit in teacher thinking and yet have a profound effect on teacher practice. In this chapter they explore ways in which they have engaged with teachers in professional learning programmes that uncover these personal beliefs, highlighting the challenges that this can present. They also point out the need for specific conditions in order for such professional learning to occur, including building high levels of trust, providing time, and actively valuing critical reflection for the social construction of professional knowledge.

Continuing the focus on how values in science are reflected in practice, Rebecca Cooper and John Loughran use values in science to consider how science is viewed (and valued) by teachers, teacher educators and students of teaching, and how it plays out in practice. As teacher educators, an important question is how to encourage students of teaching to see the importance of considering values in science as part of their teaching. This challenging work is exemplified in this chapter through Rebecca's use of her personal story of a teacher who becomes a teacher educator, teaching students of teaching.

Communicating Certainty and Uncertainty in Science in Out-of-School Contexts

Léonie J. Rennie

Introduction

A decade ago, in the first book in this book series, I proposed a model, a heuristic or way of thinking, about the communication of science as an interactive and contextual process in which a range of non-science values were introduced (Rennie, 2007). I suggested that, in order to communicate science to others, complex scientific information was selectively repackaged into a "science-related story" that might be represented in a textbook, newspaper article, or museum exhibit, for example. By interacting with this representation, people would interpret the science in ways that reflected their interest and motivation, their prior knowledge and experience, and other dispositions. The heuristic drew from the work of others, including Layton, Jenkins, Macgill, and Davey (1993), who explored how people rework information about science and recontextualise it into something that is meaningful to them, and Falk and Dierking (2000), who explained how people's personal contexts determine the uniqueness of their experience in learning places such as museums. Using front-page science-related stories in newspapers, I illustrated how various science and non-science values were conveyed in the media, describing this as "a process by which the science becomes nuanced, inflected, and sometimes distorted, by social values or contextual issues relating to economics, politics, religion and culture" (Rennie, 2007, p. 208). In concluding that chapter, I returned to cognitive attitudes and their link to epistemic science values by referring to unexpected outcomes for many people attending a science centre, museum, or genetics lecture, who subsequently demonstrated "less scientific" thinking relating to some epistemic values of science, such as its fallibility.

This chapter builds on those unexpected outcomes and is in three parts. The first part establishes the importance of understanding certainty and uncertainty in

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D. Corrigan et al. (eds.), *Values in Science Education*,
https://doi.org/10.1007/978-3-030-42172-4_2

relation to scientific evidence, risk in decision-making, and trust in science and scientists. It begins with a museum-based story about certainty and scientific evidence, then describes the circumstances surrounding two significant international events that demonstrate the consequences of failing to understand uncertainty in science. In the second part of the chapter, I revisit and amplify that reference to adults thinking less scientifically after a science-related experience, and examine how values and beliefs relating to the certainty/uncertainty of scientific knowledge are inherent in how science is communicated in public places like museums. In the third part of the chapter, I suggest that if people are to be encouraged to think more scientifically about the nature of science and its processes, a greater effort is needed to present science in ways that may be interpreted as controversial, but communicate uncertainty in scientific evidence. This is a difficult process, and the chapter concludes by exploring how a balanced exhibition might be achieved.

Part One: Science Is About Uncertainty

To indulge my passion for geoscience, a colleague (Robin Hansen) and I decided to look closely at some Australian gemstones held in the collection of the Natural History Museum (NHM) in London (see Hansen & Rennie, 2017). In old museum collections the provenance of many specimens is often incomplete, so we planned to select a few interesting gemstones with limited provenance, describe them thoroughly, then research their socio-historical background to illuminate the geological origin and likely location of the specimens. We would have fun and, hopefully, add information to the NHM's gemmological database.

Our selection included two small facetted gemstones, one red and one yellow, purchased from an English mineral dealer in May, 1889, and labelled as cassiterite from New South Wales. We chose these specimens because they were unusual, particularly for Australia. The mineral cassiterite (SnO_2) is the main source of tin and usually an opaque dark grey, "but very rarely, [it has] been found in small, transparent, yellow and reddish stones suitable for cutting" (Smith, 1913, p. 281). At the time of writing this seminal text on gemstones, Smith was a mineralogist at the museum where the stones were held, and was likely thinking of the very stones we had chosen. Much later, when Coenraads (1995) wrote about the gemstones of New South Wales, he too described the facetable gem variety of cassiterite as "extremely rare".

We first described the optical, and then the physical properties of our stones, including determining their specific gravity (SG, the density of the specimen compared to the density of water). To find SG we employed Archimedes' principle, which I still remember from high school physics as "when a body is totally or partially immersed in a fluid it loses weight equal to the weight of the fluid displaced". Traditionally, gemmologists learn to determine SG by weighing the well-cleaned gem in air, then weighing it immersed in water to obtain its volume by loss in weight. SG is calculated as the ratio between weight in air/loss of weight in water.

The measurements and the resulting calculation contain a component of error that becomes quite significant with small stones. Our red stone weighed only 0.168 g and was badly chipped, and the yellow stone was even smaller at 0.060 g, also with a tiny chip. To minimise measurement error (caused by bubbles adhering to the uneven surface of the chip, for example) the procedure was repeated three times and the average found. Not surprisingly, we found the weight in air varied in the fifth decimal place, but the weight in water varied in the third decimal place. The results were red stone, SG = 7.17, and yellow stone, SG = 3.79. The SG of cassiterite is variable (usually because of contamination with iron oxides) and generally given as the range 6.8 to 7.1 (Smith, 1913), so even allowing for measurement error, the low SG for our yellow stone indicated that it could not be cassiterite. Determining its refractive index resolved the issue; our yellow stone was actually chrysoberyl ($BeAl_2O_4$) that had been misidentified as cassiterite prior to purchase and, perhaps because it was so small and difficult to handle, it had never been fully tested to confirm its identity.

Science Is Reliable, but It Is not Certain

This science-related story highlights an important characteristic of science, albeit in a simplistic way. We began our scientific investigation believing that both gemstones were cassiterite, but our data required that we change our thinking and provide a re-identification of one stone. Science is reliable; we can use new data to change our minds, but only if we trust the data. In this case, the optical properties of both stones initially appeared to be consistent for cassiterite, but I had fallen into a trap of my own making. Knowing that the refractive index of cassiterite exceeds the range of a gemmological refractometer, and because the stones were small (making it difficult to obtain readings of refractive index), I had not looked very hard to obtain a reading because I didn't expect to find one. Having no information about refractive index meant that determining SG would be critical to confirming the stones as cassiterite. The SG of the yellow stone was too low for cassiterite, and Robin's more careful search with the refractometer detected refractive index readings characteristic of chrysoberyl. We were able to identify the gemstones by comparing our data with mineralogical data sets that were well-established through scientific consensus.

But what happens when there are no well-established data sets for the science-related questions we are trying to answer? What happens when our best scientific knowledge contains measurement error and uncertainty? This means that when science is used to make predictions about future events, predictions will not be certain, they will be probabilistic. Decisions based on those predictions will have an element of uncertainty and therefore an element of risk. Understanding the nature of that uncertainty becomes very important when decisions need to be made.

The Consequences of Failing to Understand Uncertainty

An illustrative case of decision-making when scientific knowledge was uncertain relates to the epidemic of bovine spongiform encephalopathy (BSE, "mad cow" disease), which occurred in the United Kingdom in the 1980s. The public's concern about a possible threat to human health from eating potentially contaminated beef was allayed by strong messages from the government and its advisors that it was safe to eat beef. Then, in March 1996, the Secretary of State for Health announced that a form of Creutzfeldt-Jakob Disease (CJD) detected in humans was thought to be linked to exposure to BSE. Jasanoff (1997), an academic visiting Britain from the USA to research policy in biotechnology, observed the resulting public confusion.

> What made the news so appalling was not just the thought that beef, a staple of the British diet, could be fatally contaminated. It was not even that CJD struck without notice, was incurable, and caused a horrifying death. It was that, since 1988, the government and some of its advisers had repeatedly stated that beef was safe, a formulation widely taken to mean that transmission of BSE from cows to people was impossible. If government officials had deliberately misled the public, then how could anything they now said be trusted? (p. 222)

Jasanoff (1997) described how the British people scrambled for information from other, often quite unreliable, sources to try to find answers about the risk of contracting CJD from eating beef. The lack of trust in government and its science advisors resulted in a high level enquiry by Judge Lord Phillips. Several articles in *Nature* (volume 408) provide comment on its findings. Aldhous (2000) reported that the inquiry "concludes that ministers and civil servants did not deliberately lie to the public — they genuinely believed that the risks were minimal", and that blame was attributed to "institutional deficiencies which led to a mistaken campaign of reassurance that failed to reflect the shifting state of scientific knowledge" (p. 3).

The cause of the confusion was interpreting "minimal risk" to mean "no risk". The British Parliamentary Office of Science and Technology (2004) put it very plainly:

> In the run-up to the BSE crisis in 1996, uncertainties were insufficiently acknowledged, with advisers and ministers representing the lack of any 'sound scientific' evidence for a risk as evidence that it could not occur. It was thus common for politicians to deliver unequivocal assurances of safety. (p. 1)

In reviewing this issue, Reiss (2013) concluded that an important lesson for science communication "is that public trust is easily lost when over-confident assertions are made about the conclusions of science" (p. 152).

This important lesson about loss of trust due to over-confidence was very clearly demonstrated in Italy following the L'Aquila earthquake on April 6, 2009. Here a similar lack of understanding uncertainty led to the prosecution and conviction of manslaughter of six Italian geoscientists and a public official. Duhaime-Ross (2014) related how a series of tremors had led "a local amateur earthquake buff" to predict that a major earthquake was imminent. A meeting of earthquake experts was called for March 31, 2009 to assess the risk and advise the government how to proceed.

Although the geoscientists said that the possibility of an earthquake could not be ruled out, the public official stated his assurance there would be no earthquake, believing that the tremors had discharged energy making a major earthquake unlikely. Although his view was stated before the meeting, the official gave the impression that this was also the scientists' view. Because this reassurance was official, some quake victims had stayed indoors and met their death when the earthquake struck. The citizens were outraged by what turned out to be false reassurance and the scientists and official were prosecuted, based on the argument that they were too confident that an earthquake was improbable, thus failing in their duties. The geoscientists' appeal was upheld but the conviction remained for the official (Cartlidge, 2015a), a verdict reinforced at a subsequent review of the upholding of the appeal (Cartlidge, 2015b). In her summary of these events, Duhaime-Ross (2014) cited statements from various international geoscientists as well as some of the Italians involved in this well-publicised incident. Many referred to the reluctance scientists may now feel in talking about uncertainty due to fear of misinterpretation.

Making decisions about what action to take, and when to take it, are decisions with inherent risk when scientific knowledge is uncertain. Further, decision-makers are influenced by external pressures. In the context of the BSE and L'Aquila narratives we might ask: Which political leaders would risk the economic consequences of banning the eating or export of beef and the subsequent collapse of a major industry when any effect on human health is uncertain? Which political leaders would risk the cost and inconvenience of ordering an evacuation for an earthquake the occurrence of which is uncertain? Determining whether or not risk is acceptable brings other values—economic, political, ethical, and social values—into play. As Allchin (1999) pointed out, "communicating the nature of the risk to non-experts who participate in making decisions can thus become a significant element of science" (p. 8). It also means that dealing with uncertainty becomes an issue for education in science that is closely connected with developing trust in science and the work of scientists.

Science Education and Trust in Science

Fensham (2015) argued that installing trust in science should be an output goal in science education. When Fensham examined how science was portrayed in Australian media he found little that promoted trust, but much that fostered distrust, including focusing on uncertainty in science to raise doubt about the value of evidence. Further, "experts" speaking against scientific positions often had connections with vested interests. Fensham also found a variety of media reports that uncritically implied causal relationships where none was shown to exist. Marangio and Gunstone (Chapter "Science as "Just Opinion" – The Significance for Science Education of Emerging Social Media", this volume) provide an international perspective on how the misrepresentation of science in the media is leading to a view of science as "just one opinion" rather than a rational perspective based on evidence. This phenomenon is accelerated by the unfettered purveying in social media of unsubstantiated opinion about science, health, and environmental issues. Like Fensham (2015), Marangio and Gunstone argue that science education has given little attention to assisting students to develop an informed trust in science.

This problem is not new. Norris (1995) suggested that in learning about science, as distinct from learning science, students should experience

> a full treatment of the issue of scientific expertise, including its basis in a community of trust, the uncertainty and ambiguity that often accompany expert claims to knowledge, and the disputes, disagreements, and differences of opinion that pervade science. Students should be taught the sense in which knowledge does rest on authority, and that this authority is not infallible. (p. 215)

Unfortunately, as Kirch (2012) pointed out:

> Questions that illuminate sources and types of uncertainty—have no place in current science curricula because current practices typically do not facilitate teaching and learning how scientific knowledge is constructed or how nonscientists should use or benefit from science knowledge. (p. 853)

Fensham (2015) recognised that filling "gaps" in school science curricula, by learning about probabilistic science, uncertainty in science, and nature of science, and distinguishing between correlation and causation, would require a different pedagogy and considerable societal pressure for the change. He concluded that if these new learnings were acquired, students would develop "a basis for deciding how and when to place trust in science. They will become, not experts in science, but rather *connoisseurs of science*" (p. 57, original emphasis). Fensham used the term connoisseur in the sense of "a person who has acquired the appropriate knowledge in a particular field to be discerning about aspects of it, and to make judgements about them" (p. 37). Such people would understand and be able to assess the value of science and its use in decision-making—surely an aspirational goal for all citizens.

If science education has yet to meet the challenge, how will citizens learn to understand and value the use of science in decision-making? Opportunities to learn science out-of-school are dominated by the media, but both Fensham (2015) and Marangio and Gunstone (Chapter "Science as "Just Opinion" – The Significance for Science Education of Emerging Social Media", this volume) make clear that science communication in the media is problematic, and there is no evidence that the quality of this communication is improving. There are other avenues—Marangio and Gunstone mention organisations such as museums—where the public can interact with science and learn to appreciate the more subtle values of science, such as its fallibility. Effective science communication is the key.

Part Two: Adults' Scientific Thinking After Science-Related Experiences

Two decades ago, Gina Williams and I responded to a request from the director of the local science centre to evaluate its series of public lectures about human genetics. To operationalise this task, we asked "What is the impact of a lecture on attendees' perceptions, ideas and opinions about human genetics?" We were well aware of the problems in measuring the impact of a transitory experience like a lecture and we found no reports of any similar lecture evaluations that could offer guidance. There were also practical difficulties, such as gathering meaningful data, in a very short time, from people intent on fulfilling their own agenda for attending the lecture, rather than meeting our need to collect data. There was no comparison group, so in a one-group, pretest-posttest design we used a primarily closed response questionnaire to collect complete sets of data for 72 adults in the first lecture they attended. To measure how people thought about the nature of knowledge and process in science (here, specifically human genetics), we adopted Smith and Scharmann's (1999) argument that people's ideas can be more scientific or less scientific, and framed some questions based on their lists of characteristics that make a field of study more or less "scientific". Our questionnaire contained 14 paired statements in a semantic differential format with a 7-point response format, and posttest-pretest responses were compared using the non-parametric Wilcoxon Matched-Pairs Signed-Ranks Test. Full details of the questionnaire, data collection, findings, and our interpretations are available in Rennie and Williams (2000), but of interest here are several specific findings about attendees' perceptions about the nature of genetics knowledge and genetics research.

Overall, the results suggested that lecture attendance had some impact on adults' views about science. Statistically significant increases were found on questions relating to attendees' interest in learning about genetics, their view that everyone needs to have some knowledge about genetics, their confidence in talking about human genetics with other people, their belief that research in human genetics has many practical applications, and that the benefits of research in human genetics outweighed the risks. However, when asked to choose between the statements "genetic knowledge consists of the facts", and "genetic knowledge has an element of uncertainty", there was a statistically significant move towards thinking that genetic knowledge consists of the facts. This suggested that some adults were thinking less scientifically about the nature of scientific knowledge after the lectures than before.

The finding that some attendees became more convinced that genetics knowledge was certain was unexpected. Our raw data indicated a wide spread of responses on both the pretest and the posttest, and that 24 of the 72 attendees had negative ranks (the largest change on all items), but 11 attendees had positive ranks, resulting in an effect size of −0.30. We had attended all lectures and, based on our observations and field notes, we thought a possible explanation was that because lecturers had tried to make their (often complex) topic readily understandable by a lay audience, some attendees could assume that the content was more certain than it often was. Of course, the certainty/uncertainty question is also relative to our findings. Would there be similar findings on another set of lectures? Perhaps more importantly, were these findings an impact attributable to lecture attendance? How could we be certain that our findings were trustworthy?

Establishing Trust in Research Findings

After scientific research into our red and yellow gemstones, Robin and I were certain that they were cassiterite and chrysoberyl, respectively, because the properties we had measured ruled out all other possible identifications. Reaching conclusions in social and educational research is never as straightforward as measuring properties, but one principle is the same: Researchers must rule out alternative explanations for their findings. Studies where the researcher randomly assigns subjects to treatment or control groups, introduces an intervention and then determines if the expected effect follows are rarely possible in education, because the researcher cannot randomly select subjects and assign the intervention. In naturalistic studies such as our evaluation, where there is no control group and the population is voluntary, the task becomes one of finding an impact and, assuming there is temporal precedence (that is, the intervention precedes the impact), attributing impact to the intervention by ruling out alternative explanations. The research complexity is greatly enhanced by the fact that the researcher must work retrospectively, that is, from effect to cause, with humans who are an extremely heterogeneous group! In evaluating the lecture series we took as many steps as possible to enhance confidence in our findings by controlling for extraneous factors that might affect our results (see Rennie & Williams, 2000). As we expected, impacts were variable over our sample of 72 attendees, but we were intrigued that a science-related experience had the effect of encouraging some adults to think "less scientifically" about the nature of science.

More Intriguing Findings

Further opportunities to explore adults' views about science came via parallel studies that explored the effect of visits by 102 adults to a science centre (Rennie & Williams, 2002) and a different group of 102 adults to a natural history museum (Rennie & Williams, 2006a). These studies also employed a one group, pretest-posttest design, but with a more detailed questionnaire and followed by post-visit interviews with over half of each group. At each institution we were able to survey a large number of staff and interview many of these as well. Whereas the sample for the evaluation of the genetics lectures included all of the attendees prepared to complete our questionnaire, we had more choice about who was included in the science centre and museum samples. At each venue we aimed for a stratified random sample of 100 adults with a balance of age and sex, and we collected data on all days of the week to cover different visitor groups. Our questionnaire used the same semantic differential format as the lecture series, with a 7-point response format between pairs of oppositely worded statements, but contained a more comprehensive set of items. Items were presented in three sections headed *Science*, *Scientific Research and the Community*, and *Science and Me*, containing items that reflected, respectively, Shen's (1975) ideas of cultural, civic and practical scientific literacy. They also reflected Smith and Scharmann's (1999) lists of characteristics that make a field of study more or less "scientific". A fourth, post-test only section, addressed adults' perceptions of *Science at the Centre/Museum*. Full details are available in Rennie and Williams (2002, 2006a); here we focus on those items relevant to the discussion, but it is important to note that all visitors reported positive views of their visit experience.

Table 1 summarises the findings relating to seven questionnaire items and, where possible, includes results for similar items from the human genetics lecture series (a more complete comparison of items is available in Rennie & Williams, 2006b). Although the data are ordinal, not interval, means and standard deviations are included to indicate the location of an "average" response and the spread of responses, because on nearly every item the full range of scores was used, indicating varying views particularly on items where the mean was around the midpoint of 4.

Inspection of Table 1 reveals that nearly all adults at all venues had positive views about the need for ordinary people (i.e., non-scientists) to have some knowledge about science/genetics, a view that became more positive after the visit/lecture (see Item 1). Item 2 had a wider spread of responses but also a tendency for people to feel more confident to talk about science/genetics after their visit/lecture. The results for Item 3 show that adults were generally positive that research in science does more good than harm, a view that was unchanged by the visit. In a similar item, attendees became more positive after the lecture that benefits outweighed the risks in genetics research. Although the associated effect sizes for statistically significant changes over these items are small, these results, and indeed the results on most items, revealed generally positive perceptions and views about science and scientific research, views that were often enhanced by the visit/lecture. However, when asked questions relating to uncertainty in science/genetics knowledge a different picture emerged.

The results for the fourth item in Table 1 show that, after their visit to the science centre or museum, adults were more likely to think that scientific explanations are definite, rather than have an element of uncertainty. This result is consistent with the finding that lecture attendees became more likely to think that genetics knowledge is factual rather than uncertain (see also Item 4 in Table 1). These changes were statistically significant with effect sizes ranging between −0.17 and − 0.27, modest but noticeable. For visitors to the science centre and museum, these findings were supported by the results of two more items (Items 5 and 6 in Table 1) that revealed a clear tendency to respond, after their visit, that science has the answers to all problems and that scientists always agree with each other. These effect sizes were mostly

Table 1 Adults' changes in perceptions about science after visiting a Science Centre, Museum, or attending a lecture

Item	Pairs of statements (CM = Centre and Museum, L = Lecture series)		Science Centre (N = 102)			Museum (N = 102)			Lecture Series (N = 72)		
	Negative or less scientific wording (score = 1)	Positive or more scientific wording (score = 7)	Pretest mean (SD)	Change in mean (posttest-pretest	Effect size	Pretest mean (SD)	Change in mean (posttest-pretest	Effect size	Pre-test mean (SD)	Change in mean (posttest-pretest	Effect size
1	CM: Only scientists need knowledge about science L: Only specialists need knowledge about genetics	CM: Everyone needs knowledge about science L: Everyone needs knowledge about genetics	6.04 (1.45)	+.20	ns	6.08 (1.32)	+.28***	d = +.24	5.73 (1.61)	+.43**	d = +.28
2	CM: I don't feel confident talking about scientific topics with friends L: I don't feel confident talking about human genetics with others	CM: I feel confident talking about scientific topics with friends L: I feel confident talking about human genetics with others	4.53 (1.89)	+.24**	d = +.14	4.93 (1.96)	+.14	ns	5.28 (1.94)	+.38**	d = +.20
3	CM: Scientific research does more harm than good L: Risks of research in human genetics outweigh benefits	CM: Scientific research does more good than harm L: Benefits of research in human genetics outweigh risks	5.54 (1.61)	−.03	ns	5.66 (1.36)	.00	ns	4.66 (2.14)	+0.39*	d = 0.19

4	CM: Scientific explanations are definite L: Genetic knowledge consists of the facts	CM: Scientific explanations have an element of uncertainty L: Genetics knowledge has an element of uncertainty	4.32 (1.72)	−.46***	d = −.27	4.54 (1.83)	−.30**	d = −.17	4.87 (2.10)	−.54**	d = −.25
5	CM: Science has the answers to all problems	CM: Science doesn't always have the answers to problems	4.64 (1.84)	−.74***	d = −.42	4.70 (1.80)	−.45***	d = −.26	na		
6	CM: Scientists always agree with each other	CM: Scientists often disagree with each other	6.03 (1.33)	−.74***	d = −.53	5.90 (1.43)	−.59***	d = −.41	na		
7	CM: Scientists do not communicate their research clearly to ordinary people L: Scientists do not communicate their findings to the public	CM: Scientists do communicate their research clearly to ordinary people L: Scientists communicate their findings to the public	3.74 (1.50)	+.74***	d = +.51	3.51 (1.38)	+.67***	d = +.48	4.84 (1.71)	−.13	ns

Notes: *p < .05; ** p < .01; ***p < .001; *ns* change not statistically significant so effect size not calculated; *na* parallel question not asked at lecture series substantial, ranging between −0.26 and − 0.53. Many adults began to think less scientifically, a result at odds with the generally accepted notion of fallibility in scientific knowledge.

We explained this result from the genetics lectures in terms of the lecturers simplifying quite complex content for their lay audience, and in the process, making it seem more definite and less uncertain. In other words, it was about how the science was being communicated. Our lecture questionnaire found no overall change in attendees' fairly positive view that scientists communicate their findings to the public (see Item 7 in Table 1). This result wasn't surprising because the scientists were there, in person, talking about their research. At the science centre and museum we were more specific, asking if scientists communicated their research *clearly*. After their visit, many adults became more positive that scientists do communicate their research clearly, indeed the mean score moved from below the midpoint to above it, with effect sizes around −0.5. This change in views was the result of experience with exhibits designed to convey information about science, rather than personal experience with scientists. Somehow, communication via exhibits seemed to result in making scientific knowledge seem more certain. How could this happen?

Communicating Uncertainty in Science Centres and Museums

In earlier explorations of science communication in out-of-school contexts, a heuristic was used to explain how values other than science permeated front page news stories about science-related topics (Rennie, 2007), and also to demonstrate the importance of provoking a two-way dialogue between visitors and various museum exhibitions for successful communication of the science content represented (Rennie, 2013). This heuristic has been reworked into Fig. 1 to refer specifically to the context described here.

Figure 1 shows that representing science content in an exhibit or a lecture requires three steps. First, the developer must select what science is to be communicated. Second, this science content must be translated, or reworked into a form that can be understood by the intended audience. Third, the developer must decide how this reworked content will be presented to the audience. Once it is selected and reworked, the developer no longer has "science" as the scientists know it, but a science-related story. The process of restructuring the science content continues, because the audience, the visitors or lecture attendees, respond by reshaping it again, into personal structures that are meaningful in the context of their own background knowledge and dispositions. The term "background knowledge and dispositions" emphasises the heterogeneity of the audience and the uniqueness of their response.

I suggest that the findings reported above, where some adults have responded to their science-related experience at the science centre, museum, or lecture, in ways that are less scientific, are attributable to how the science is communicated. As illustrated in Fig. 1, this response depends on two factors. The first is the way the science content is selected, translated, and represented to the audience as a science story.

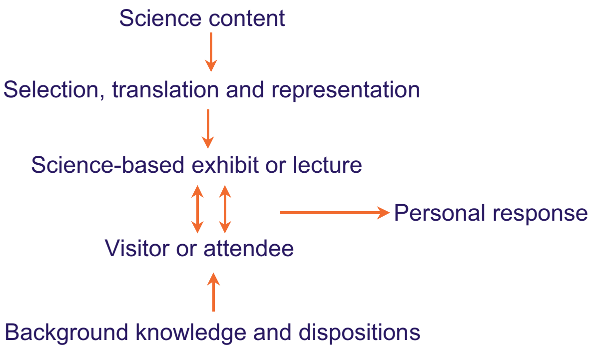

Fig. 1 A heuristic demonstrating the communication of science via an exhibit or lecture

Some of the possibly controversial aspects of science and/or uncertainty in the science knowledge that could have been revealed in those exhibits or lectures had been glossed over, either by omission, oversimplification, or ineffective representation. This is not a criticism of the developers, but recognition that it is exceptionally difficult to portray uncertainty, risk, and controversy in ways that are readily understood, particularly in stand-alone representations such as exhibits. The second factor is the nature of the audience's engagement with the science story presented and this depends on their personal context. Engagement with the science story is crucial. Did visitors stop and think about the exhibit, or did they pass it by? Did they listen critically to information presented by the lecturer or accept it at face value? Unless a person engages thoughtfully with the exhibit or lecture, there can be no communication; effective communication requires a two-way dialogue between person and exhibit (Rennie, 2013).

Staff perceptions about the educative role of their science centre or museum are important determinants of whether or not exhibits that demonstrate controversy are developed and displayed. We found evidence that some staff at the science centre and museum were concerned that their exhibits were not demonstrating controversial issues in science. One item on the *Science at the Centre/Museum* section of the questionnaire was responded to by both visitors and staff, and the distributions of responses at the science centre and museum are reported in Fig. 2. Although the responses are wide-spread, it is clear that, overall, staff were less satisfied than visitors that controversy was represented in their exhibits, differences that were statistically significant at both venues.

In interview, some staff commented on their desire to show more about the controversial and value-laden aspects of science, as the following two quotations demonstrate.

> *One of the things I believe really strongly, that we need to work more on at the centre, is the fallibility of science. Like I think the perception among a lot of people is that scientists…know it all…they're always right. Science says this so it must be this, but really science is very fallible. (Exhibitions Manager, science centre).*

> *I believe that done properly we can awaken [visitors'] questioning and so instead of museums in the past saying this is the truth, what we are going to be saying more and more is,*

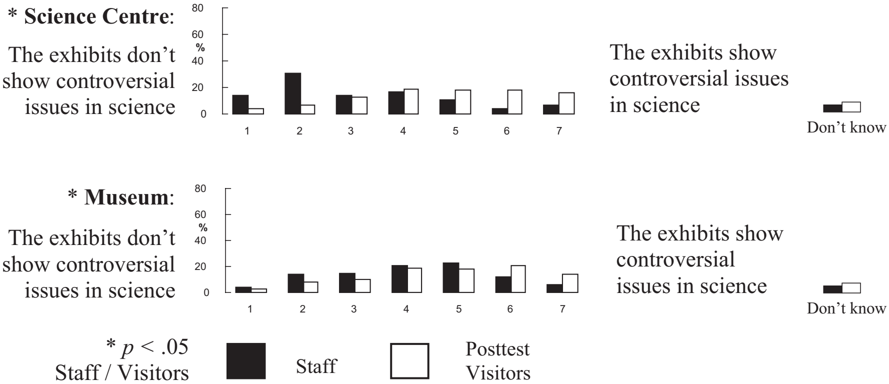

Fig. 2 Responses of science centre and museum staff and visitors to an item about controversy in exhibits

> *well, here is a story from an Aboriginal perspective, here is a white person's perspective, and here is the historical perspective. What do you think? And that's more scientific because you are presenting a series of arguments, check your hypotheses, what do you think? You make your decision. (Director of Museum Services).*

But many staff at both venues were proud that they could show science that was readily understandable, and perceived the role of their institution was to communicate that to their visitors.

> *I know how particular exhibits work and so I'm able to explain [that]…and I think that's where [the centre] is really important as a hands-on exhibition centre, because it's able to simplify science for lay people like myself and the general public…We're able to understand it a lot better than we would had we been taught it in a textbook at school because we can see science working at [the centre]. (Visitor Service supervisor).*
>
> *I think our main aim in life is to tell the story of the collections to the general public, not to address it to the already educated. (Coordinator, Museum Travelling Exhibits).*
>
> *The museum has a very special role in science education…because one of our major briefs is to present science in an easily digestible format that the average member of the public can assimilate. (Curator).*

Unquestionably, science centres and museums have a major educative role to play in presenting science in ways that are understandable by their visitors. The question of interest to this chapter is whether or not controversial aspects of science should be presented to enable visitors to consider the fallibility in a social context. Two decades ago, Emlyn Koster (1999), then President and CEO of the Liberty Science Centre, New Jersey, argued that science centres should be innovators in science and technology; facilitating informed public discussion was part of the science centre's social responsibility. "Science centres also have the power, as yet almost entirely untapped, to empower people to be active commentators on the science and technology issues surrounding them" (p. 289). In order to make informed comment on science and technology issues people need an understanding of the nature of science and scientific knowledge.

Part Three: Valuing and Portraying Uncertainty in Science in Museum Exhibitions

The arguments in this chapter are based on the premise that the inherent uncertainty in science is something to be both understood and valued. Henry Pollack claimed that "uncertainty is one major driving force for scientists in their production of knowledge about how the world works" (as cited in Kirch, 2012, p. 852). Carlo Rovelli (2012), a physicist working in quantum gravity, espoused a similar view:

> Science is not about certainty. Science is about finding the most reliable way of thinking, at the present level of knowledge. Science is extremely reliable; it's not certain. In fact, not only it's not certain, but it's the lack of certainty that grounds it. Scientific ideas are credible not because they are sure, but because they are the ones that have survived all the possible past critiques, and they are the most credible because they were put on the table for everybody's criticism. (p. 6/11)

Science is not certain for most real-world issues. The science about global warming is reliable but there is a lack of certainty about its impact. Mitchell (1997) explained the reasons for this uncertainty very clearly some time ago, pointing out that "the uncertainties really begin to intrude when we look to the future" (p. 2/8). As the Union of Concerned Scientists (n.d.) stated, "To most of us, uncertainty means not knowing. To scientists, however, uncertainty is how well something is known. And therein lies an important difference, especially when trying to understand what is known about climate change". This difference is used as a strategy by those who aim to discredit science by focusing on uncertainty. Their purpose is to encourage lay-people, the public, to think that because scientists are uncertain, they don't know. In fact, scientists do know, they know a lot, they know it well, and it is part of their job to convey how well they know it in probabilistic terms. In a manuscript supported by the US National Science foundation, Fischhoff and Davis (2014) set out a protocol for providing decision-makers with the sources of uncertainty in circumstances where decisions need to be made about when to take action, and what decision choices to make. The details are beyond the scope of this chapter, but the development of such protocols demonstrates the need to recognise uncertainty and the importance of communicating it to decision-makers.

Understanding and interpreting what uncertainty means is a significant skill that ordinary people need if they are to make sensible decisions about health and environmental issues. One avenue for adults to learn about uncertainty and risks in decision-making in science is through visits to science centres and museums. However, the results reported earlier suggest that it is much easier to present science in exhibitions and lectures as factual, non-controversial, and readily understandable than as human, fallible, often controversial, and frequently complex. This is because exhibitions designed to portray risk and uncertainty usually deal with socio-scientific issues that evoke a range of social, ethical, and political values and/or cultural or religious beliefs. These kinds of exhibitions can be complex, confusing, and unsettling to those visitors whose views are being challenged (Pedretti, 2004). Should science centres and museums even consider mounting exhibitions that are likely to confuse and upset their visitors? I believe the answer is yes, they should, because people need to experience these kinds of exhibits if they are to become informed and, in Koster's (1999) words, active commentators on the science and technology issues around them.

Pedretti (2002) produced an insightful analysis of "how science should be re/presented in informal science settings, specifically the possibility of science centres and science museums addressing socio-scientific issues" (p. 2). She described five exhibitions about critical science issues and discussed the issues involved in communicating controversy. Pedretti concluded that "promoting public *debate about science* (as opposed to learning more scientific facts) entails understanding the nature, workings and achievements of science, as well as critiquing the institution and practice of science" (p. 34, original emphasis). What steps can institutions like science centres and museums take to communicate the nature of science more effectively? How can this be done in ways that are not only provocative in that they challenge people's perspectives, but also encourage people to reflect on their perspectives?

Communicating Uncertainty in Controversial Science Exhibitions: Finding Balance

To plan any kind of communication, the communicator must consider the purpose of the communication, how best to make the intended communication accessible by the audience, and how to make the message clear and credible.

The Purpose of the Communication

Stocklmayer (2013) explained the purpose of science communication in terms of three levels of intended knowledge outcomes. Knowledge giving is essentially a one-way communication to inform the audience about the message, perhaps a scientific tenet, such as Archimedes Principle, or information, such as the SG of cassiterite is 6.8–7.1. Knowledge sharing requires a two-way communication because the public audience's own knowledge will become part of the interaction, so the mutual understanding of the science is a shared goal, such as the nature and function of greenhouse gases. Knowledge building also requires two-way communication, with the intended outcome an increased understanding or a different interpretation of the science, such as how the level of carbon dioxide in the atmosphere might change in the future. Knowledge giving is a common goal in exhibitions involving uncertainty because often people do not know the relevant science, however, knowledge sharing and building must be goals of at least parts of the exhibition to enable the audience to use their existing knowledge, confront possible misconceptions, and begin to understand and reflect about the scientific uncertainties relating to possible actions about the issue. An effective exhibition will usually contain exhibits that together provide a balance of all three purposes; knowledge giving, knowledge sharing, and knowledge building.

Making the Communication Accessible

The most fundamental skill of science communication is "the ability to match the communication to the beliefs, values and knowledge of the audience" (Stocklmayer & Rennie, 2017, p. 541). Museum visitors are very diverse in their background knowledge and interest, their beliefs and values, so there is no single, "right" level for presenting science content. Instead there needs to be a "layering" of information from straightforward to more complex so that visitors can find something that fits their cognitive level and interest.

People learn in different ways so communicating science content should not be restricted to signage and panels of text accompanying an exhibit. Science museums depend on an experiential, interactive, hands-on approach to engaging with exhibits, and other means of communication include incorporating web-based information, simulations, computer and other interactives, creating exhibit-related apps for visitors' own digital devices, even involving the visitor in drama, role-play or other dialogue events. Pedretti and Navas-Iannini (2018) described a Brazilian exhibition tackling the controversial issue of teenage pregnancy in an excellent example of a knowledge building using role-play and dialogue. The key to coping with audience diversity is to offer variety in the ways visitors can access the information embodied in the exhibition. Balancing the level of information also includes balancing the nature of its delivery.

Making the Message(s) Clear and Credible

Controversial science issues are invariably complex and value-laden, making them difficult to understand and challenging to communicate. There may be a single, overall message within an exhibition about a controversial issue, but individual exhibits have their own message and each should present a clear translation of the part of the science story it is designed to portray. To represent science as both a practice and producer of knowledge, a balance must be struck between clear explanation of the scientific concept, phenomenon or issue, and conveying its complexity in terms of its uncertainty and relevant social and personal factors (Rennie, 2013). It is a delicate balance: Too much technical jargon leaves the visitor confused and frustrated; too much simplification can be equally frustrating because it reduces the opportunity for learning and may result in misconceptions due to oversimplification. The secret for successful communication through controversial exhibitions, as in other kinds of science communication, is to draw "on a range of scientific and other sources [in order] to compose clear, persuasive and contextualised arguments for a range of audiences" (Stocklmayer & Rennie, 2017, p. 542).

Choosing what content to present and how to package it into a science story is not easy, but if the story can be made personally relevant to the audience, it will not only promote engagement, but the content can be grasped more easily by the audience. Personal context is particularly relevant in critical issue exhibitions (Pedretti, 2004). Based on a synthesis of research in learning science outside of school, Stocklmayer, Rennie, and Gilbert (2010) identified twelve attributes that encourage engagement with science content in informal settings, and these provide suggestions for thinking about effective exhibit design. Two attributes are “facilitating social and community interaction” and “presenting science as messy, human and exploratory in nature, addressing real and current problems” (p. 25). Clearly these attributes are central to learning about uncertainty in science, and lend themselves to knowledge giving, sharing, and building.

Communicating uncertainty and risk is a particularly difficult challenge. As Bryant (2013) pointed out, “Science communicators have great difficulty communicating the concept of risk. Risk for scientists, on the other hand, has a very firm basis in statistical theory and probability” (p. 283). However, statistical theory and probability are often not well understood by a lay audience, so innovative ways are needed to assist the public to come to grips with its meaning. Establishing credibility is fundamental to success. Trumbo (2013) emphasised that “Credibility can be hurt when the audience perceives the message to be inconsistent with the facts or inconsistent with previous messages, when the messenger has a reputation for deceit, or when experts sources appear incompetent or in disagreement” (p. 103). Readily recognisable in this list are some of the things that went wrong in the BSE and L’Aquila events. Generally, science centres and museums are considered to be trustworthy sources of information (American Alliance of Museums, n.d.) so it is important to ensure that trustworthiness is maintained by using and naming credible sources for the science that is presented.

Developers of controversial science exhibitions must be able to distinguish between informing people and influencing them (Trumbo, 2013). People can easily identify messages that are designed to influence and this reduces trust. The answer is to provide alternative responses to the critical issues presented and give people the opportunity to think about the various arguments but make their own decisions about them.

Examples of Controversial Exhibitions

A brief reference to two different kinds of controversial exhibitions will illustrate the points made in the previous section. The first deals with climate change and is forward looking in terms of what decisions might be considered; the second is about evolution and deals with decisions generally made retrospectively.

Dealing with Climate Change

Climate change is a controversial science topic because it has many perspectives, and the social, political, and economic values that underpin decision-making mean that what action to take, and on what level, is often more contested than the underlying body of scientific evidence. How can an exhibition be designed to cope with these many perspectives?

Dillon and Hobson (2013) described how the Science Museum in London prepared to develop a new exhibition about atmospheric science that explored climate change. The Science Museum undertook a comprehensive research process to determine what their potential audience understood and believed about this topic, thus designing their exhibition on evidence rather than opinion about what people thought. Dillon and Hobson discussed a variety of issues raised in the research, including the public's levels of trust, and how the Science Museum responded to these issues. This background work enabled the exhibition designers to identify strategies to engage the public, such as focusing on human stories, explaining the personal relevance of this global issue, providing examples of possible adaptation and innovative solutions, and providing examples of solutions from other countries. These various strategies provided a balance between personal and community aspects and both local and global perspectives about climate change action.

The Science Museum's background research also revealed that the public held many misconceptions about global warming and climate change, so some knowledge-giving exhibits were needed that focused on explaining relevant science principles. The Science Museum also endeavoured to provide evidence about the anthropomorphic impact on climate change and to show the causal links between climate change and its effects, such as rising sea levels. This approach enabled visitors who did not believe there was a human role in climate change and/or did not see connections between global warming and its effects to confront their views. Schneider-Bateman (2012) discussed how a section of the Science Museum's Atmosphere exhibition used questions to encourage people to reflect about possible responses to climate change. Response choices to questions such as "should we engineer the climate?" were accompanied by short videos of ordinary people (rather than experts) making a case for that choice. By having pro and con response choices, Schneider-Bateman suggested that the Science Museum was not providing answers to these difficult questions, but allowing visitors to become more familiar with arguments from different perspectives. Displaying issues like climate change from different perspectives engages visitors, encourages them to ask questions and to evaluate their own perspectives, and stimulates both knowledge sharing and knowledge building.

Exhibitions About Evolution

Reiss (2013, 2017) discussed the kinds of decisions places like museums make in order to communicate information about issues that are considered controversial, using evolution as an example. Although evolution is a well-accepted theory based on scientific evidence, there are differing opinions and beliefs about it, both religious and non-religious. Reiss (2013) asked "To what extent should the curator(s) concentrate on scientific consensus and to what extent should they address scientific controversy?" (p. 157). Finding a balance between these perspectives is another challenge for exhibit developers, but it is a challenge that varies with the nature of the controversy. Even if exhibits about evolution are designed to put forward a mainstream scientific account, many decisions need to be made, including finding a balance between clarity and complexity.

When people's personal beliefs contribute to controversy in science issues like evolution, developers need to recognise that many visitors will feel uncomfortable with the topic and be unwilling to accept, or even consider, alternative explanations that are more scientific. Reiss (2017) discussed how this "uncomfortableness" might be approached in the context of evolution, and Orthia (2013) addressed how to negotiate the public's resistance to science and technology more generally. Incidentally, Schneider-Bateman (2012) explained how simple questions are commonly used to pique visitors' uncertainty and therefore their curiosity to search for answers within museum exhibitions, and this is a useful strategy to promote engagement. But he also gave examples from a creationist museum where questions were asked but deliberately left unanswered; the purpose was to imply an uncertainty in science that does not exist, thus undermining the scientific perspective. Of course there are genuine uncertainties in exhibits about evolution and an example comes from the *Megalodon: Largest shark that ever lived* exhibition at the Florida Museum of Natural History. Program Director Betty Dunckel explained that the "parentage" of the now extinct shark was unknown (due to lack of fossil evidence) so uncertainty about its evolution was presented in alternative evolutionary trees to encourage debate (Novick, 2017). Curiosity was stimulated and personalised by the simple question: "Who's your daddy?"

Concluding Comments

This chapter began with a story about collecting scientific evidence to confirm the identity of red and yellow gemstones both labelled as cassiterite. Comparison of the results with established mineralogical data sets confirmed the red stone as cassiterite but the yellow stone was re-identified as chrysoberyl. This simple story about trust in scientific data was juxtaposed with stories of tragic events that occurred when government officials made decisions that ignored uncertainty in the contemporary scientific evidence.

It was argued that it is important to provide opportunities for non-scientists to learn about uncertainty in science, to understand its meaning for decision-making and to develop a trust in science and scientists. Evidence was presented from research in science centres and museums suggesting that viewing science-related exhibits, or listening to lectures about science, sometimes resulted in people thinking less scientifically about the nature of science knowledge. Yet science centres and museums are generally trusted sources of information, and have a responsibility to provide people with opportunities to learn about uncertainty in science.

Three fundamental principles of effective science communication were described. They provide a framework that can be generalised to a range of intended communications about science, scientific evidence, and decision-making, from classroom situations (e.g., Buntting & Jones, Chapter "Using Biotechnology to Develop Values Discourse in School Science" and Cooper & Loughran, Chapter "Exploring Values of Science Through Classroom Practice", this volume), to media representations as well as educational institutions like museums, the focus in this chapter. These three principles require the communicator to consider (i) the purpose of the communication, (ii) how best to make the intended message accessible by the audience, and (iii) how to make the message clear and credible. Two controversial topics, climate change and evolution, were used to explain how effective science exhibitions could present issues that included uncertainty in credible, balanced ways.

There is evidence that science centres and museums are taking on board their responsibility to communicate science effectively. Pedretti (2002) recognised that science centres and museums were increasingly positioning themselves to be trustworthy sources of knowledge about science and technology and their social implications. This repositioning continues as these institutions strive to move beyond their traditional role of communication based around objects to a more political and social educative role as they "participate actively in, or to encourage visitors to participate actively in, dealing with socio-scientific issues" (Achiam & Sølberg, 2017, p. 137). In their efforts to remain relevant and valuable resources for their communities, science centres and museums have an increasing role to play in assisting their communities to understand and have opinions about scientific issues, and that means, in part, understanding uncertainty in science and the valuable role it plays in building scientific knowledge.

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Teachers' Perceptions of the Values that Underpin Science as a Way of Thinking and Acting

Kathy Smith and Deborah Corrigan

Over the past 10 years we have worked with both primary and secondary teachers to explore personal values and beliefs about science and the relationship of these perspectives with science teaching and learning. This was often a complex, difficult and a highly personal area to research. We, as researchers, were extremely mindful of the individualised nature of this work. We worked together with participants to find ways to access and enable all parties to understand the deeply held personal values and beliefs which frame individual professional practice. This chapter attempts to capture the recurring challenges in this work. It is not our intention to share all aspects of the research but to provide insights about how to uncover what has largely remained implicit in teacher thinking in relation to science education. The following story is just one incident, shared by a participant, which captures both the inherent challenges and changes in thinking confronting teachers in this research experience.

> The bell goes and my new Year 10 'Science for Life' class enters the room. The 'Science for Life' course is intended as an option for students who are undecided about what they want to do in the future and as a consequence it just concentrates on the fundamentals of the science curriculum.
>
> I'm still feeling upbeat about my previous lesson so I choose to begin the lesson in the same manner. What do you like about science? How can you see Science playing a role in your future? What do you hope to get out of doing this course next semester?
>
> Daniel put up his hand and replied, "I HATE SCIENCE…When am I ever going to need any of this rubbish in my life?"
>
> I ignored his question and asked Daniel, "What are you thinking about doing when you finish school? He shrugged his shoulders and said in the typical 16 year old boy voice: "I dunno."
>
> Trying to get a gauge of other students in the room, the conversation with my class continued:
>
> "Science is boring."

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D. Corrigan et al. (eds.), *Values in Science Education*,
https://doi.org/10.1007/978-3-030-42172-4_3

> "Science is useless."
> "Do we get to blow stuff up?"
> "Do we get to cut anything open this year?"
> "I'm not doing VCE[1] science next year so I don't see why I should have to do it now so I'm not going to even try!"
> Fifteen minutes ago, I was feeling upbeat and excited about how great this semester was going to be, and now I was thinking how far off the end of the year is and how on earth am I going to get these kids remotely interested in science? (Keating, 2013, p. 16)

Daniel and his classmates hold very strong views about the place and importance of science in their lives. Daniel's teacher also appears to hold views that may not be in keeping with her students' views. In this small interchange between Hannah (Keating) and her students we find that Hannah's initial question "What do you like about science?" implicitly conveys the message to the students that Hannah likes science. What must be very confronting for Hannah is Daniel's extreme (but common for a teenager) response: "I HATE SCIENCE". Daniel is not alone as his peers also share at least a disinterest in science, with comments such as "science is boring". Hannah's next question also puts her at odds with her students. "How can you see Science playing a role in your future?" again implies that Hannah feels it is useful—she is a science teacher—but again this view is not shared by her students. Responses such as "When am I ever going to need any of this rubbish?" and "Science is useless" seem to demonstrate pretty emphatically that Hannah's students do not see any relevance of science to their lives. And finally, the question "What do you hope to get out of this course?" implies that Hannah may be looking to meet some of the needs her students have. She must be disappointed when the responses indicate more entertainment value that science may provide through comments such as "Do we get to blow stuff up?" and "Do we get to cut anything open this year?" These student comments give insights into students' perceptions of what it is about science that might be of interest to them.

Unfortunately, this very real case in not unusual. It captures a clash of values and beliefs at play and provides a powerful reminder that how science teachers see and understand science is not always easily aligned with the experiences and perceptions of their students. The way these students think about school science and possibly science itself and the total disregard they assign to both scientific endeavour and associated knowledge based on their experiences is real and confronting for science educators everywhere. This case also stands as a reminder that years of school-based science education provide little guarantee that learning 'science' will transform such beliefs or even provide a positive educational experience for students.

[1] VCE is the Victorian Certificate of Education, the final secondary school qualification received in Victoria, Australia

Digging Deeper: The Need to Understand Teacher Values and the Challenge of Change

Hannah's case is particularly interesting because when examined closely it appears to be framed around what Brookfield (1995) would define as a key 'paradigmatic assumption', an idea that is so foundational that it is particularly hard to uncover and even harder to challenge. Applying the notion of a paradigmatic assumption in Hannah's case, teaching science is about facilitating students' thinking in ways which align with scientific thinking. This assumption is so fundamental to science teaching that it is unquestioningly reinforced through curriculum documents. Hannah clearly expresses this at the end of the interchange when she identifies the impending challenge of "getting these kids remotely interested in science". Hannah assumes that as a science teacher it is her role to change her students' attitudes and perceptions about science and, ideally, she wants to move her students from seeing science as the content of a school subject to recognising the everyday relevance and importance of science within their own futures through the subject called 'Science for Life'. These values of the relevance and usefulness of science drive her thinking and determine the type of science learning that she strives to achieve for her students. To achieve these outcomes Hannah will need to develop her students' capacity to think differently about the nature of science and the inherent value processes that ensure the construction of rigorously contested science knowledge. She must address not only her students' existing conceptual knowledge but also the resistance evident in student attitudes—undoubtedly a really problematic process.

How Hannah values and thinks about science strongly influences the change in thinking she wants to realise for her students and the conditions for learning that she will seek to create. Hannah wants to achieve change but she is aware of the enormity of the divide between the value sets at play, i.e., her own and those of her students.

Achieving such change in student thinking is the paradigmatic assumption that drives science teaching everywhere. Not all science teachers may be as overtly passionate or well informed about science as Hannah, nor would they so openly seek student input as Hannah does with their students. As products themselves of an outcomes-based education system, each teacher's personal understandings of both science knowledge and the nature of the endeavour may be very different. If we accept the assumption that teachers seek to promote change in student thinking then how these different perspectives shape science learning becomes an interesting consideration. Hannah's understanding of the nature of science informs her awareness of the challenges associated with translating the curriculum, both the explicit and implicit dimensions, to the contextual reality of her classroom. This suggests a level of sophisticated thinking about science education that goes well beyond mastering content knowledge.

How teacher values and understandings of science shape the quality of student learning is not well considered as a significant factor in school-based science education. Hannah represents a teacher with a broad and deep understanding of science who is actively attempting to align her own thinking about science with both the curriculum and her students' learning needs. In contrast, some science teachers may hold a more limited understanding and therefore how they read and enact the curriculum (Roberts, 1982) will align with their personal views, i.e., as a roadmap of content which defines what needs to be achieved. This chapter seeks to explore the relationship between the paradigmatic assumption for change in student thinking and teacher values and beliefs about science, and consequently the implications for science education. The chapter works from a perspective of critical reflection (Brookfield, 1995) as a means of understanding how values are embedded within, give meaning to and determine the routines which shape science education, in particular learning about science as a way of thinking and acting. By attempting to learn more about how teachers understand science and how their beliefs and thinking shapes the kind of learning that students experience we can understand more about why some teachers adopt particular routines, why these are accepted unquestionably and what conditions promote effective change in both teacher and student thinking.

Understanding the relationship between teacher values and science learning requires teachers themselves to undertake a critical stance to noticing existing trends in their practice and a preparedness to expose the more deeply embedded prescriptive and paradigmatic assumptions that drive their actions. Taking such a stance requires particular conditions that not only support teachers to reflect on their personal and professional values but enable them to go further and consider how these values influence the learning their students experience. In these instances, it is important teachers confront the assumptions they hold about the epistemic values of science, societal values, and the personal values of scientists, and how they as teachers use such knowledge to make decisions about curriculum and teaching. We will now outline some of the inherent challenges in this learning process.

The Challenge of Attaining a Shared Understanding About the Nature of Science

What is often not clear to both teachers and particularly students is why an understanding of the nature of science is important. In other words, the reality of how science is a powerful way of thinking and acting is not clear to many engaging in science education. The indication of this lack of clarity is apparent when a person is confronted with the question "What is science?" There is no one answer for this as each response will be dependent on an individual's past experiences and the views generated based on those experiences. Rarely would a response encompass the following:

> Science embodies a way of thinking and acting, a knowledge-seeking enterprise that is continuous and purposeful, generated by a need to understand, make sense of and communicate thinking about phenomena and experiences. In this context, science is a process of human endeavour, a human attempt to create explanations for what is observed and experienced; it is entrenched in human experience, reflects cultural diversity and is built upon

> individual perceptions and understandings. To this end it is a type of thinking which depends upon the rigorous pursuit of evidence for validity of ideas and seeks to effectively communicate findings to a wider audience to establish a shared meaning and understanding. (Corrigan & Smith, 2015, p. 102)

While the explicitly stated goal of school science, as evident in a wide range of curriculum documents, may be to establish a shared set of values about the nature of science like the one articulated above, such an outcome is not common and is difficult to achieve.

All participants in the education process, teachers and students alike, bring to the classroom many different ideas and practices based on their value positions about science. For example, Corrigan and her colleagues (Corrigan et al., 2018) have worked with preservice teachers (PSTs) to monitor their changed personal views of the nature of science as they engage with authentic experiences of contemporary sciences. The PSTs from the study acknowledged the impact that collaborative discussions about the Nature of Science (NoS) had on building their confidence and ability to communicate a coherent and more contemporary view of science. Many of the PSTs spoke of how their thinking and view of science had changed from one in which they originally privileged understandings of science content to one with a broader understanding of the processes by which science is undertaken. On reconceptualising a personal view of NoS, the PSTs reported greater self-confidence in constructing and justifying a personal coherent view of NoS and an improved ability and confidence in discussing and communicating NoS understandings across a range of professional settings.

It is often assumed that everyone holds a shared understanding of what 'science' means. As discussed this is not the case. Hannah's case above demonstrates, by the reactions of both Hannah and her students, a differing view of science. Achieving a shared understanding often presents a challenge for many teachers.

The Challenging Space Between Teacher Values and External Expectations

To effect change in student thinking requires teachers to make decisions about what matters, for their students, their teaching and the contextual reality of their teaching experience. Such decisions are not based on issues of content but are more likely to be framed by professional and personal values, personal experience and a personal sense of adequacy. Even if curriculum documents intentionally position science as a human endeavour and explicitly frame this understanding as critical to science learning, many students experience a school science that is not framed in ways which enable them to appreciate science as that which is entrenched in human experience. Nor do students come to see science as purposeful, or driven by an individual's need to understand (Corrigan & Smith, 2015). Instead students, such as those in the case above, often experience a 'science' at school that they believe represents a static body of 'useless' knowledge, detached from everyday life, irrelevant to their needs and interests, uninviting and ultimately a waste of time and effort. Such representations are inevitably influenced by teacher thinking.

Hargreaves (1994) argued that teachers do not merely deliver the curriculum, they interpret, redefine and re-evaluate it too; it is what teachers think and what teachers do that matters at the level of the classroom. Similarly, many of the teachers in our research translated the curriculum, such as Hargreaves described, based on a tension they experienced between their own sense of purpose as a teacher and the demands of external expectations. Working within education systems that have high demands for accountability, in particular short-term evidence of change, potentially presents challenges for the work of science teachers. Allowing students to experience the endeavour of science and the uncertainty that sits within the nature of the enterprise requires time and opportunity for ongoing exploration and investigation of a range of possible outcomes. The education system, through curriculum, may indicate an expressed value of a particular perspective about the nature of science but the constraints of time and the demands of short-term success which are also imposed by the system creates conditions where it becomes unlikely that such science learning will be achieved.

Many of the teachers in our research had entered the profession in order to be accountable to their students, i.e., to make a difference to the lives of young people. However, the accountability to a system that values statistical evidence of students' learning and short-term improvements dominated their decisions as professional teachers of science. For many teachers, balancing these accountabilities remained an on-going tension throughout their careers, particularly when high-stakes testing was part of their reality.

In summary, the intention of school science may be to enable students to develop a capacity to see, act and think about the world in a sceptical, rigorous, engaging, evidence-based and empowering way. This intention is in reality extremely problematic to achieve as teachers will inevitably respond to many of the complex demands associated with science education in line with their personal values and beliefs. The outcome is a lived experience for students that often intensifies their diversity of views about the nature of science. Our research identified that such experiences frequently nurture oppositional perspectives about the purpose and value of science as evidenced in Hannah's case above. It would be easy to dismiss such diversity on the basis of teacher deficit but the reality is far more complex. School curriculum by its very nature embodies political, economic and social values by prioritising areas of learning. To be effective within any education system a teacher must find ways to coexist within the values of the system itself. Teachers may find that the science they value may not necessarily translate to be the science their students get to experience.

The Challenge of Developing Rich and Deep Understandings of Science While Being a Product of an Outcomes-Based Education System

As products of the system themselves, perhaps teacher thinking about the nature of science has also been shaped by similar processes.

Teacher thinking is deeply embedded in each teacher's personal experience. Individual ideas and understandings about the nature of science have been developed when they as students worked within systems which traditionally valued the reproduction of factual information as the best measure of a knowledge and understanding of science. For example, in Hannah's case above, she describes "[t]he 'Science for Life' course is intended as an option for students who are undecided about what they want to do in the future and as a consequence it just concentrates on the fundamentals of the science curriculum" (Keating, 2013, p. 16). In this phrase Hannah conveys her view that concentrating on the fundamentals of the science curriculum will provide these students with options in terms of their future. Given the students' reactions, their experiences with many teachers across their educational life does not appear to have encouraged these students to see science as creating future options.

Teacher professional knowledge is intertwined with the nature of teaching itself and entrenched within the contextual reality of their teaching situation. Teachers trust what they know to be true and when working within a system that overtly values statistical evidence of student learning, teachers become as much a product of the system structures and agencies to which they are accountable as do their students. Perhaps for many teachers it is possible to effectively and easily align their values with the requirements of the system in which they operate because these values have been nurtured through a similar system and are by nature compatible.

Understanding More About Teacher Thinking and Values

The tensions between teachers' values and classroom realities prompted us to explore in more depth the often tacit and deeply held values teachers hold about science and find ways to identify how these values underpin and shape their science teaching and ultimately their students' learning. 'Conditions for learning' (Smith, 2017) became a major consideration as this was inevitably going to be challenging work for teachers. Therefore, consideration needed to be given to the conditions that would support and actively encourage teachers to lay bare their personal values while also feeling safe and confident. The experience of exploring personal values was developed as an interactive session situated within a professional learning (PL) programme. It was important that the design and approach used in the programme overall actively encouraged teachers to acknowledge and attend to the personal values that drive their teaching. The session required teachers to be critically reflective, actively interrogating their own thinking and articulating their reasoning. The research revolved around two key issues: Identifying the type of learning experience that enabled teachers to identify and articulate the values they hold about the nature of science, and understanding how such an experience enables teachers to see a connection between their own understanding of science and the ways they represent science in their classroom teaching.

Exploring Teacher Thinking About the Nature of Science: Key Conditions for Professional Learning

The reflective experience needed to acknowledge that teacher thinking is always inherently personal while situated within a system that is contextual and overtly driven by external policies and expectations, where teachers often struggle with notions of identity and success. While it was possible that enabling teachers to expose their thinking could be an empowering way of assisting teachers to explore their own professional knowledge in action, this research focus was also potentially intimidating because many teachers could find it difficult to identify and articulate their values about the nature of science and may not be comfortable with confronting the limitations of their own thinking. Indeed, for some teachers there may be a need to acknowledge that there are values underpinning science as many may see science as value free. Therefore, three key elements became vital to the success of this research: trust, time, and using interactive conversation as a prompt for critical reflection.

Conditions for Learning: Trust

Any attempts at accessing teacher thinking required professional learning conditions that were supportive and safe and this inevitably took time and was dependent on establishing effective relationships between facilitators and teachers. Within safe and supportive professional learning conditions, the approaches needed to deliberately create a number of tensions for teachers—moments when they would feel some degree of intellectual or emotional resistance to what they assume to be accepted and shared understandings. These experiences were critical for uncovering deeply personal thinking, and it was believed that in these moments it would be possible to gain an insight into teacher professional thinking. Therefore, the research needed to be positioned within a professional learning programme that valued diversity and followed an extended timeline and which placed strong emphasis on facilitator-teacher relationships and ongoing support.

Conditions for Learning: Time

Investing time to change the accepted routine of conversations, rethink the role of the facilitator and provide challenging yet well supported learning experiences became the focus of the values session. The session was designed to encourage teachers to engage in critical interactive discussion so that they could articulate the professional knowledge that shaped their practice. This required time and attention to and acceptance of such thinking. In the contextual reality of prevailing school activity, reflective collaboration becomes constrained by time and driven by the requirement for collective, agreed outcomes. Extended time is rarely allocated for teachers to examine their personal professional thinking in detail; instead such thinking is often explained as 'intuitive' and an assumption follows that everyone shares the same understandings. In these conditions, it becomes almost inevitable that teachers work to find manageable and efficient ways to think and talk about teaching, in particular (in this case) teaching science. Almost by default teacher talk tends to focus on the tangible and technical aspects of teaching, that is, the practicality of what teachers do. As a consequence, these conversations tend to become systematic, practiced and habitual (Smith, 2017). In the case of science teaching in particular, when teachers can demonstrate they 'know' science through a capacity to articulate and demonstrate science knowledge, the assumption is often that these teachers think about the nature of science in similar ways. On this basis planning and teaching is conducted without ever really examining the prevalence and validity of individual views and beliefs. In our research approach allowing time for teacher talk was considered a vital condition for the research process.

Conditions for Learning: Critical Reflection Leading to Social Construction of Professional Knowledge

When professional thinking becomes routine and operational, by nature it cannot be assumed to any longer be a process of critical reflection. Reflection is not by definition, critical. Brookfield (1995) contends that power underpins all aspects of classroom learning and teaching and critical reflection seeks to understand more about this power-based interplay. Critical reflection also questions the intentions and validity of practices that have become routine in teaching. It was therefore essential to create conditions in our research approach where it was far more likely that teachers would undertake reflection that was critical and purposeful. Therefore, a valued outcome needed to be framed: to collaboratively construct a shared understanding of science. The learning experience by design required participating teachers to clarify their ideas about the fundamental beliefs they hold about science and then move to a group consensus. Conversations then needed to position individual values within a social context of alternative perceptions. These conditions also produced a different type of teacher talk to the very linear and process-orientated talk often present in most science professional development programmes. Often in such situations conversations tend to be one dimensional, focusing on the daily routines of school and on the technical aspects of teaching practice. In our work, these conversations needed to be challenged as this type of talk would potentially struggle to peel back the layers of complex thinking about science that the teachers hold and use every day in their teaching. One-dimensional interactions would be of little assistance in enabling teachers to share personal values and then develop deeper understandings of the nature of science. Conversations needed to enable teachers to contrast and align their thinking with the ideas of others because it was in this process of critical reflection that teachers would more likely realise how their perspectives about science are personal and, in turn, how this thinking may shape the various dimensions of their science teaching.

With these conditions in mind a ‘Values session’ was designed and implemented within existing science professional learning programmes that attended to these learning conditions. Consistent monitoring of these conditions was critical to the intentions of the experience.

The Experience: Articulating Personal Values

The ‘Values session’ became situated within two key teacher professional learning programmes: *The Science Teaching and Learning* (STaL) project, a collaborative in-service teacher professional learning programme involving Monash University and the Catholic Education Office Melbourne (CEOM), and the Professional Learning in Primary Science (PLiPS) programme, developed for the Department of Education and Early Childhood Development (DEECD) involving teachers working in government primary schools located across the state of Victoria in Australia. Both programmes aimed to build teacher capacity as reflective practitioners in science in an attempt to transform approaches to learning and teaching in science within schools. Both programmes were also ongoing; STaL was a five day (2 + 2 + 1) intensive, residential course spaced across the school year and PLiPS was a three day programme (2 + 1) with the final day taking place a short period of time after the first two days. In both programmes, the programme design and implementation facilitators worked to explicitly link their pedagogical purpose to the learning approaches encouraged and teaching procedures adopted. In both programmes all participants received ongoing in-school support; in STaL a ‘critical friend’ engaged teachers in school-based meetings throughout the programme, and in PLiPS ongoing online support was available. In both programmes discussions promoted reflective thinking and supported the trialling of alternative approaches to science teaching and learning. STaL involved both primary and secondary teachers and PLiPS involved only primary teachers. Given the need to attend to the conditions of trust, time and critical reflection leading to the social construction of professional knowledge, the design elements of both programmes provided ideal contexts in which to explore teacher thinking about the nature of science. The ‘Values session’ encouraged teachers to discuss and debate the validity of their ideas while programme facilitators intentionally worked to create conditions where teachers felt willing and confident to express and justify their views.

Part 1: Exploring Individual Thinking

In the 'Values session' each individual teacher was initially presented with a series of 19 statements about the nature of science and how it could be performed. The statements were all deliberately constructed to be highly value laden to intentionally evoke strong opinions from the participants and were taken from Carrier's (2001) Test of Scientific Literacy developed in relation to Lederman's (1992) seven characteristics of the nature of science. These statements are listed in Table 1. We selected 19 of the 24 original statements as we felt the final set were accessible to teachers working across both primary and secondary levels of education. Working individually, teacher participants examined the statements and classified them as either 'true' or 'false', and recorded individual responses.

At this stage, it was often observed across multiple sessions that teachers considered any pre-existing knowledge, experience and ideas to determine a personal view about the accuracy and credibility of the statement under consideration. This first stage of the task revealed a capacity of teachers to identify a personal position in relation to a number of contentious statements about the nature of scientific work, and confirmed our selection of statements as these decisions did not appear to be dependent upon a sense of personal adequacy with science or qualifications or experience with science. Additionally, teachers' language skills became important ways in which they could temper their views around science, and particularly perceived lack of confidence in science, as these language skills could provide an anchor for their decision-making. For example, they focused on the word 'must' in the statement 'To be scientific one **must** conduct experiments'. All participants were able to record individual decisions.

Part 2: Reaching a Group Consensus

The format of the session then required participants to form a group with four to five other teachers to work together to reach a consensus of opinion about each statement. This part of the task was designed to expose teachers to the ideas of others who often provided alternative perspectives or understandings to that of their own. Teachers were required to engage in open debate about the validity of each statement. Reaching a group consensus was seen as an important step in encouraging every participant's voice and discouraging the acceptance of the "loudest" voice. The outcomes were recorded as a group response. At this stage in the session a new option was made available, 'Undecided'. This option enabled the group to record an

Table 1 Value statements about the nature of science

Statement	True	False	Undecided
1. Scientists usually expect an experiment to turn out a certain way.			
2. Science only produces tentative conclusions that can change.			
3. Science has one uniform way of conducting research called "the scientific method."			
4. Scientific theories are explanations and not facts.			
5. When being scientific one must have faith only in what is justified by empirical evidence.			
6. Science is just about the facts, not human interpretations of them.			
7. To be scientific one must conduct experiments.			
8. Scientific theories only change when new information becomes available.			
9. Scientists manipulate their experiments to produce particular results.			
10. Science proves facts true in a way that is definitive and final.			
11. An experiment can prove a theory true.			
12. Science is partly based on beliefs, assumptions, and the non-observable.			
13. Imagination and creativity are used in all stages of scientific investigations.			
14. Scientific theories are just ideas about how something works.			
15. Scientists' education, background, opinions, disciplinary focus, and basic guiding assumptions and philosophies influence their perceptions and interpretation of the available data.			
16. An accepted scientific theory is an hypothesis that has been confirmed by considerable evidence and has endured all attempts to disprove it			
17. Scientists invent explanations, models or theoretical entities.			
18. Scientists construct theories to guide further research.			
19. Scientists accept the existence of theoretical entities that have never been directly observed.			

outcome if a consensus was unable to be reached. In every session teachers were observed openly articulating their personal decisions about each statement and explaining their positions. Participants listened to alternative perspectives and discussed and acknowledged thinking and evidence that was similar to their own and interrogated new or alternative positions. Teachers explicitly demonstrated personal levels of comfort or discomfort with ideas being expressed and this was indicated by volume and tone of voice and body language.

The reasoning shared was sometimes personal and often involved reflections on their own teaching and their own learning. It revealed the capacity of teachers to use new information to re-examine the validity of personal ideas and also the capacity to use group comments to determine where personal thinking was positioned in relation to the group's overall preference. It was at this stage that teachers were given permission to potentially construct new ideas, i.e., move away from initial thinking, and this revealed a willingness or resistance to accommodate different ways of thinking about science. The level of commitment teachers demonstrated to their initial ideas appeared to correspond with the extent to which these ideas represented or reflected their science teaching practice, i.e., if a statement aligned with their teaching practice there was a professional investment worth defending. These statements and the ensuing discussions appeared to bring to the surface deeply held values embodied in the connection between ways of understanding the nature of science and perceptions of personal professional identity.

Each group's results were recorded to provide an overall tally of whole cohort's responses. An example of one cohort's (n = 5 groups, where each group was made up of 6 people) responses from STaL is provided in Table 2 below. While the test developed by Carrier (2001) provided 'correct' answers, the intent in this session was to use the results as prompts for further discussion. In every session, the similarities and differences of responses were explored and discussion was promoted across the cohort to identify the arguments and thinking used when determining the validity of the statements. At this stage in the session, the underlying values driving selected responses were identified and articulated by participant teachers. For example, Statement 14 (Scientific theories are just ideas about how something works) produced responses of undecided, true and false. Groups then provided insights as to why their group responded in those particular ways.

In the STaL programme many of these values were captured in teacher case writing, which was a valued outcome of the programme. All teacher participants produced a written case capturing moments of practice when they began to think about their science teaching differently and the impact this had on their teaching practice, of which Hannah's is an example. Over 200 cases have been produced to date as a result of the STaL programme. This rich data set has been analysed and categorised to develop an understanding of the range of issues that are prominent among school-based science educators, prevalence of these issues across various cohorts of participants, and changes in teacher thinking about these issues that occurred as a result of their experiences in the STaL programme. For further information about these data see Loughran and Smith (2015).

Table 2 2013 STaL cohort's responses to NoS Statements (n=5)

Gp	Statements																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
A	T	U	F	U	F	F	F	U	U	F	T	T	T	U	T	T	T	T	T
B	F	T	F	T	F	F	F	T	T	F	T	T	T	U	T	T	T	T	T
C	U	T	F	T	T	F	F	T	T	F	T	T	F	T	T	T	U	U	T
D	T	T	F	T	U	F	F	F	U	F	U	T	T	T	T	T	T	T	T
E	T	T	T	T	F	F	F	T	T	F	U	T	F	F	T	T	T	T	T

ENTER TRUE= T, FALSE= F, UNDECIDED = U

Representations of the Nature of Science in Teacher Writing

It was possible through analysis of these cases to identify teachers' views of the nature of science evident in descriptions of their science teaching practice. When teachers wrote about their science teaching their comments often outlined dilemmas they experienced, and while these statements did not always specifically outline how a teacher defined their understanding of the nature of science, the expectations teachers conveyed about their own teaching practice framed a purpose for teaching science. This purpose in turn conveyed some very interesting information about their intentions for student learning and the models of thinking they valued in science teaching and that they openly represented through their teaching practice.

When examining cases the emergence of repeated themes contributed to the development of a continuum of teacher thinking about the nature of science teaching. This thinking is captured as a continuum of thinking in Table 3. A very depersonalised view of science frames teacher thinking and actions on one side of the continuum moving towards a highly-personalised view of science. This shift in thinking also indicates a shift in the power base of learning and teaching from that of teacher to a shared ownership of all involved in the learning process. Both extremes are represented in the ways teachers talk about teaching science. In these cases, the shift in thinking and practice was reliant upon teachers engaging in a process of critical reflection within a supportive learning environment. Regardless of where teachers are located on these continua, time is of crucial importance.

When reviewing the data from teachers' case writing two strongly opposing views about the intention of science teaching and student learning framed the majority of teacher reflections. For many teachers their initial thinking prior to participating in the STaL programme was best represented in a view that saw science teaching intending to move student thinking from naïve to the 'right' or accepted answer. Following participation in the programme, for many teachers this thinking shifted to enabling students to construct understanding of accepted explanations, i.e., experience the rigours of the social construction of knowledge. This thinking appeared to be more in line with the nature of science as a human endeavour. Teachers' reflections conveyed this change in thinking and such change is captured in the following case excerpt.

> In a crowded curriculum, the covering of content before tests and exams was the ultimate goal of both students and teachers…. this is not to say that the curriculum was bad, or that students did not learn…. What was missing, however, was an appreciation by students that Science was more than just a body of content knowledge to be memorized from a text book. The Science curriculum at Year 10 gave very little time to undertaking 'student inquiry' and the few prac experiments that were carried out were so rushed that they amounted to little more than scripted recipes for the students to follow. The challenge was to embed a culture of critical, scientific thinking into a heavily teacher centred, traditional curriculum. (Bell, 2013, p. 29)

Table 3 A Continuum of Teacher Thinking about the Nature of Science

What is** (the nature of) **science? ***A continuum of teacher thinking as evidenced in teacher writing***		
Science is depersonalised	→	**Science is highly personalised**
A rigid body of knowledge		*Science as a human endeavour*
Intention of teaching:		
Moving student thinking from naïve to the 'right' or accepted answer	→	Enabling students to construct understanding of accepted explanations, i.e., experience the rigours of the social construction of knowledge
Characteristics of teacher talk:		
Emphasis on the delivery of information	→	Use of student questions to drive inquiry & purpose for learning
Teacher controls all decisions about learning		Continual reflection on ownership of learning: whose learning is it?
Teaching driven by planning & curriculum agendas		Attends to curriculum while demonstrating flexibility in teaching approaches & time for learning
Frames discussions around the need for students to get the right answer, i.e., content acquisition		Sees value in exposing students to a variety of alternative perspectives
Assumes science teaching requires a level of expertise in content knowledge		Focuses on pedagogical issues of teaching and learning
Little discussion about teacher's personal level of knowledge.		Teachers identify themselves as learners within the learning process.
Implements accepted & unquestioned routines of teaching		Trials alternative classroom teaching
Tensions for teaching practice		
Pressures of curriculum & sector expectations	→	Reframing teacher's role, letting go, shifting students' learning behaviours
Time		Time

Conclusion

It is undeniable that students often leave their years of school science with little appreciation of science as a way of thinking and acting that is entrenched in human experience, a purposeful and continuous knowledge-seeking enterprise driven by a need to understand. It is also undeniable that teachers possess a diverse range of understandings about the nature of science. It is the values which shape these perceptions that often determine what 'play outs' to become the 'science' students experience at school.

The decisions teachers make about how they frame science education are complex and are influenced by the many demands and expectations of the systems within which they work and also their own knowledge and experience. Changing school-based representations of science is challenging. The greatest challenge is finding ways to empower teachers to notice the values they hold while supporting teachers to consider how these values both sit within the requirements of their work as science teachers and shape their approaches to science teaching in ways that influence student learning. If done effectively this thinking can be explicated and shared collectively in ways that potentially enable teachers to develop broader understandings, and a deeper and more accurate conceptualisation of the humanness of science. The 'Values session' achieved the conditions necessary to enable such critical reflection and the social construction of professional knowledge. Teachers were able to use knowledge gained from this collective experience to shape their practice and as a result many were better equipped to find ways to enhance a richer student understanding of the nature of science as a human endeavour.

A Final Comment

Many readers of this chapter would be wondering—so what happened to Hannah? While Hannah's story is intriguing, its real value lies in the contribution it has made to our research in building an overall understanding of the complexities associated with teaching science. One insight may be revealed in one final comment Hannah included in her case:

> I was no longer hearing any of the usual, "I hate science!" In fact I was hearing more things like, "That's actually pretty cool." What a turn around, well it was at least a good start. (Keating, 2013, p. 17)

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Exploring Values of Science Through Classroom Practice

Rebecca Cooper and John Loughran

Introduction

> Science provides opportunities for students to develop an understanding of important science concepts and processes, the practices used to develop scientific knowledge, of science's contribution to our culture and society, and its applications in our lives. (ACARA, 2016)

Curriculum and policy documents often attempt to create opportunities for teachers to consider/reconsider their views of teaching and learning, and in science education, as the quote above suggests, there is always a need for teachers to think carefully about the way they portray science to their students. One implicit message in the statement is the importance of being conscious of how science is viewed and understood and, as a consequence, how teachers can connect science to everyday contexts in order to shape students' views of science. However, as even a scant read of the literature demonstrates, the need for science teaching and learning to be more relevant to students and to link what they are learning to the world beyond the classroom (Goodrum & Rennie, 2007) has been a high priority for science education. While there are individual examples of great work being done by science teachers and educators, large scale change has not been realised.

An abiding issue, then, is how to support teachers to think about their views of science and the ways they portray these to their students so that school science is not limited to interpretations of science as propositional knowledge, but an invitation to curiosity, interest, questioning and engagement, that is, a conduit to relevance to everyday life. This chapter uses the notion of *values of science* in order to consider how science is viewed (and valued) by teachers and how these views play out in practice. It does so by placing an emphasis on the role of science teacher education as a driver for purposeful consideration of views of science.

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D. Corrigan et al. (eds.), *Values in Science Education*,
https://doi.org/10.1007/978-3-030-42172-4_4

Context

In the earlier version of this book, *The Re-emergence of Values in Science Education* (Corrigan, Dillon, & Gunstone, 2007), the first author of this chapter (Rebecca) wrote as a science teacher as reported in a vignette, describing her work (with a colleague) to illustrate how teachers wrestle with the ideas of values of science as part of their teaching. In particular, their journal entries around the nature of those struggles offered insights into the implications of those struggles and how the struggles impacted their practice.

Since that time, Rebecca has transitioned to being a science teacher educator. This, once again, provides her with an opportunity to consider the place of values associated with science in her teaching. Now her students are students of teaching, beginning their own journeys of thinking about what it means to consider values as part of their developing understanding of learning and teaching science. As a teacher educator, Rebecca has begun to ask: *How do I encourage students of teaching to see the importance of considering values of science as part of their teaching?* This question is significant because, for students of teaching, it is common for concerns to centre more on accumulating 'tips and tricks' of teaching rather than asking deeper philosophical questions about the nature of practice. Herein lies one of the challenges of being a science teacher educator—creating experiences for students of learning that will influence their practice in order to enhance the learning of science of their students. In other words, beginning to challenge the 'learning science as facts' approach to school science teaching.

Over time, as Rebecca began to experience changes in her own understanding of teaching through being a science teacher educator, she came to realise that teaching science in a way that promotes values of science is challenging. Although she thought she was addressing the link between values and practice, a change in practice that unsettled her led her to question what she was really doing and why. The implications for her students and their understanding of values of science came starkly to the fore.

It is through Rebecca's experience of the transition from science teacher to science teacher educator that this chapter explores the ways in which students of teaching think about and develop their own ideas about values of science while learning to teach. The link between how science is valued and science teaching practice is the main emphasis of the chapter (as opposed to a consideration of the values of science per se, which is addressed in other chapters of this volume, including the chapters by Rennie and Smith & Corrigan). Reflecting on this link between valuing science and science teaching practice, and the challenges associated with doing so in preservice teacher education is arguably a tangible beginning point for setting a foundation for science teachers' developing views of teaching and learning.

Values and Science Teaching

> … the term values is used to refer to principles, fundamental convictions, ideals, standards or life stances which act as general guides to behaviour or as points of reference in decision-making or the evaluation of beliefs or action and which are closely connected to personal integrity and personal identity. (Halstead, 1996, p. 5)

The values a teacher holds can greatly influence what happens in a classroom (Hildebrand, 2007; Pajares, 1992; Ratcliffe, 2007). As Levinson and Turner (2001) suggested, teachers' value positions impact on the pedagogical approaches that they adopt and their interpretations of the "intended" curriculum. In other words, what teachers value has strong implications for what they teach, when, how and perhaps most importantly, why.

Teachers learn as they "construct new knowledge and understandings based on what they already know and believe" (Putnam & Borko, 1997, p. 1125). To do this requires teachers to reflect on their practice at a level that goes beyond retelling and moves into analysis (Davis, 2006). Loughran (2002) noted that "… one element of reflection that is common to many models is the notion of a *problem* (a puzzling, curious, or perplexing situation)" (p. 33). While the identification of a problem is clearly important, the way the problem is framed is also significant. In other words, it is not enough to simply point out the problem; the way it is recognised and described is important as this can shape what happens next: "there is little doubt that the initial framing inevitably impacts on what is seen, the nature of the risks taken, and the diversity in learning through action" (p. 35).

Teachers see problems as having different levels of significance. Some problems challenge a teacher's values, while others may not. Further, the values that a teacher holds can influence the way a problem is framed and may therefore influence the action taken. If we accept that there is a strong link between beliefs, values and behaviour in the classroom, then that which is valued can influence the nature of practice, and the teacher's disposition towards trying new things and/or taking risks in that practice:

> … teaching concerns coming to terms with one's intentions and values as well as one's view of knowing, being, and acting in a setting characterized by contradictory realities, negotiation, and dependency and struggles in sociocultural domains. (Britzman, 2003, p. 31)

From School Teaching to Teaching Teaching

As is clearly evident in the literature, the transition from school teacher to teacher educator has many challenges (e.g., Bullock & Ritter, 2011; Martinez, 2008; Murray & Male, 2005). The challenge to one's identity (Davey, 2013) often leads beginning teacher educators to see themselves as needing to bring the 'real world practice' of school teaching to the teacher education classroom (Dinkleman, Margolis, & Sikkenga, 2006).

As Rebecca made the transition from science teacher to science teacher educator, she carried a desire to build on the challenge of operationalising her views of science through her teaching as a science teacher educator. Hence, problematising her practice became important in helping her to better understand teaching and learning about teaching and thus begin to establish a pedagogy of teacher education (Korthagen, 2016; Loughran, 2006; Ritter, 2007). In seeking to make clear (through her own practice with her students of teaching) that values of science inevitably influence the nature of science teaching itself, she began to recognise the tensions of teaching about teaching (Berry, 2007) that can complicate what it means to model teaching and to make the tacit features of practice explicit (Bullock, 2009).

As the remainder of this chapter illustrates, by adopting a reflective stance (Cochran-Smith & Lytle, 2009) Rebecca became increasingly cognisant of the influence of values on her understanding of science and how these values impacted her practice as a science teacher educator.

Values and Science Teacher Education

Rosaen and Wilson (1995) observed that as teachers become teacher educators they often struggle to maintain a teacher education focus. Teachers new to teacher education are typically comfortable articulating their problems in the school classroom and reflecting on their teaching practice there, but when they move into teacher education they do not necessarily problematise their *teaching about teaching* in the same way. This may be because:

> While classroom teachers are expected to teach subject matter, university-based teacher educators are expected to teach about how to teach subject matter. Given this different emphasis for instruction, it seems obvious that the pedagogy used by a teacher educator would differ in some important ways from the pedagogy used by a classroom teacher. (Ritter, 2007, p. 5)

This quote highlights the difference in emphasis between the underlying purpose of school teaching and the development of a teacher educator's pedagogy of teacher education (Korthagen, Kessels, Koster, Langerwarf, & Wubbels, 2001; Loughran, 2006). As detailed time and time again in the literature, teacher educators tend to be school teachers who have made the move to teaching in higher education settings without any formal training in teacher education. Often this shift is based on a view that good teachers will make good teacher educators (Korthagen, Loughran, & Lunenberg, 2005) and the assumption that 'teaching' in teacher education is the same as the teaching in schools. Adding further complication to this scenario is that teacher educators often work in a specific subject area (e.g., Languages, Science, Maths, Music, and so on), each of which brings its own particular set of values and views that need be considered in the teaching about the teaching of that particular subject. If due consideration has not been given to the values related to teaching a specific subject area, then there is a risk that the true nature of the subject area will not be acknowledged as part of pre-service teacher education, which may result in a generic delivery of the skills and characteristics required for developing expertise in teaching the specific subject area. Grimmett (1998) was of the view that teacher education requires an exploration of connections between subject specific materials and the minds of learners such that "detailed examination of both the structure of knowledge in each of the disciplines that make up the area, and also how the disciplines could combine to address real-world problems" (p. 258).

Thus, bringing together the skills and characteristics of quality teaching practice and the subject-specific knowledge around the nature and values of a subject area, matters. Further, Kim and Tan (2011) found that when decisions need to be made in the classroom, the beliefs students of teaching have about the nature of science and their science pedagogical values hold a greater influence than anything else on their decision making and the actions they take. Kim and Tan also noted: "They [students of teaching] struggled with the uneasiness of reconciling the desire for certainty and re-questioning their values of good teaching in their science classrooms" (p. 483).

So it seems reasonable to assert that science teacher educators should be aware of the need to support students of teaching to consider the influence of their values of science on their teaching. Further, science teacher educators should provide opportunities for students of teaching to incorporate aspects of the values of science into their thinking about their planning and in their reflection on their practice.

The knowledge of learning and teaching that students of science teaching develop is embedded in their perceived values of science, and so science teacher educators need to support their students to understand how their practice promotes science as a way of thinking about the world. Thus, it is important that science teacher educators pay attention to how they value science when developing their own understanding of teaching about science teaching.

As science teacher educators develop their pedagogy for teacher education, they need to maintain a focus on challenging students of teaching to examine their views of science and consider how these views might influence their practice and consequently their students' learning of science. Rebecca did this through her Big Picture Science unit.

Big Picture Science Unit

As noted earlier, this chapter emphasises the role of science teacher education as a driver for purposeful consideration of views of science and how these influence teaching. To do this, the chapter now follows Rebecca's transition from science teacher to science teacher educator and explores her consideration of values of science along with her attempts to promote similar thinking among her students of teaching.

This next section is based around insights into the pedagogical journey of two teachers (one of whom is Rebecca) as they created and taught their Big Picture Science unit (see Gunstone, Corrigan, & Dillon, 2007). Their experience is explored further as an example of two teachers coming to terms with their values of science and their intentions for teaching science in ways that challenged and inspired them to take risks with their practice. In problematising their teaching and reflecting on their students' learning, they came to understand and value science in new and different ways.

Briefly, the Big Picture Science unit emerged from Rebecca's thinking about, and science challenges inherent in, an episode of the television series *Grey's Anatomy*. What sparked her thinking about Big Picture Science was the way in which the episode dealt with how decisions are made in life and death situations. The episode centred around a serious train accident. Two people arrive at the hospital and it quickly emerges that they have been harpooned: there is a pole running through the middle of them. The episode graphically displays them sitting facing each other, able to talk. After many tests and discussions, the doctors decide that they cannot save both of the people and so the decision is made that one must die in order to save the other.

The vignette below is designed to set the context for the Big Picture Science approach developed using the episode of Grey's Anatomy as the stimulus for the unit. To embrace the personal nature of this journey, the following is written from Rebecca's perspective on the situation.

Setting the Scene for Big Picture Science

Vojtech and I were teaching year 9 science together and attended a professional development session by academics from Monash University. The professional development session inspired us and was the catalyst for our collaboration in writing and delivering a unit called *Big Picture Science: Who Makes the Decision?* The unit became a long-term project that we combined with our teaching of a unit on body systems.

We used an episode of *Grey's Anatomy* called *Into you like a train* as a stimulus for the unit, and created an assessment task that required students to work co-operatively to use their science knowledge in creative ways. During the teaching of the unit, we each kept a reflective journal that documented our experiences. This journal became an outlet for us to explore our thinking about science and the way we were presenting it to our students. The intent of the journal was not to retell what had happened that day in the classroom but more to consider what had happened and to question what that showed us about students' understanding of science, as well as our own.

Reflecting on the Big Picture Science Experience

The Big Picture Science unit was a huge success but afterwards Vojtech and I were still caught up in what it is we have learnt and/or feel we need to change. Perhaps this was just our nature or maybe it was indicative of being part of a bigger project where you are constantly being asked to explain and explore and analyse, but nonetheless our headspace was not one of elation. It was, however, still positive; not what did we do wrong, but what did we do right and how can we do more of it? Our list of learnings at the end of the unit included:

- The way the teacher views science has a great impact on the way they present it to the students, which in turn influences how the students view science;
- Choice of stimulus material is vital; and
- Articulating publically and thus opening up your view of science for challenge is at the heart of the progress you make in teaching science.

A Teacher's View of Science

It became clear to us that the way the teacher views science has a significant impact on the way they present it to the students and therefore the way the students view it. If it is presented as a list of facts used to answer questions from textbooks and to be repeated on tests, then that is the way that most students will view it and operationalise it; they will just memorise and regurgitate facts and call it science.

The science as facts view was reinforced through this experience because there was actually a third year 9 teacher involved in Big Picture Science. However, that teacher was not able to be a part of the bigger project we developed and so did not attend the initial session that inspired the approach to the Big Picture Science unit. Although every effort was made to include this third teacher in all of the discussions about the unit, it quickly became clear that her views of science and teaching were more traditional in nature than that which was being pursued in the Big Picture Science unit and so she did not connect with the approach at the same level.

The Big Picture Science project was a year level project which created new and different demands from the more normal individualised classroom approach. For example, students worked on the Big Picture Science project until either the teachers or students saw a need for science content to be introduced. As the third teacher taught the content based on her planning of what she thought students would need and when, she became more isolated in terms of the intent and purpose of the project.

It seems reasonable to suggest that her different approach to teaching the Big Picture Science unit was in no small part a reflection of her view of science teaching and learning (i.e., that the students learn by working from the textbook—the source of correct factual information—and learning is measured through achievement on a knowledge-based test); a view of science that the unit was actually designed to challenge.

Stimulus Material

Teaching the Big Picture Science unit highlighted the importance of stimulus material in the initial engagement of students in a topic. For example, in a previous unit a BBC documentary called *If drugs were legal* was used as the stimulus material. Although many students found it engaging and challenging, others found it difficult to follow as some of the issues were (to them) a little too complex to comprehend. Despite the fact that the programme drew some very obvious links to science curriculum content related to the nervous system and brain function (the topic being taught) it did not create a powerful need to know for all students.

In contrast to the BBC documentary, the *Grey's Anatomy* episode was accessible to students not only in terms of the issues but also the nature of the content, i.e., body systems. Students connected with the material in both an emotional and cognitive way. They could quite easily picture themselves, or someone they knew, in the situation; their thinking was challenged; and they raised questions that created opportunities for them to articulate their views on the situation. The use of *Grey's Anatomy* as stimulus material became the link between students' existing science knowledge and the world outside of the science classroom—the Big Picture of Science.

Challenging Views of Science

An important aspect of the Big Picture Science journey was built around collaboration. Having the opportunity to discuss and plan for teaching together, then writing about those experiences, provided 'data' that could be revisited and reflected upon, which in turn led to new learning and pedagogical change. The many layers of analysis led to great personal growth. Sharing and challenging views of science out of the classroom led to new developments in the classroom for both teachers and students and fostered an understanding of science that was qualitatively different to that experienced before embarking on the Big Picture Science adventure.

Ongoing Reflections on the Big Picture Science Unit

Post the Big Picture Science experience, I spent a great deal of time reflecting with Vojtech about our shared experience of developing the pedagogical experience together. What quickly emerged was an articulation of what we valued about teaching science (such as making science authentic, emphasising problem solving and usefulness, and contextualising content). However, as we considered our planning an interaction with the third teacher highlighted that these values were not always shared. Although we did not necessarily recognise this at the time, it later occurred to us that the discussions we had engaged in as a duo in planning their Big Picture Science unit had been based around shared values.

When our values (such as contextualising content and others listed above) were challenged by the third teacher, the importance of those values became clearer, stronger and more articulable. Further, the differences in practice highlighted the significance of values in shaping students' science experiences. We shared particular values that supported our pedagogical approach; the third teacher's views of science (and thus the values underpinning them) led her to create different pedagogical experiences for her students that did not necessarily align with the intent of our notion of Big Picture Science.

We wanted our students to experience science in a way that would lead them to value science as meaningful, useful and authentic. Thus, our practice was designed to emphasise our values and encourage students to experience science as contextualised and that linked content with real life. It also revolved around encouraging students to collaborate, and assessments valued the very creativity and problem solving that we saw as crucial to challenging science as simply restating facts and information.

Vojtech and I also came to recognise that through our approach to the unit, our students' values were similarly brought to the surface as a consequence of the discussions about the situation depicted in the *Grey's Anatomy* episode. After viewing the episode, our students were asked to write a journal style response to the episode and to include some indication as to whether or not they agreed with what happened. Of course, there were a multitude of views expressed, but some common (paraphrased) concerns included:

> "The younger person should live because they have their whole life ahead of them."
>
> "The older person should live because they probably have people (partner, children) that they are responsible for and need to look after."
>
> "The doctors should have tried to save them both; irrespective of what the tests are telling them, they should have tried."
>
> "The doctors made the right decision based on the data they had."

Another interesting aspect of the episode, and one which became a major point of concern for the year 9 students, was a scene in which a doctor was running neurological tests on both patients, specifically, testing to see if they could wiggle their toes. Due to the positioning of the patients and the fact that they were both wearing neck braces, neither patient was able to see their toes or the toes of the other patient. One patient was able to wiggle their toes, the other patient was not. In the scene, the doctor told both patients that they were able to wiggle their toes. The majority of students were not happy about that response and suggested that it was entirely inappropriate of the doctor to lie; something they saw as a breach of trust. Again, through the Big Picture Science unit the class was delving into values rather than content per se.

Vojtech and I recognised opportunities in the episode as ways to talk about decision making and the skills required to evaluate data and the place of evidence in decision making. In so doing, we were able to use the material as a way of discussing ethical conduct, not just for doctors but also for researchers. That allowed a deeper consideration of what could be involved in conducting experiments and how researchers may not always know what the outcome might be (unlike most of the experiments that students tend to experience in school through recipe-type practicals). Subsequent discussion about the need to consider the consequences of not only carrying out an experiment but also of the outcome and how the knowledge gained might be used once again went to the heart of values of science (consider the Manhattan Project).

The Big Picture Science unit created a new way into having our students learn science as something broader, richer and more meaningful than simply memorising facts. The unit purposefully sought to push students to think much more about how the content (e.g., knowledge of the skeletal and nervous system) could be used to inform decision making. The Big Picture Science unit became an impetus for shifting students' thinking—or perhaps surfacing that thinking—about the value of science.

From Science Teacher to Science Teacher Educator

The following vignette continues to explore Rebecca's journey as she transitioned from school science teacher to science teacher educator and begins to consider how she came to portray science and science teaching with her students of teaching. The vignette is made up reflective notes from the time of teaching, reflections post teaching, and more current reflections. The account illustrates how a focus on values influenced her understanding of being a science teacher educator as she attempted to make visible the multitude of issues inherent in teaching and learning about teaching science that she now deemed required significant attention as a teacher of prospective science teachers. Her experience with Big Picture Science had helped her to realise that the values inherent in a teacher's understanding of science education, such as making science authentic, emphasising problem solving and usefulness, and contextualising content, should be a significant focus of teacher education: these values had had such a strong impact on not only the learning of content for her secondary school science students, but also their views of science and how science knowledge could be used.

Vignette: The transition from science teacher to science teacher educator

During my transition from science teacher to science teacher educator I was teaching general science method [a unit for students of teaching who wish to teach science at Years 7–10]. I was in the privileged position to be team teaching this unit with two other colleagues. Initially, we found this fantastic handout called "The day we made pancakes at school" (Doig & Adams, 1993, see Fig. 1 at the end of the chapter, a sample page from the handout), which we began using in our class simply as a handout. However, what we soon came to realise was that the real value of the handout lay in actually making the pancakes.

When we first used the handout …

Upon discovering this handout, we simply used it as a handout, setting it as a homework task at the conclusion of the first week. These student teachers had considered their current notions of science by exploring specific topics, such as states of matter, and come up with ideas about how they might go about teaching a topic to a given year level. Essentially, they had to plan the topic as a unit of work to run over four weeks, including assessment strategies and monitoring the development of students' conceptual understanding. The task was designed to elicit the current understanding of the nature of science held by our student teachers and what they felt good learning and teaching looked like in a classroom. At the conclusion of the lesson, we gave them the handout and asked them to complete it for homework as if they were secondary school students in year 8. Upon returning to class the following week, the student teachers switched handouts and marked each other's work. Initially, the marking was done individually, but later in the class it was analysed through class discussion about what would be deemed acceptable as an answer, how much detail might be required to get full marks for an answer, what would constitute a correct answer

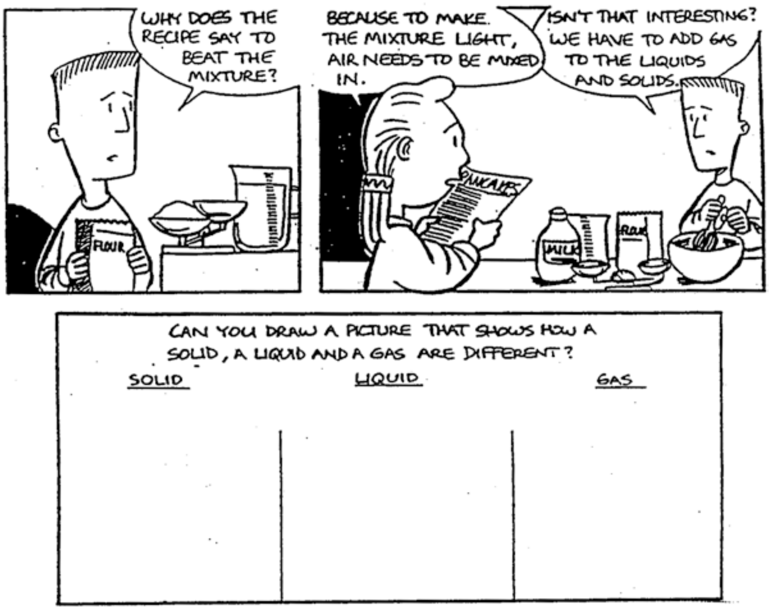

Fig. 1 Sample page from "the day we made pancakes at school". (Doig & Adams, 1993)

at different year levels, what might the teaching look like if this was the assessment task, and how they felt students would react to a task such as this.

What happens now …

After a few years of using the handout as described above, we decided to make a change. As the name of the handout suggests, it is all about making pancakes, and so we decided to get the students of teaching to actually make pancakes in class. A great deal of time was spent considering the purpose of doing this as it was going to take up a considerable amount of class time. We came to the conclusion that we should give it a try and see if this would further challenge their ideas about the nature and values of teaching science. The handout was still set as a homework task, but now that the student teachers had actually made pancakes, we felt that it somewhat changed the nature of the task from being totally theory and content driven to incorporating a memorable learning experience (i.e., what White (1989) described as an episode, a common science teaching anchor for learning). We found that this greatly changed the conversation in the following lesson from being about the answers on the handout in front of them to being more about how they connected the experience they had had with the handout and, further, whether this was what they expected science learning and teaching to be like. That provided us (the science teacher educators) with a great "way in" to challenging their notions of science, learning and teaching science and of course, their values of science.

Lesson 1: Making pancakes

This lesson felt a bit shaky to start with and even a little uncertain as we ran it. I suppose this was mostly because we were trying something new and actually cooking the pancakes for the first time as opposed to just having the students of teaching complete the handout. I was conscious of ensuring that our students of teaching were not thinking that we were just making pancakes for fun and therefore wasting their time. What would happen if they didn't see the point or make the link? Was it up to us to make this explicit or would this actually defeat the purpose of challenging their views of science? During the class, a couple of the girls said they saw no science in it! "What?!" I thought. "Perhaps completing the handout as homework would help to focus their thinking and begin to establish some links."

Lesson 2: Discussing the 'pancake' handout

The lesson today also feels a little shaky, but more from the students' perspective than mine. Even though they swapped handouts and responded to our questions as if they had written the handout in front of them (so not replying as themselves in an effort to create a sense of distance from what they were saying), there was still a sense of pressure and uncertainty in the room. We have been really pushing and challenging their understanding of some concepts, which I think is a good thing, especially for those who think they know it all, but sometimes I worry about those who are a bit nervous about their level of content knowledge ... just something for me to be aware of and perhaps attempt to counter.

We asked them how they approached making the pancakes last week and more specifically if they approached it with a science lens. Their responses included:

"We tried to be strategic about it, started small and moved from there, but we didn't treat it like a serious experiment because we didn't think it was science."

"It's a chemical reaction and physical change, its structure has changed and it has now become cooked batter … I know to explain it like this now but I didn't think like that last week."

"… taste the batter, it's floury, but taste the pancake and it tastes different because a chemical reaction has occurred and we have a new substance … I never thought of this as putting science into practice … (student then mutters to self) why don't I?"

Their responses made me think that perhaps we'd made a dent in their thinking, or at the very least, started them thinking. We decided to capitalise on the dent and slowly turn it into something that could be reshaped rather than repaired.

I don't think that our students of teaching hold views or thinking that requires complete remodelling, but it would be nice to think that they are up for a challenge and open to new possibilities about what science is, how it can be learned and how it can be taught. But where are we in all of this?

As science teacher educators we are standing in the eye of the storm; there is a sense of messiness, chaos and complexity all around as we try to untangle science, science learning and science teaching—and yet we have to remain calm and focused on our own teaching of science teaching so that our students actually have a sense that our practice is worth noticing and responding to if our teaching and our notions of science are to be accessible and able to be critiqued, unpacked and examined. In other words, we have to help our pre-service teacher students reflect on their experiences of our teaching and their learning in order to learn about their teaching of science and their students' learning.

Ongoing Reflections on My Teaching: A Focus on Values

Through the experience outlined in the vignette above, I came to recognise that my view of the nature and value of science was firmly situated in emphasising the usefulness of science in and for the everyday. However, I also recognised that pursuing this through my teaching of science teaching is significantly challenged when my students of teaching do not value science in a similar way. For example, in the cooking pancakes activity, I quickly recognised that many of my students of teaching did not see the science in this everyday action. While the pancake cooking activity was established as a way of challenging the views of science of the students of teaching, I did not anticipate how challenging it would be to make the links between cooking pancakes and science not only obvious but also meaningful.

Reflecting on the Big Picture Science experience reminded me of the impact of the way I thought about and valued science in my practice, and thus the views of the nature and value of science held by my students of teaching. Consequently, I recognised a need to continue to challenge what my students of teaching valued in science in order to help them think carefully about how they presented science to their students in schools, and how they assessed their students' learning in science. Thus, a focus on values in my role as a science teacher educator became an essential aspect of my developing pedagogy of teacher education.

I found the experience of shifting context from science teacher to science teacher educator an educative one, in that it made me recognise that knowing what good science teaching 'looked like' in school did not necessarily translate in the same way in the science teacher education setting. In moving into the science teacher education space, I was confronted by the need to unpack my thinking and to be able to articulate my pedagogical reasoning. The need to be able to 'give reasons' for my practice reminded me once again of my experience with Big Picture Science. By engaging with values in the teaching of science teaching, I began to make explicit for myself and my students of teaching why values matter and how considering them more carefully impacts one's practice.

My teacher education experience is increasingly shaped by one of my values of science; I value the way science is dynamic and responsive to the complex problems in the world. Thus, my teaching of science teaching attempts to acknowledge the complexity of science, but in so doing illustrates the importance of authenticity; again, the stimulus material for the Big Picture Science unit captures this point.

A focus on values, such as the way science can be dynamic and responsive to complex problems matters because it shifts thinking from the "what" (content) to the "why" (why this content?) and "how" (how can it be useful?). Through an emphasis on the "why" and "how" I have been able to recognise more easily how they influence the focus of assessment, i.e., from tests and recipe style practical reports (mostly encouraging the restating of the "what") to assessment that is centred around creative problem solving of more authentic problems (which requires decisions to be made around "why" this content and "how" it can be useful to solve the problem). Raising these ideas and showing them as a contrasting pair is one effective way of challenging students of teaching to appreciate the place of values of science in the development of their own knowledge and practice of teaching.

My experiences have highlighted for me how, through science teacher education, challenging students of teaching to reimagine science goes hand in hand with questioning their underlying views of learning and teaching science, and the practice inherent in those views. In reflecting on the purpose of their teaching in light of their understanding of the values they associate with science, meaningful links can be made to the science curriculum, authentic assessment and classroom practice—all key components to helping students of teaching begin to make sense of the complex nature of science teaching and learning.

My experiences suggest that in coming to make sense of teaching about teaching science through the lens of values, I have reconsidered and learnt more about what it means as a teacher to place emphasis on values. Reflecting deeply on my understanding of learners of science and how they experience science—both as students and students of teaching—and continually reflecting on, and drawing together the richness of both experiences of practice (school and teacher education), has encouraged me to purposefully challenge students of teaching to think more deeply about the values they associate with science and the nature of learning and teaching science.

Reflecting on the Role of Values of Science

Reflecting on the time since the first values book (Corrigan et al., 2007) was published I am conscious of the shift in my own thinking about values of science and, in particular, I note my ability to better articulate these values and to incorporate them into my teaching about science teaching. However, I also note that during this time, my students of teaching have not changed much in the sense that they still consistently hold views of science that are quite traditional—perhaps even perceived by some to be 'value free'. Yet there is significant research (some of which is referred to in this volume) that would suggest that science is value-laden and that this is an important point to highlight with both school students and students of teaching. As a consequence, two issues come to mind.

Firstly, during my time as a science teacher I was privileged to work with incredibly supportive and innovative colleagues and a school management team that was not only supportive but willing to take risks. An idea raised at the beginning of this chapter—that the values a teacher holds can greatly influence what happens in a classroom—becomes operationalised in an environment where the teacher's values are welcomed and viewed as a priority. Without this support, perhaps teachers are more likely to become enculturated into practice that carries different (perhaps hidden) values which may run counter to one's implicit intentions. Teaching in ways that explicitly emphasise that which is valued requires time, effort and thoughtfulness. Clearly, then, such an approach requires support and an openness to questioning the values inherent in particular practices. Such support allowed me to collaboratively develop and work on the Big Picture Science unit.

Secondly, students of teaching tend to (initially) have very clear expectations of what it is they are going to do as a science teacher and, thus, what they expect of their science teacher education experience. It seems fair to suggest that cooking pancakes in lesson one is not what they might expect.

Discussing values of science can be a challenge, but what my science teacher education experience has increasingly taught me through these experiences is that asking my students of teaching to consider *their* values of science can be a little uncomfortable for some. However, as "an uncomfortable learning experience can be a constructive learning experience" (Berry & Loughran, 2002, p. 20), it is important not to avoid such situations but to pedagogically engage in constructive ways.

My journey has shown me (and hopefully through sharing it, it has shown others too) that values really do influence the way a teacher teaches. Bringing them to the fore in practice is essential—and all the more so in science teacher education—because values influence not only what is taught, but also how and why, and crucially how those intentions are interpreted in students' learning.

Conclusion

This chapter aimed to highlight the importance of recognising and responding to notions of the values of science and how doing so can influence a science teacher educator's pedagogy of teacher education. The vignettes and experiences detailed in this chapter illustrate how science teacher educators can explicitly support students of teaching in ways that both challenge and embrace a wider view of the science curriculum, including a reconsideration of the nature and place of values associated with science, in order to encourage and improve the quality of science learning and teaching in teacher education and in schools.

As the vignettes and their discussion sought to make clear, purposefully reflecting on the messages, intent and purposes underpinning approaches to science teaching and the teaching of science teaching requires a shift in thinking and teaching that goes to the heart of science values and how they are portrayed through practice. Ultimately, science learning is shaped by the values inherent in science teaching. Therefore, opening up to scrutiny the dynamic interplay between both in what comprises the complex work of teaching science teaching must be fundamental to quality science teacher education.

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Part II
Values for Science Education

Deborah Corrigan

As highlighted in the first book in this series, *The re-emergence of values in science education* (Corrigan, Dillon, & Gunstone, 2007), science is not value free; it is an integral part of society as citizens make decisions about their lives. One role of science education, in developing scientific literacy, is to build bridges and linkages between science and society. In this second section of the book, the focus is on values for science education—exploring the role of values in providing science education that addresses the development of scientific literacy for all students. This section comprises three chapters that provide very different examples of how values for science education develop links between science and society for learners in a range of different contexts.

Karen Marangio and Richard Gunstone examine the issue of "fake news" as an example of the risks associated with the misrepresentation of science in an uncontrolled way through media and particularly social media. They contend that science education has a role in facilitating learning about communicating science to a wider audience. While many would argue that science education has always had the opportunity to promote science communication in our society, it has become obvious more recently that science education needs to identify possible heuristics and contextual and social cues within news stories that limit the nature and depth of our thinking.

Joseph Roche and Colette Murphy take a different approach to values for science education by focussing on informal science education. The Science Gallery in Ireland communicates contemporary science to the public, with a particular target group of youth aged 15–25 years old. It is this age group, which traditionally has been the most difficult age group to engage and is also when significant life choices are being made, that can benefit from informally engaging with science in areas where interesting science is being created at the disciplinary boundaries. When these boundaries are crossed, for example between science and art, connections are made in what appear to be unrelated areas and new insights enable novel solutions to complex problems. The success of Science Gallery is evident. Perhaps its success is due to "being in the right place and the right time" for the target group, or that it has changed the way society perceives science, museums and public engagement.

Perhaps it provides a mechanism for providing authentic connections to scientists, engineers and artists that "ignite creativity and discovery where science and art collide" (Brunswick, 2017, p. 174).

In the final chapter in this section, Cathy Buntting and Alister Jones explore the potential for biotechnology to provide a context for students to develop their scientific and technological literacy and values discourse even when such contexts are values-laden and associated with significant public controversy. Referring to contemporary examples of biotechnology together with frameworks for developing students' ethics and futures thinking, they provide insights into how students can be assisted to develop the skills needed to evaluate and use scientific and technological ideas and processes to address current and emerging problems. While this approach provides rich examples for engaging students in values discourse, there are also challenges for teachers who have had limited experience in this area.

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Science as "Just Opinion" – The Significance for Science Education of Emerging Social Media

Karen Marangio and Richard Gunstone

Introduction

Phrases such 'alternative facts', 'fake news', 'instinctive decisions' and 'science-denier' are now common place in all forms of media, with 'post-truth' awarded the Oxford Dictionaries 2016 Word of the Year (see https://en.oxforddictionaries.com/word-of-the-year/word-of-the-year-2016). Social media channels, of which Facebook and Twitter are but two of many, are becoming the major (and increasingly the only) sources of information for more and more people (Pew Research Centre, 2017) and traditional media is now digital and can be followed on social media platforms. Both traditional and social media are now pervasive influences on our lives. New forms of and ways to access information, including 'fake news', proliferate on an unprecedented scale. While it is not unusual to see a variety of perspectives in the media, and while 'fake science news' is not a new problem, the rise of misleading headlines and exaggerated news suggesting science is just one "opinion" puts science in danger of being seen as more flexible and unreliable than ever before. As science media and social media sites adjust and address these new twenty-first century challenges, there is great opportunity for science education to respond and promote the core values of science and science communication in our society.

In this chapter, we explore what this range of twenty-first century issues might mean for science education in schools. We are particularly concerned with both the threats posed to school science by these ubiquitous features of social media and how school science might seek to respond in positive ways that embrace rather than attempt to deny these new media. We argue that in order to develop student capacity to critique a science-related news story, science education needs to pay more considered attention to media analysis and response. In so arguing, we support long

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D. Corrigan et al. (eds.), *Values in Science Education*,
https://doi.org/10.1007/978-3-030-42172-4_5

standing positions that have advocated the teaching of different science values—values such as complexity, risk and uncertainty, and trust in science (see Rennie, Chapter "Communicating Certainty and Uncertainty in Science in Out-of-School Contexts" also Roche & Murphy, Chapter "Changing Values in Science Education and the Emergence of Science Gallery", this volume). In this way, we seek to reinforce both core values of science and central purposes of science education that explicitly encourage students to consider differing relevant perspectives as they construct their own, well-informed views about a range of science-related issues.

Our exploration of values begins long before this century, as we very briefly consider some ways more traditional media have been used in past eras to promulgate views that can usually be summarised as "science as opinion". These views are the antithesis of many of the core values of science that have been central to both its public face and its advancement through research since the Renaissance, for example, reliance on data, seeking to be as objective (and data-reliant) as possible in drawing conclusions, subjecting hypotheses to rigorous testing, using replication studies as a critical aspect of determining the validity of claims, etc.

Next we consider the impact of social media in general on society in this second decade of the twenty-first Century. We then turn to multiple issues associated with the ways science is communicated via social and traditional media, the consequences that can result from these issues for the forms of understanding of science and the way of knowing that is science, and some of the deliberate distortions of science and the way of knowing that is science that have been promulgated by various forms of vested interests (broadly, from the time of the first specifically industry funded attempt, in 1954, to "foster the impression of debate" (Oreskes & Conway, 2010, p. 17)). We conclude the chapter with our thinking about how science education, particularly school science education, might respond in ways that accept and embrace the reality of media in this century.

Science as "Just Opinion" Is not a Twenty-First Century Phenomenon

In the introduction to the proceedings of a late Twentieth Century New York Academy of the Sciences conference on *The Flight from Science and Reason*, Gross, Levitt, and Lewis (1996) write

> Whenever and wherever what we generally mean by "science" *really* began, it is true that rejection of it began in earnest with the Enlightenment itself. Nor has it been a rejection solely by the ignorant, by professional irrationalists, or by minor figures…. There are common, and obvious, forms of antireason and antiscience…. [r]eligious obscurantism….[t]he mountebank healer….[t]he cults of UFO-watchers…spoon benders…adjusters of human energy fields….opposition [to science] not on the basis of evidence but by denial of the efficacy of rational inquiry—or insistence upon the epistemic merit of alternatives. (pp. 1–2, emphasis in original)

A once very widely known populariser of science, mathematics and data-based reasoning in the Twentieth Century, Martin Gardner, wrote much about those who claimed to have come from science but who also claimed 'the epistemic merit of alternatives', for example, Velikovsky, Wilhelm Reich, Uri Geller, Scientologists, etc. In a very popular book of this genre, he noted that "[t]he problem of determining the degree to which a theory is confirmed is extremely difficult and technical, and…there are no known methods for giving precise 'probability values' to hypotheses" (Gardner, 1957, p. 7)—a matter that appears to have been used to their advantage by those with vested interests in, for example, opposing smoking bans or action on anthropomorphic climate change (Flannery, 2005; Oreskes & Conway, 2010).

A prominent US historian, in particular of medicine in that country, John Burnham, has written persuasively about the popularising of science and health in the US through the Nineteenth and Twentieth Centuries (Burnham, 1987). He argues that the popularisers were "fervent disciples of science" (p. 9), and so promoted a highly positivist view of science and the world—which in turn led to a new form of superstition. To the extent that this argument is accepted, we assert that this has contributed to the ways in which vested interests, so well described (with evidence) by Oreskes and Conway (2010), have been able to create in the second half of last century disturbingly widespread acceptance of science as 'only' one side of a debate.

When reporting on an issue, it is now standard journalistic practice to provide different sides of a debate, with any serious consideration of the extent to which the debate is 'real' (i.e., more than a twenty-first century version of Velikovsky versus every other cosmologist on the planet) being exceedingly rare. Rather, journalists tend to present different sides of the debate equally, with equal credibility and weighting given to both sides, even when there is a strong consensus within the science community for only one position in the debate. For instance, to use the most prominent contemporary example, while there is overwhelming consensus on climate change among climatologists, news stories frequently include opposing views from non-experts (Boykoff & Boykoff, 2004), for example, non-scientists and scientists specialising well outside this field of science. Such reporting gives the more extreme and oppositional views greater representation (Boykoff, 2013) and can help foster incorrect science ideas and plant 'seeds of doubt' about the science that have no support in any body of evidence that is relevant. This in turn makes the science seem more controversial and uncertain than the science community would accept, and consequently undermines public trust in science (Boykoff & Boykoff, 2004). We are not arguing here that different perspectives should not be considered, or that people cannot oppose science, or that scientists do not, cannot or should not disagree, but we are arguing that such opposition cannot ignore data or claim an unreasonable epistemic alternative. We need to be extremely careful with reports that misrepresent the science or those media 'debates' that are 'unbalanced', that is, media reports that do not explain that one perspective is the science community consensus and that the other is held by, at best, only a very small minority of the scientific community, or that there is conflict of interest among some of those arguing one side of the 'debate', or some are getting paid to comment (give a certain view) and so on; accepting all perspectives without scrutiny is unreasonable and distorting (McCright, 2007).

This is not a recently emerging issue. Perhaps the most striking example of this in the Twentieth Century is the books of Erich von Däniken (e.g., von Däniken, 1969). His views were unsupported by any data, and he publically and unequivocally admitted that he had both taken the ideas from earlier writers and constructed his books specifically as a money making venture (e.g., Colavito, 2005). Yet he was for a decade from the late 1960s frequently presented in print and television journalism as a legitimate alternative to conventional scientific thinking about the origins of life. (And just his books made him very wealthy: by the mid-1990s the paperback version of his most well known book—*Chariots of the Gods*—had sold over 1,000,000 copies in Australia alone!) We see it as important to our arguments in this chapter to note that the almost universal response of science education at all levels (from kindergarten to post graduate) was to completely ignore von Däniken and his writings and his prominence on the most significant media of his time (television). We also see it as particularly important that the apparent emergence in this century of issues such as 'fake news' and 'alternative facts' is giving a much higher and much more diverse public profile for issues that have been with us for decades and decades.

Unfortunately, this broad set of issues ('alternative facts' and the consequences for science education) has existed for centuries. Over the last 50+ years (essentially from the time of the pseudo-debates over smoking and lung cancer) it has often evolved through the deliberate and strategic intervention of vested interests, usually financially-vested interests (see Oreskes & Conway, 2010 for an account of specific strategies employed by such interests). It is clearly too simple to assert that we should just ask journalists to report more substantially the side of a debate that is the widely held science consensus and highlight the limitations or give less time to another perspective that has little (or no) supporting evidence, especially when reporting on a contentious socio-scientific issue. When journalists do not give multiple sides of a story, or give unbalanced attention to the alternatives, they are often considered to be biased (with such a position very often being fervently argued by those holding the non-scientific view). Hence they are criticised by members of the public as complicit in 'cover-ups' and therefore at risk of having their reputations damaged (and, in cases such as vaccination or anthropomorphic climate change, having public acceptance of the science position considerably diminished) (McCright, 2007).

One most unfortunate casualty of this evolution of reporting has been the word 'sceptic'. No longer is its common usage as it once was; now this word has been appropriated by science deniers as a badge to describe themselves. And so it is a science denier who asserts that they do not 'believe' in climate change who is very likely to also assert they are a 'sceptic', even though there is not a shred of evidence of any scepticism being applied by them to the claims of the deniers they follow. It is really difficult to argue with a self-described science 'sceptic' or science denier (Lewandowsky, Gignac, & Oberauer, 2015). They may critique the science research, highlighting limitations in a way that seeks to cast doubt on and discredit a particular science study and then seek to generalise this to discredit the whole body of research. Or they may pick parts of the science to support their particular opinion, downplaying all the rest. For instance, a 'climate-change denier' may exaggerate the degree of uncertainty in predicting change or imply that uncertainty justifies inaction (Nisbet & Scheufele, 2009; Rennie, Chapter "Communicating Certainty and Uncertainty in Science in Out-of-School Contexts", this volume). But more often they tend to ignore the empirical evidence, seeing this as having less importance than other arguments. They often deliberately focus on anecdotes and personal stories and claims of lack of freedom of speech and choice, with some resorting to personal abuse, misquoting or quoting out of context, cherry-picking data, unsubstantiated assertions and/or refuted claims and conspiracy theories.

Science in the Media in Today's Society

The widespread and rapid adoption of an extensive range of social media has dramatically changed the way almost all of us communicate and interact and go about our daily lives. Social media provides platforms for interaction, collaboration, participation and freedom to both express a range of views and seek information. Social media differs from traditional online media in that it is user-generated, interactive and tailored and targeted towards specific users (Cacciatore, Scheufele, & Iyengar, 2016), with like-minded individuals able to find, 'friend', follow and interact with each other. In this highly dynamic environment, the popularity of a platform can change rapidly. And, broadly, these massive media changes have been even more dramatic and more ubiquitous among the students we teach.

Today many people source most, if not all, their news and information via social media, with sharing news and information a key activity among Australian teenagers (Perrin, 2015). This group mainly uses social media to communicate with friends, share photos and source information (ACMA, 2013). Traditional media is now digital and often on social media platforms, too, allowing people to comment and share. This phenomenal growth of news stories in the digital media has spread an endlessly increasing number of ideas, growing in volume and complexity each day, and, it seems, endlessly increasing new opportunities to reach a wide range of people all over the world.[1] Consequently, the way people access, share and some-

[1] Among many sets of data we could give to support these assertions of dramatic growth and spread we offer:

∗∗Facebook was established (in its original 'just Harvard' form) on 4 February 2004 (crazy as it may seem, just 13 ½ years ago); in the first quarter of 2017 Facebook had over 1.94 billion (>1,940,000,000) at least monthly users (see https://www.statista.com/statistics/264810/number-of-monthly-active-facebook-users-worldwide/).

∗∗In Australia, as an example of a wealthy society that is relatively technology rich, of the 24.3 million Australians (of all ages) alive in Jan 2017 about 6 out of 10 were active Facebook users, 1 in 2 YouTube, 1 in 5 Instagram, 1 in 6 Snapchat, 1 in 6 Tumblr, 1 in 6 LinkedIn, 1 in 8 WhatsApp, 1 in 9 Twitter, 1 in 9 TripAdvisor, 1 in 12 Tinder, 1 in 13 Blogspot, 1 in 14 Yelp (and figures exist times create science information has changed dramatically with the proliferation of traditional and social media platforms, podcasts, videos, news feeds, blogs, tweets, posts, reviews and opportunities to share websites.

While the positive potential of the range of social media for science communication (a term we use here in the conventional public science education sense) is clear, like all disruptive technologies, these media present major and profoundly different challenges. Perhaps the most obvious of these challenges is that the traditional 'gate-keeping' once applied to public communications of and about science can now be bypassed, for example, no longer is science expertise necessarily involved in newspaper story selection, scrutinising, or editing. While social media platforms, like Facebook (Mosseri, 2016), are starting to respond to this challenge, and many science-related organisations are taking a lead in communicating and 'checking' science stories, 'fake news' will continue. Any and all opinions, data-rich or data-free, can now find a place in a completely unmoderated form—including those that are of major concern here, that is, opinions that misrepresent science and may distort the nature of scientific debate.

'Fake news' is fabricated information and often combined with misleading titles, to deliberately deceive users and motivate them to disseminate the information (Media Matters, 2016). We use the term 'fake news' from this point to describe specifically science-related opinions masquerading as 'news' or 'legitimate' or 'supported by scientists', etc. Lewandowsky, Ecker, Seifert, Schwarz, and Cook (2012) outline some different origins of deliberately misleading science information disseminated as 'fake news' via rumours (such as vaccinations harming children), works of fiction (misrepresenting climate change), governments and politicians (misinforming the public or oversimplifying the message), vested interests (cigarette companies and the fossil-fuel industry) and extreme views (conspiracy theories, such as 'NASA faked the moon landing').

Misleading or out-of-context information based on actual events that occurred may not be deliberately fabricated and does not necessarily constitute fake news (Media Matters, 2016) but is nevertheless of serious concern. Mistakes happen, sometimes accidentally and innocently and without any intention to mislead (Tan, Lee, & Chae, 2015). A writer may use poor wording to convey a science story, or lack some necessary information or understanding, and so mislead (deceive) the reader without any intention to do this. A common example is in journalism. In attempts to meet deadlines with limited time and opportunities to check and scrutinise messages and in attempts to get the audience to understand and be interested in the piece, the science may be oversimplified or exaggerated by the journalist (Lewandowsky et al., 2012, Rennie, Chapter "Communicating Certainty and Uncertainty in Science in Out-of-School Contexts", this volume).

In other words, science-related information can be unintentionally misrepresented or deliberately twisted to deceive others, including the creation and

for another 6 increasingly less popular social media platforms) (see https://www.socialmedianews.com.au/social-media-statistics-australia-january-2017/)

distribution of fake news. Likewise, some people may deliberately attempt to spread fake news, while others may share fake news without realising it is false, and thus fake news often goes viral through 'shares', 'likes' and 'retweets'.

As noted above, many stories misrepresenting science, including fake news, are associated with hotly contentious debates in our society that concern science issues, for example, the role of human impact on climate change, safety of childhood vaccinations, genetically-modified (GM) foods, food and energy security, and the effects of cigarettes. Some of these issues, such as climate change, are not debated in science among experts in the field but most certainly are in the broad community. Furthermore, a science story may say it is "supported by scientists" but fail to state the scientist is from an unrelated field of science.

When there is information that both represents and misrepresents issues in our society these mixed messages have the potential to create confusion, frustration and indifference. Individuals may feel overwhelmed with the amount of information and may refuse to consider evidence-based recommendations (Nagler, 2014). For instance, people may refuse certain medications in light of exaggerations on social media suggesting that the dangers of these medications are extreme and certain, therefore potentially having significant effects on the beliefs and behaviours of individuals and communities, and ultimately whole community health (Poland & Spier, 2010; Tan et al., 2015). New policies, funding and campaigns have been needed to attempt to override such cases of fake news, yet these misrepresentations of science often persist, even when (and long after) corrections are made.

Our age has become one where, for any science-related issue that has some social controversy associated with it, even when that controversy has been demonstrably artificially created, fake news is now impossible to ignore. In our society, we enjoy freedom to be our own editors, source information, choose what is important to us, share stories that resonate with us, and make our own decisions. This highlights the way reliable, credible and accurate news is vital to democracy, something that can be threatened by stories that misrepresent science. While education has become acutely aware of some major modern technology issues such as cyber safety and privacy, the proliferation of fake news should be seen as an opportunity for science education to increase attention given to preparing students to, for example, scrutinize science stories in the media.

Personal and Social Influences on Understanding Science News Stories

The proliferation of and easy access to science news—and fake news—stories in the media has profound consequences for the ways science is understood and misunderstood, represented and misrepresented. We are all susceptible to being influenced by misrepresented science news, including fake news. Furthermore, having sound science knowledge does not necessarily mean a positive attitude to science, with a meta-analysis of qualitative and quantitative research finding only a small positive correlation between science knowledge and attitudes towards science with even that small correlation varying little across cultures (Allum, Sturgis, Tabourazi, & Brunton-Smith, 2008). Lack of science knowledge is not enough to explain why people may reject science claims or support ideas that are not in line with science evidence.

A large 2017 survey of US citizens (N = 4024) found that most trust scientists although they recognise issues around the communication of science in both traditional and social media, and the way it is understood by the public (Pew Research Centre, 2017). The majority of respondents rely on general news sources for science news (54%) even though they say science speciality sources are more trustworthy, and most report distrusting science posts on social media. Furthermore, over 40% viewed the communication of science-related issues (such as climate change, childhood vaccinations, GM food, human gene editing) as problematic, with most blaming the media (73%) rather than the way researchers publish or share their findings (24%). In addition, many thought 'the public' do not know enough about science to understand the findings of science (44%) but quickly jump to conclusions about how to apply new science findings to their lives (42%). Overall, this survey suggests that although USA citizens see that there are some problems around science communication and public understanding, they rely more on general sources in the media for their science information than on other possible sources. Of course, understanding that there may be some problems does not necessarily mean that people will identify and not be influenced by stories in which science has been misrepresented.

There are multiple and complex reasons influencing the ways we use, share, communicate and understand science news stories. Our personal attitudes, beliefs and values, as well as our affective responses, cognitive evaluations, motivations, past experiences, group influences, social, political, religious and cultural influences, all have some forms of impact on the way we seek and receive information in the media. Hence all play a role in the way we understand and use science news stories. We can be influenced by clever marketing and persuasive techniques, including the message in a headline, an advertising slogan or catch phrase, direct-to-customer advertising, and 'likes' or retweets by those we respect. In other words, while we are certainly influenced by our own values, including the way we value science and its role in our lives and society (addressed further in the final section of this chapter) we are also susceptible to a range of other factors, including specific attempts to influence our thinking.

Further, while we may seek to take a systematic approach with the science stories we view, we often do not. It has been known for decades that we often rely on *heuristics*, or mental shortcuts, as 'rules of thumb' to reach decisions quickly (Newell, Shaw, & Simon, 1958). Heuristics are based on intuition, past experience and other relevant information that comes quickly to mind. In the absence of information about the various alternatives and without time to deeply consider the story and our understanding, it is not easy to make rational decisions, even in important matters. While heuristics usually serve us well, they also make us more vulnerable to misleading headlines and the way we understand and respond to science news stories in the media, including fake news.

While we all like to think we are rational thinkers and that we make sound decisions, the use of heuristics can lead to cognitive biases, systematic illogical thinking and behaviours (Tversky & Kahneman, 1974). Heuristics are specifically relevant to our arguments here as they influence the way we understand science news stories.

Examples of Heuristics and Social Influences on the Way We Understand Science News Stories

Some, but by no means all, influences on the way we understand, communicate and use science news stories are outlined below.

- **Motivated reasoning:** Our motives influence the way we assess information and lead us to set up biases in our interpretations of information. We are more likely to believe something that is in line with what we want to believe—we have a tendency to discount information or evidence that challenges our beliefs and accept without questioning information that is in line with our beliefs. This phenomenon is known as ‘motivated reasoning’ (Kunda, 1990) or confirmation bias. We tend not to accept or consider explanations that conflict with our long held views or values.
- **Familiarity:** Familiarity with a statement is linked with feeling it must be true (Fazio, Brashier, Payne, & Marsh, 2015). Exposure to a fake news headline can have an impact on what we remember and our opinions and beliefs about what we remember; subsequent corrections or retractions do very little to remedy the impact of the original exposure. If a fake news headline is viewed multiple times, then it can seem even more correct, even when it conflicts with what we already know and believe. Fazio et al. (2015) propose that this tendency to believe information to be correct after repeated exposure, an ‘illusory truth’, is because we use heuristic memory short cuts that take less cognitive effort. Since it is easier to recall a repeated statement, rather than recall and evaluate the source of the statement, we are more likely to think the statement is true.
- **The ‘Backfire’ effect:** Flagging a website or placing a warning that a social media site may contain misinformation or fake news will not help. Again, we tend to remember the information, but not remember that it is false, for example, via a disclaimer indicating that the science has been misrepresented, or the offering of an apology, or giving the correct information—such attempts rarely have impact. Refuting information may even ‘backfire’: it is known that refutations can sometimes reinforce the original misinformation by having the misinformation then viewed as well supported and the discrediting forgotten (Lewandowsky et al., 2012). Again, the repeated statement can now be easier to recall, and more likely for us to think it is true.

- **Social influences:** Social groups and social norms within these groups have powerful influences on each of us, with the views of our friends and family, a desire for favourable evaluation from others, and a need to maintain important relationships all playing a role in influencing our attitudes, behaviours, beliefs and values (Cialdini & Trost, 1998). In terms of media, we are influenced by characteristics within our social connections and exposure to their views, including what our social network post, share, like, follow, retweet, blog, review and comment on. In many ways, social media can set us up in a 'social bubble'. We decide who we "friend", "like" and "follow" and find and share information that we care about and matters to us. These social norms help us gain an understanding of issues and influence how we respond, especially when the issues seem uncertain, difficult to understand or ambiguous (Cialdini & Goldstein, 2004). Reviews of and comments on a story, including anonymous reviews/comments, can have a greater impact on people's understanding and beliefs than the original story, especially with those who are less familiar with the topic (Anderson, Brossard, Scheufele, Xenos, & Ladwig, 2014).
- **The 'Bandwagon' effect:** Social influences can be highlighted in a number of heuristics such as the bandwagon effect (Simon, 1954). "If everyone else is doing it" or "if everyone else agrees", we may follow the lead of our social group, or our desired social group, without fully evaluating our judgements and decisions. People tend to gravitate towards positions and beliefs that already have some established popularity (Neumann, 2010), so it is no accident that many sites show 'views', 'hits' and 'likes' for specific stories, and include 'ratings' and 'comments' about stories. Such 'bandwagon' heuristics can work in favour of some health campaigns, for instance Quit Smoking or Road Safety, or can diminish such campaigns if our social group actions are negative. For health campaigns in particular, this can result in a person's decision to use the 'bandwagon' heuristic to quantify risk and ignore the campaign.
- **Echo chambers:** Our beliefs can be reinforced or amplified when they are shared and repeated by other like-minded members within our social circles—a Facebook group, for example. By being part of an echo chamber, we are also able to seek out information that reinforces our existing views, potentially as an unconscious exercise of confirmation bias.
- **Further use of heuristics for marketing:** The use of messages that rely on heuristics, such as a catchy fake news headline, are part of a range of common persuasive techniques (Petty & Cacioppo, 1986). Heuristic cues are not based on logic, but could centre on superficial characteristics of the message, such as the attractiveness and likability of the presenter, speech tones, catchy slogans or provocative and emotionally charged messages. Such cues rely on us acting in more of a reflexive, less critical, non-thinking way to make decisions and act and resolve issues quickly. This is especially the case when the message is one we are not interested in or not able to understand, or when we are not able to think about the content at the time. Thus, we put little or no cognitive effort into evaluating aspects of a message such as the intent, motivation, plausibility and empirical evidence (or otherwise) that supports the claims within the message.

The relationship between science and its communication in the media is far from simple. The way we use, share, communicate and understand science is influenced by, and influences, our values, attitudes, beliefs and behaviours, whether we realise it or not. Even when presented with a credible science story, we will differ in how we interpret the data, understand the message and make decisions on risk, relevance or accuracy. We can handle a news story quickly, using heuristics and other contextual and social cues as shortcuts for instant judgements, with little cognitive effort or reflection.

Three broad steps forward in seeking to respond to the proliferation of incorrect science stories, including fake news, are to seek to (a) understand the role of our personal values in our response to science in the media, (b) understand science, how science works and the increasing centrality of values in science such as complexity, risk and uncertainty, and social constructs (e.g., argumentation, debate, peer review and consensus within the science community), and (c) recognise possible heuristics and other contextual cues and social influences. Taking time to carefully weigh up an argument, consider the underlying intent and motivation of the proposer of the argument, and the data-driven evidence underpinning a science news story may help demonstrate science as much more that "just an opinion".

Possible Science Education Responses

Both traditional media and social media are now vitally important and immensely valuable sources of science information and science communication tools. This massive quantity of information and complete ease of access to this information are a continuing feature of our modern world. That this information both represents and misrepresents science calls for carefully considered responses from science education, realistic responses that reflect the modern world. Science education can, if it chooses, empower teachers and students to develop capacities to critique science in the media and to effectively communicate science to the general public. Such responses should include a focus on how science is sourced, communicated, shared and understood in our society. In doing so, we reinforce ideas that have been advocated by science educators for a long time: the need to consider the values, role and use of science in society, and ways to promote more cognitive effort given to the intent, plausibility and empirical evidence that supports the claims within a story when accessing that story. In other words, science education can use science news in the media as opportunities to promote a more complete understanding of the ways science knowledge is created and the science values that underpin the development of this knowledge.

It is important that people have access to and engage with science information for decision making, both at personal and societal levels. Students will come across science news stories now and into the future and will make judgements about such stories. Goodrum and Rennie (2007) and many others advocate that the fundamental aim of school science is the development of scientifically literate citizens. This means "helping students to understand more about science and its processes, recognise its place in our culture and society, and to be able to use science to make informed decisions in their daily lives" (Goodrum & Rennie, 2007, p. 3). Accessing science news stories and other forms of science information and making informed and responsible judgements about science-related news stories should be seen as part of this informed decision making. Informed decision making includes encouraging students to be mindful of not making decisions quickly and being ready to revisit decisions. Rather than making instant judgements about a science-related news story, it includes carefully weighing up the argument(s), considering the empirical evidence underpinning the argument(s) and the motivations behind them, asking further questions about what understanding is needed to make a more informed decision, and considering the heuristics and other contextual cues and social influences that may come into play. Of central significance for almost all science-related issues within the media is the importance of students considering the relevance of the specific science in their own lives and in society more broadly, the science relevant to their decision making related to the issue, and the broader values of science and their own values.

Fensham (2015) raised concerns about the way science has been communicated in the Australian media, particularly in the reporting of issues involving complexity, uncertainty and correlation in science, the ways in which misrepresenting science raises doubt and diminishes trust in science and limits the use of science in decision making. At the same time, Fensham (2015) found "learning gaps" in these areas within the school science curriculum and consequently has called for different pedagogies and societal pressure to facilitate overcoming these "learning gaps".

Some Areas to Consider in a Science Education Response

We now describe four possible areas for science education to consider when responding to the challenge of the ways science-related news stories are sourced, represented, understood and used.

1. **Scrutinise the source of science-related news stories**

Not only are there now abundant and varied sources of science-related news stories, any of us can create science news stories. These creations can be shared, followed, retweeted, liked, reviewed, recreated or repurposed. In addition, science-related stories and advertising (e.g., health-related products and programmes) can be specifically targeted 'direct-to-consumer' and via specific sites that are likely to attract their targeted audience.

More effective communication of science in all forms of media is gaining increasing attention, especially in terms of creating coherent messages and scrutinising reports published for public consumption. Shanahan (2015) provides an example of how science is being played out in a public forum in the case of #Arseniclife, where the normally private scrutiny of science was carried out on media platforms. A range of science-related organisations and people, such as museums, science centres, science magazines, scientists and science educators now connect and engage with the public via traditional and social media. These offer up-to-date and reputable sources of science information for teachers and students to access. Others, such as Science Media Centres and PubMedia Health, are also designed to communicate science to the public and also offer support for scientists and 'science checking' of news stories, as discussed later in this chapter. An innovative online platform in New Zealand, www.sciencelearn.org.nz, supports teaching and learning of science with multimedia resources and extensive social media activity, as discussed in Buntting, Jones, and Cowie (2018).

At the same time, fake news sites are being cleverly designed to look more like legitimate sites and may have domain names that create confusion with more legitimate sites (e.g., AbcNews.com.co is not the Australian ABC News). This makes checking sources of information now more difficult. The important point here is that while we can be mindful of where we source science information, it is not that easy to always know or detect whether or not the science within the news story is credible.

Teachers may want to consider some of the quality 'science checking' associations who regularly post expert appraisals to science news stories. These sites offer opportunities to examine science reports and associated media articles. This can help teachers and students tease apart what is valid and reliable and representative of science versus news that is misinterpreted, sensationalised, exaggerated or simply fake. It enables them to explore how science is represented in the media, and sometimes misrepresented, including through fake news.

For instance, rich discussions can be created from the following detailed example of misrepresentations in the media (refer to Exemplar 1) in box below, and significant learning about the issues raised above can result.

1. ***Original Study***

Consider this published science research article:

Korem, et al. (2017). Bread affects clinical parameters and induces gut microbiome-associated personal glycemic responses. *Cell Metabolism, 25*(6), 1243–1253. e1245.

The abstract of this research paper gives a summary of the findings (see www.cell.com/cell-metabolism/fulltext/S1550-4131(17)30288-7). In essence the researchers find the glycemic response to bread type to be person specific and microbiome associated, highlighting the importance of nutrition personalisation.

Class discussions could be extended to consider the intended audience of this article (specialists in this area within the science community) and the accessibility of this article for a general (in this case school) audience.

(continued)

2. ***Press Release***

Consider the following news release derived from the research paper and published on the less expert-focussed website Science Daily:

Cell Press. (2017, June 6). Is white or whole wheat bread 'healthier?' Depends on the person. *ScienceDaily*. www.sciencedaily.com/releases/2017/06/170606135754.htm

This press release is a valuable starting point for a discussion: Why was the press release written? What are the publically interesting aspects of the research? What is interesting in the areas for further research (i.e., the caveat at the end of the *Science* Daily page)?

3. ***Science news stories in the media***

The research paper then attracted the following reports in the media:

- Sliced white bread's 'just as healthy as brown', shock findings reveal. The Sun, June 6, 2017
- Is white bread better for you than brown sourdough? It depends on your gut. The Guardian, June 6, 2017
- Is wholemeal bread really any better for you? People who eat white are no less healthy, study finds. Daily Mail, June 6, 2017
- White or whole wheat bread study may shed light on diet failure. Healthline, June 15, 2017

It is worth discussing what these headlines suggest, keeping in mind the original study.

4. ***Expert reactions***

Soon after these media reports, the Science Media Centre and PubMedia Health (both Australian websites focussed on checking of science reports in the general media), both performed 'quality science checks' and posted expert reactions to the study.

- http://www.sciencemediacentre.org/expert-reaction-to-study-investigating-|the-effects-of-consuming-white-processed-bread-vs-sourdough-bread/
- https://www.ncbi.nlm.nih.gov/pubmedhealth/behindtheheadlines/news/2017-06-08-is-white-bread-just-as-healthy-as-brown/

These two reports highlight a number of concerns important to discuss with students in terms of helping them understand the original study and how and why very important aspects of the original study have been totally lost in the

(continued)

popular media reports at the end of the communication chain. Discussions could be facilitated around the science news stories in the media, including:

- How is the story written to capture the audience's attention? Who is the intended audience? Is it relevant for this audience?
- What are the motivations behind creating this story? Who is the author and who published the story or where is the story located? Why does this story exist? Is there a bias?
- How does the story support its claims with science evidence? Is the science evidence in line with the original research study? (If not, how does it differ? What are the possible reasons for the differences?) Further questions to critique the science could include: Is the science current (When was it published? Has it been updated?)? Who are the researchers (credentials)? Who paid for the study (considers conflicts of interest although need to remember that scientists need funding, and trials are often sponsored by manufacturers)? Is this research an initial trial? What conclusions do the researchers give? What do the expert reviewers say?
- Does the story actually match what is in the headline (and what is the purpose of headlines)?
- What are possible heuristics the audience may use to make a quick decision about the story?
- Do the findings from this study raise further questions and suggest further research into specific areas? Explain.
- What does this news story mean to you—personally? And for society?
- What else do you need to know to make a more informed decision about the topic in the article? (claims and counterclaims; questions the article raises and further information or research needed?)

5. ***Rewriting a science news story*** Students can now attempt to rewrite one of the news stories. Ways of framing the science content in a manner that captures the attention of the intended audience, is understandable and represents the science could be discussed further. This could highlight ways to approach the interpretation of news stories, including how they differ in context, structure, content and style from a research investigation report.

This broad structure (original research paper, popular science-specialist account of the original research, popular media account) can of course be used with a wide range of science studies.

Science media is responding, but there is, and will always be, a need for all of us to scrutinise the source of science-related news, whether traditional or social. A science education response should support students in monitoring and critiquing the source of science-related news stories.

2. **Scrutinise the way science may be represented (or misrepresented) in a news story**

Science is relevant for many personal and societal decisions. It is important that the general public has informed access to information relevant to this decision making. To help students learn about how science may be represented (or misrepresented) in the media, a focus on the considerations and complexities of framing the science content into a context that the intended audience understands (e.g., writing for an expert audience or the general public). One possible approach is to compare and contrast science-related news articles with writing a scientific report, as outlined in the example above. In addition, it is worth pointing out that errors in a news story can come from a variety of sources, not just the author of the story, and this can lead to science being misrepresented—accidentally or deliberately—as we discussed earlier in this chapter.

3. **Consider how the science news stories may be understood**

As discussed earlier, there are many different reasons for interpreting a news story in different ways: different people have different values, beliefs and understandings of science relevant to the story, and often bring different perspectives related to issues central to the story. As well as critiquing the science within a news story, it is worth discussing the need not to make decisions quickly about a science news story. It is also worth considering the heuristics and other contextual cues and social influences that may be at play, carefully weighing up the argument, and considering the data-driven evidence in light of the theoretical models of science that underpin it. In this way, we can foster learning about, and identifying the use of, persausive techniques (as best we can!) and why we are all suspectible to believing fake news.

Science news articles in the media offer rich opportunities to discuss values of science and, in doing so, to learn about the way science operates. Opportunities include discussing the complexities of science and multifactorial, non-directional and dynamic influences on a science system(s) and use of complex models, including emerging science and technologies. Particularly rich domains of science include health, security and environment. Science news stories offer opportunities to show how science may change as new evidence and methodologies come to hand, and that some science is more durable and currently supported by widespread scientific consensus, while other science is more speculative, vague or contested within the science community.

Rennie (Chapter "Communicating Certainty and Uncertainty in Science in Out-of-School Contexts", this volume) discusses the importance of understanding uncertainty as it relates to scientific evidence, risks in decision-making, and trust in science and scientists as she explores possible ways of and associated challenges with communicating these ideas within science centres and museums. Science embraces uncertainty as a way forward, to capture what is 'more certain' (perhaps 'less uncertain' is better) and to raise questions and investigate further. It is critically important to science that uncertainty does not mean a lack of understanding. Careful thinking about uncertainty is required, and to delay a decision or prematurely dismiss the current science understandings may have substantial consequences. Through discussing science news stories, there will be frequent opportunities to discuss ideas around uncertainty and risk. In 'media rich' areas such as climate change, there are many rich examples that allow distinguishing between what is well supported (such as sea levels: these have already risen and are now rising more quickly) and what is scientifically uncertain (such as exactly how quickly sea levels will rise).

Using a biotechnology context, Jones and Buntting (Chapter "Using Biotechnology to Develop Values Discourse in School Science", this volume) explore the role of values and ethics in futures thinking in our society. They discuss the toolkits on the Science Learning Hub (www.sciencelearn.org.nz), including media links, as a way to encourage students to think beyond their immediate personal issues, and thoughtfully consider the risks and benefits, ethical rights and responsibilities, and future possibilities.

In adopting values-based approaches to science teaching in the twenty-first century, one needs to be sensitive to personal, social and cultural values of students and school communities, while at the same time highlighting the science role in delicate socio-scientific issues. For instance, in a school community known to have low childhood vaccination rates, some families are likely to disagree with, or at least downplay, relevant science. Scrutinising a "childhood vaccination" news story presents opportunities to discuss how science works. While teaching how vaccinations work and the evidence supporting (herd) vaccinations, it is important to know and be mindful of possible motivations behind parent opinion and opposition. For instance, opposition could relate to fears (e.g., fear of medical intervention, fear of adverse reactions), beliefs and world views (e.g., religious beliefs, belief in 'Big Pharma' conspiracies, alignment with a particular political party) and social influences (like many others in the community, a belief that they are showing that they are concerned parents by not vaccinating).

A major, if ambitious, goal of science education should be the promotion of a lifelong interest in science and enabling students to critically think about personal, local and global science-related issues. To have any actual impact on the lives of former science students, this must include times when science-related situations suddenly arise, such as the Zika virus crisis in 2016 and the World Health Organisation identification of women of childbearing age as the priority population to protect through vaccination.

A classroom climate where it is acceptable to share and debate ideas and change your mind is ideal (and can certainly be achieved), just as scientists put forward claims and counterclaims and may shift their views when new evidence or new theoretical models come to light. Scientists communicate with each other to build cumulative understandings. Shared deliberations (ideas, uncertainties, arguments, debates) on the relationship between data, evidence, explanation and theory highlight the social (rather than individual) activity of science (Duschl, 2008). The value of social dynamics in creating science knowledge can and should be explored and discussed, including through creating the same dynamics in the science classroom.

4. What next? Create, Share, Like, Follow, Delete, Comment, Review…

Schools in many countries already have policies around general aspects of the use of social media, including privacy, safety and social media footprints. These policies can also inform the use of creating, sharing, liking, following, commenting, reviewing and blogging science-related news stories. Importantly, teachers can work to have students think about when to delete and so play some role in stopping the spread of fake news.

Discussions can extend to how we consume news, and how we then communicate with friends, family and wider audiences. It is easy to 'share', 'like', or re-purpose content, thus expanding the reach of our views and enabling others to share them with their networks. In addition, the value for scientisits, science centres, museums and organisations to reach out and engage with the public could be a focus for exploration.

Science communicators have the wonderful opportunity to translate science for everyone in our society, and to pass on the wonders and worries of modern science. Science communication now involves much more than writing a traditional news story—it can include creating videos, games, podcasts, animations, blogs, etc. Communicating to a general audience, such as creating a popular science-related news story, requires different understandings, skill sets and approaches to those for writing a science research investigation report. Science education has a place in faciliatating learning about communicating science to a wider audience—via writing science news stories, creating videos, etc. Students could create a science-related news story from one of their own research investigation reports, and compare both approaches in terms of different context, style, structure and content. These matters will also depend on the type of story about their investigation that they decide to create.

Science education has always had the opportunity to promote science communication in our society. Today that opportunity is greater and more important, involving as it should, the navigating and critiquing of science news stories and so the enhancement of students' understanding of the values of science. There are many messages relevant to science education in this century that go hand-in-hand with scrutinising social media. Examples include knowing where to seek reputable online science sources and support, being sceptical (in the original sense) of assertions and opinions on traditional and social media, and being careful not to share unreliable sources of information. In addition, we argue that identifying possible heuristics and other contextual and social cues within a news story that may limit the nature and depth of our thinking is also central to informed decision making. Such approaches demonstrate that science communication is far more than writing formal (standard) practical reports in science classes. We believe approaches that include the analyses of media, as we suggest above, will support students to understand the relevance of science in their own lives and society, the science relevant to their decision making, and the values of science and their own values.

Massive amounts of misrepresented science are spread in an uncontrollable fashion on social media. Because of this, students encounter large quantities of science news stories that have been misrepresented in social media, including fake news, and will of course continue to do so long after they have left school. With this misinformation comes huge risk, to both individuals and society and, in our democratic society, science education has a responsibility to respond. While there is no easy solution to fake news, the way a media report is perceived by the public is critical to the way science is valued in our society. It is now more important than ever to discuss issues around fake news and scrutinise the way science is sourced, communicated, understood and shared through traditional media and social media. Science has significant benefits to our lives, including health, safety and quality of life, and at times may conflict with world views and beliefs of vested (and other) interests. This raises moral and ethical concerns, and is central to many economic and political issues. Our beliefs, values and attitudes will influence the way we understand media articles and commentary, and more specifically, so will our understandings of the value of science in our society.

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Changing Values in Science Education and the Emergence of Science Gallery

Joseph Roche and Colette Murphy

The Emergence of Science Gallery

The biggest development in the field of informal science education in Ireland in the last 15 years has been the establishment of Science Gallery. Science Gallery Dublin is a gallery space that opened on the grounds of Trinity College Dublin in 2008. It is often described as being similar to a small science centre or museum that has no permanent collection (instead it relies on exhibitions that run for several months at a time) and all the exhibits are designed specifically to engage and challenge teenagers and young adults in the 15–25 year-old age group. It has had more than 2.5 million visitors since it opened. It also spawned a sister organisation—Science Gallery International—to help establish other similar venues around the world. Brunswick (2017) describes the genesis of Science Gallery in detail by drawing on interviews with four of the key individuals who contributed to the initial work establishing the gallery in 2006 and 2007. Brunswick explains that a unique situation in Ireland at the time led to the perfect platform for Science Gallery to take its place among Ireland's cultural, scientific and arts scenes. The four most important factors that contributed to Science Gallery's genesis included:

1. A group of university scientists motivated to communicate with the public about contemporary science
2. An increase in government investment in science and in science communication
3. A university-wide policy in Trinity College Dublin making public engagement a component of all new building projects
4. A project leader with a well-defined concept, and the support and freedom to pursue an experimental and unproven model. (Brunswick, 2017, p. 160)

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D. Corrigan et al. (eds.), *Values in Science Education*,
https://doi.org/10.1007/978-3-030-42172-4_6

An environmental factor that contributed to the establishment of Science Gallery was the relatively low level of interest and trust in both science and scientists in Ireland at that time. The National Development Plan (Government of Ireland, 2007) had a special focus on science, technology and innovation. It also highlighted the need to encourage young people to consider careers in these areas. Science Gallery presented a means to informally engage with young people in a way that could embolden them to pursue any latent interests in science they might harbour. The founding director of Science Gallery, Michael John Gorman, described in *Nature* just before the gallery opened:

> Interesting science is often created where boundaries are crossed, in border territories where connections are suddenly perceived between problems in seemingly unrelated areas. Critically for science's future, the widespread image of science as a narrowly focused, socially isolated vocation for the initiated can put off the brightest young talent from entering for one day, let alone decades. (Gorman, 2008, p. 522)

Some of the key values that guided the development of Science Gallery in these crucial early years can be traced back to the emphasis on the target audience, the process of developing the exhibitions, and the visions of the staff—all of which are considered below.

Target Audience Values

The biggest impact on the development of Science Gallery can arguably be attributed to its focus on a distinctive target audience. One specific age group—15–25 year olds—has been targeted since its inception. The reason this age-group was targeted is because it is commonly considered to be the most difficult audience to engage. It represents a group of people at key stages of their life regarding school subject choices, college courses and decisions relating to future careers. Science centres and museums are usually attractive to children (or specifically parents with children) and school tours. Art galleries on the other hand can be more attractive to independent adults. Between those two age groups are the teenagers and young adults who are free to make their own decisions on whether they visit cultural institutions but who are unlikely to take that step unless they feel like they belong in those spaces.

Until the establishment of Science Gallery in 2008 there was no purpose-built science centre in Dublin. Rather than developing a more traditional science museum, a decision was made to try and do something different. Given the modest space available (compared to international standards for science museums) a gallery was considered more attractive than a museum. By targeting the most difficult audience it meant that the initiative would be markedly different from other cultural organisations by providing a space for 15–25 year olds to pursue creative ideas that interrogate and explore the boundaries of art and science. Science Gallery embodies the opportunity that art and science are two different ways of exploring and understanding the world around us. While science and art are obviously different in many ways they are both powerful processes that rely on creativity, interpretation, understanding and communication. By examining the similarities in practices that are common to both fields, Science Gallery draws on an underused but powerful method of exploring ways to broaden youth participation in informal learning.

Exhibition Values

Science Gallery has also been defined by the exhibitions it runs. The exhibits themselves are designed for the 15–25 year-old audience and the exhibitions are designed using several key innovations. An open call process that is shared with international networks of artists, scientists and designers means that anyone from across the world can contribute an idea, a suggestion or a full exhibit. The exhibition themes are not just guided by the curatorial staff of the Science Gallery but also by a special invitation-only think-tank of leading experts called the "Leonardos". This group of individuals have diverse backgrounds in science, technology, the arts, media, education and business. Although Science Gallery receives a small amount of support from Trinity College Dublin and the Irish Government through its Department of Arts, Heritage and Gaeltacht, most of its funding is raised or generated through its own means. The lead partner is the Wellcome Trust and other organisations that contribute funding are: Deloitte, ESB, Google, ICON, NTR Foundation, and Pfizer. A complete list of all 41 exhibitions since 2008 can be found in Table 1.

Values of Staff

Another factor that governs the running of Science Gallery is the staff and the values they hold. These values are perhaps the most difficult of all to capture and understand. The key figures in the initial development and the establishment of Science Gallery were Michael John Gorman and Lynn Scarff. Together they shaped Science Gallery to ensure that it was not just an exciting and innovative project but also something that would be open, accessible and free for anyone to participate in. When Michael John Gorman moved to take up the role of CEO of Science Gallery International (a role later held by Andrea Bandelli) Lynn Scarff became director of Science Gallery Dublin and Ian Brunswick took on the role of Head of Programming. These individuals, and the values they stand for, have had the biggest impact on the development of Science Gallery and all of its activities. More than anything else, Science Gallery has been shaped by their attitudes towards science, art, culture and education as well as their relentless commitment to "stay edgy".

Table 1 All the exhibitions that have taken place in Science Gallery from its launch in 2008 until the end of 2017

Exhibition name	Tag line	Dates
LIGHTWAVE	READY TO BE ILLUMINATED?	02.02.08–01.03.08
PILLS	WHICH ONES HAVE YOU TAKEN?	15.03.08–12.04.08
TECHNOTHREADS	WHAT FASHION DID NEXT	26.04.08–25.07.08
ARTBOTS	THE ROBOT TALENT SHOW	19.09.08–21.09.09
PAY ATTENTION	LAB IN THE GALLERY	04.10.08–31.10.08
LIGHTWAVE II	DEFY THE DARKNESS	23.01.09–20.02.09
METROPOLIS	CROWD CONTROL	24.03.09–29.03.09
INFECTIOUS	STAY AWAY	17.04.09–17.07.09
BUBBLE	DON'T BURST IT	31.07.09–25.09.09
WHAT IF...	FUTURE FORM, FUTURE FUNCTION	08.10.09–11.12.09
LOVE LAB	THE SCIENCE OF DESIRE	11.02.10–12.03.10
HYPERBOLIC CROCHET CORAL REEF	A WOOLLY WONDER	19.03.10–11.06.10
BIORHYTHM	MUSIC AND THE BODY	02.07.10–01.10.10
GREEN MACHINES	KICK-START THE REVOLUTION	10.10.10–22.12.10
VISCERAL	THE LIVING ART EXPERIMENT	28.01.11–25.02.11
MEMORY	HAVE I SEEN YOU BEFORE?	11.03.11–08.04.11
HUMAN +	THE FUTURE OF OUR SPECIES	15.04.11–24.06.11
ELEMENTS	THE BEAUTY OF CHEMISTRY	15.07.11–23.09.11
SURFACE TENSION	THE FUTURE OF WATER	21.10.11–20.01.12
EDIBLE	THE TASTE OF THINGS TO COME	10.02.12–05.04.12
HAPPY?	TAKE A SECOND LOOK	27.04.12–03.06.12
HACK THE CITY	TAKE CONTROL	22.06.12–08.09.12
MAGICAL MATERIALS	UNLEASH YOUR SUPERPOWER	15.09.12–14.10.12
GAME	THE FUTURE OF PLAY	15.11.12–20.01.13
OSCILLATOR	EVERYTHING IN MOTION	08.02.13–14.04.13
RISK LAB	ARE YOU FEELING LUCKY?	02.05.13–06.06.13
ILLUSION	NOTHING AS IT SEEMS	11.07.13–29.09.13
GROW YOUR OWN	LIFE AFTER NATURE	25.10.13–19.01.14
FAIL BETTER	A FREE EXHIBITION OF BEAUTIFUL, HEROIC AND INSTRUCTIVE FAILURES	02.02.14–27.04.14
FAT LAB	IT'S DELICIOUS	16.05.14–29.06.14
STRANGE WEATHER	FORECASTS FROM THE FUTURE	18.07.14–05.10.14
BLOOD	NOT FOR THE FAINT-HEARTED	24.10.14–23.01.15
LIFELOGGING	DO YOU COUNT?	13.02.15–17.04.15
HOME\SICK	POST DOMESTIC BLISS	01.05.15–19.07.15
SECRET	NOTHING TO SEE HERE	07.08.15–01.11.15
TRAUMA	BUILT TO BREAK	20.11.15–21.02.16
FIELD TEST	RADICAL ADVENTURES IN FUTURE FARMING	11.03.16–06.06.16

(continued)

Table 1 (continued)

Exhibition name	Tag line	Dates
SEEING	WHAT ARE YOU LOOKING AT?	24.06.16–25.09.16
DESIGN AND VIOLENCE	–	14.10.16–22.01.17
HUMANS NEED NOT APPLY	–	10.02.17–21.05.17
SOUND CHECK	MAKE IT. PLAY IT.	10.06.17–24.09.17
IN CASE OF EMERGENCY	–	12.10.17–11.02.18

The Role of Science Gallery in Informal Science Education

Science Gallery has committed to researching and evaluating informal science education for the foreseeable future through a "Science Learning+" collaboration. Science Learning+ is an international initiative that aims to understand the power of informal learning experiences inside and outside of school and is a partnership between the National Science Foundation, the Economic and Social Research Council and the Wellcome Trust. The first phase of this project was undertaken as a collaboration between Science Gallery Dublin, the Exploratorium in San Francisco and the University of Washington in Seattle and gathered together 24 educators and researchers from 5 countries to assess "full and meaningful participation in STEM learning" (Bevan et al., 2017, p. 7).

The next phase of the Science Learning+ project will address a clear changing value in the field of informal science education: the increased focus on equity and access for youth communities that are historically underrepresented in STEM fields. This aligns with the European-wide shift among educators and researchers at science museums and science centres to tackle issues of equity—a critical theme of recent international science engagement conferences such as the Ecsite Annual Conference (Roche, Davis, Stanley, & Hurley, 2018). This focus comes from the growing body of work that suggests "identity" is central to young people's informal science education. It is more than 20 years since Eisenhart, Finkel, and Marion (1996) called for "socially responsible science and the broader involvement of more and diverse people in science" (p. 290). Since then Lemke (2001) has argued for sociocultural perspectives in science education while Nasir (2002) also stressed the role of identity in learning. In 2009, the National Research Council's Committee on Learning Science in Informal Environments again highlighted the need for understanding youth identity in order to better predict career pathways in STEM (National Research Council, 2009). Carlone, Scott, and Lowder (2014) showed the importance of longitudinal studies when it comes to comprehending how identity changes in science education, especially among adolescent groups. Phase II of the Science Learning+ project began in 2017 and sees Science Gallery Dublin working with its partners to develop a number of different lines of inquiry including:

1. Developing an evidence base for how productive art + science programs expand young people's STEM engagement by conducting cross-setting and longitudinal studies of youth learning trajectories
2. Expanding accounts of how equity-oriented program design and facilitation broadens participation in STEM learning within the program and beyond through case study development of a range of different strategies referencing a common framework to allow cross-case comparisons
3. Supporting the informal science education field engagement with evidence related to broadening participation, the potential of art and science integration, and the need for more culturally responsive approaches (Bevan et al., 2017, p. 12).

The prominence of Science Gallery Dublin, and subsequently Science Gallery International, at the vanguard of using an *Art + Science* approach to broaden youth participation in STEM learning has provided a fresh opportunity for global conversations about informal science education. An example of this is the presence of Science Gallery at the World Economic Forum in Davos, Switzerland in 2017. Since 1971 this forum has been one of the most important meetings of political, business and other leaders of society to shape global, regional and industry agendas. That Science Gallery was invited to engage world leaders on how to empower young people shows the vast potential it now possesses to steer the conversation on twenty-first century science education. It demonstrates how world leaders are belatedly recognising the fact that "we cannot take access to equitable out-of-school science learning for granted" (Dawson, 2017, p. 539).

A Challenge to Future Values

Building on the success of Science Gallery Dublin, its sister organisation Science Gallery International emerged in 2012 thanks to the foundational support of €1 m provided by Google's philanthropic arm, Google.org. Science Gallery International was created so that it could help establish Science Galleries around the world. While Dublin is the first of these "nodes", Science Gallery London opened at the foot of The Shard building beside London Bridge station in 2018. Further nodes are planned to open in Melbourne, Venice, Bengaluru and Detroit in the years thereafter. This rapid expansion could have the biggest impact on the universal values guiding Science Gallery. While Science Gallery Dublin will surely retain the values inherent to its development, it is likely that Science Gallery Bengaluru, for example, will adopt slightly different values in line with the different cultural settings and staff directing it. Indeed, this could be seen as a challenge for the Science Gallery Network: to somehow keep its shared identity amid a series of nodes with their own values. However, the opportunity this represents for learning and comparing how different communities engage with art and science around the world make the larger Science Gallery project an opportunity that is as interesting as it is daring. The network could be particularly useful for measuring the "science capital" of young people around the world. Science capital is a concept and framework for tracking factors that influence young people's relationship with science (Archer, Dawson, DeWitt, Seakins, & Wong, 2015). By using the Science Gallery network to evaluate and understand the social justice within science education it can make informal learning organisations like museums and science centres more inclusive for disadvantaged youth groups (Dawson, 2014).

Changing Values in Science Education as a Context for Science Gallery

Many of the values dominating science education currently link school science with careers. There is a strong focus on gender, with the aim of attracting more females into scientific careers. Also, engagement of students with science has become important, as opposed to an earlier emphasis on instruction in scientific principles and procedures. Hence the *nature of science* is a more prominent feature in many school science curricula. For example, in Ireland, nature of science is represented in the Junior Cycle curriculum as the unifying strand, through which to develop the four contextual strands: physical world, chemical world, biological world, and earth and space (NCCA, 2015). Scientific skills now emphasise critical thinking, collaboration and communication, to address requirements for the so-called twenty-first century skills.

In addition, the very notion of 'science' has been broadened to incorporate the other STEM/STEAM subjects of technology, engineering, arts and mathematics. Collaboration in science education research and practice has also been broadened to include industry, along with academics and government agencies. More than five centuries ago, the work of Leonardo da Vinci (1492–1519) combined art and science. More recently, Albert Einstein, an outspoken opponent of the formal organisation of science and a defender of the solitary scholar discussed science in relation to atomic war or peace:

> I do not believe that a great era of atomic science is to be assured by organising science, in the way large corporations are organised… Only a free individual can make a discovery… Can you imagine an organisation of scientists making the discoveries of Charles Darwin? (Einstein, 1945)

STEAM collaborations are even more relevant now in the light of C. P. Snow's (1959) lecture *The Two Cultures* in which he opined the fracture of intellectual life between sciences and the humanities. The arts and humanities disciplines can be energised by scientific understanding and the process of exploration and discovery; science can be improved via engagement with ethical and aesthetic insights, as well as issues of uncertainty (uncertainty in this instance is in contrast to uncertainty as a value of Science as discussed by Rennie, Chapter "Communicating Certainty and Uncertainty in Science in Out-of-School Contexts", this volume) in the impact of science on society and vice versa. Collaborative efforts between literary scholars and computational linguists have recently traced the early onset of dementia in authors Iris Murdoch, P.D. James and Agatha Christie by examining the evolution of language and syntax in their respective canons of work (Lancashire, 2015). STEAM approaches are crucial to facilitating short and long-term insights into social and environmental interactions—their possible impacts, benefits and consequences.

Alongside Science Gallery Dublin, a new interdisciplinary research group, STEM Education Research and Communication (STEM-ERC) was developed at Trinity College Dublin in 2014. It emerged out of the growing need to considerably enhance the links between science departments and education. It is anticipated that the resulting synergy of educationalists, social scientists, Science Gallery Dublin and STEM education colleagues working together will have significant transformative potential in teaching and research within and beyond the University. Members of the STEM-ERC group are committed to providing equitable access to STEM careers and literacy through innovative and socially responsive research, teaching, and teacher preparation informed by the learning sciences. Research in the group focuses on learning, communicating and teaching the STEM subjects in both formal and informal contexts. It spans STEM education and research in higher education, secondary, primary and early childhood, as well as informal STEM learning in all age groups.

This chapter will now focus on two areas of changing values in the context of Science Gallery International: the relationship between twenty-first century pedagogy, Generation Z and STEAM careers; and bridging informal and formal science learning.

Twenty-First Century Science Pedagogy, Generation Z and Preparation for STEAM Careers

In addition to critical thinking, collaboration and communication skills, Gerstein (2015) describes and illustrates *other* twenty-first century skills and how these may be facilitated in the learning environment (see Fig. 1). Such facilitation requires a change in teaching and learning, frequently referred to as twenty-first century pedagogy.

The term pedagogy originates from the Greek *paidagogos*, referring to the slave who brought children to school. Nowadays the emphasis on children (*paidia*) has become more generalised, and pedagogy is used for post-compulsory education as well as in the education of children. In this chapter pedagogy is used as a term which embraces both learning and teaching, and as a way of knowing, as well as doing.

So, what is twenty-first century science pedagogy? Essentially the term describes a shift from twentieth century (modern) ways of learning and teaching to twenty-first century (postmodern) approaches (Murphy, 2016). The shift is required for

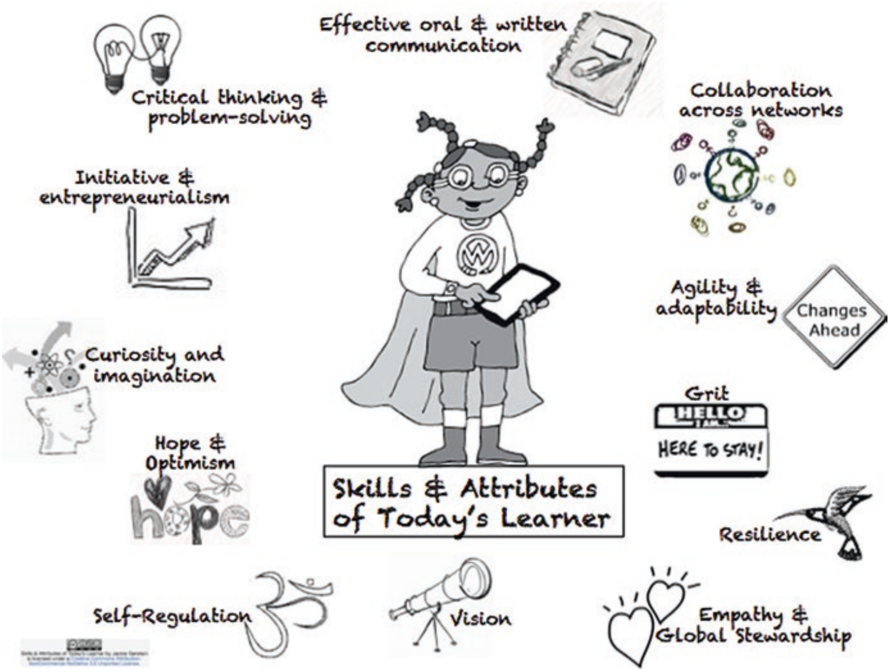

Fig. 1 The Other Twenty-first Century Skills. (Gerstein, 2015)

schools and universities to keep pace with the changes in social theory, political thought, and education in the twenty-first century. *Modernism* describes society from the mid-eighteenth to most of the twentieth century, which saw the development of capitalism, industrialisation, nation states, and science, as well as a major expansion of European interests into the rest of the world. It was seen as a time of great 'progress'. The big ideas were that people are rational, autonomous individuals who think and act independently of other individuals, and reason and knowledge (particularly scientific) was the route to human freedom and happiness. The big problem with these ideas is that they exclude people and groups who are marginalised from them, for example, women, indigenous peoples and working-class people.

Postmodernism describes the current period in history and a set of ideas that 'go with' this period. It critiques the ideas of modernism. It is known as The Knowledge Age, an advanced form of capitalism in which knowledge and ideas are the main source of economic growth. New patterns of work and new business practices have developed, and, as a result, new kinds of workers, with new and different skills, are required. Knowledge is defined for what we can *do* with information, not for what information *is*, and is produced by 'collectivising intelligence', that is, groups of people with complementary expertise who collaborate for specific purposes.

These changes have major implications for science learning and teaching. In order to prepare young people for successful lives in the twenty-first century, schools need to take account of the new meaning of knowledge *and* the new contexts and purposes for learning this knowledge. They need to prepare students to be able to work productively in collaborations with others. Students need to be adaptable, creative and innovative, and to be able to understand things at a 'systems' or 'big picture' level. They need to be able to think and learn for themselves, in order to help create new knowledge.

The early twenty-first century is seeing the end of traditional structures and institutions, and the big, one-size-fits-all stories of modern thought (Lyotard, 1984). There is no longer the idea of 'progress', that we are gradually heading along the one true pathway towards certain universal goals. Instead, there is an emphasis on multiple pathways and plurality, on diversity and difference, and on the partiality of knowledge. Change is no longer seen as a linear progression, but as a "series of networks and flows, connections and reconnections that, because they are always forming and reforming, never have time to solidify" (NZCER, n.d.). Where *modern* thought emphasises direction, order, coherence, stability, simplicity, control, autonomy, and universality, *postmodern* thought emphasises fragmentation, diversity, discontinuity, contingency, pragmatism, multiplicity, and connections. This has major implications for social theory, political thought, and education in the twenty-first century. Education can be said to have moved from its key twentieth century role in providing basic skills and then to screen and sort students for participation in an industrial, largely localised economy, towards the twenty-first century emphasis on competencies, such as self-regulation, innovation and critical thinking.

The current school student body is made up largely of what is termed 'Generation Z' students. Generational characteristics in terms of digital technology can be summarised in Table 2. In the USA, there are 23 million Generation Z who, in five years' time, will become the fastest-growing generation in both the workplace and the marketplace (Centre for Generational Economics, 2016).

So what does research tell us about Generation Z students and STEM careers? The single biggest difference between Generation Z and other generations is how connected they are, and have been since birth. On average, young people in the UK, aged between five and 16, spend three hours online every day (Barr, 2016). Connectivity permeates their lives—relationships, news, entertainment, shopping—and has transformed how they interact. The implications of such connectivity are speculative, although there does seem to be evidence of increased mental health issues among Generation Z students.

In terms of science education, it appears that Generation Z students, in many ways, appear more responsible than their predecessors: they are generally more politically engaged and eager to reframe perspectives on sexual orientation and gender, while demanding action on the issues of mental health, education, equality and racism. It could be argued that they have a keener interest in socio-scientific areas than previous generations. Barrett (2017) suggests that the current generation of university students rank meaningful work and a healthy work life balance ahead of other considerations such as salary and benefits when it comes to choosing careers. A key finding from the Think Future study (KPMG, 2016) which surveyed 4750

Table 2 Characteristics of generations in relation to digital technology

Name	Years (approx)	Characteristics
Silent generations	1925–1945	
Baby boomers	1946–1960	Digital immigrants
Generation X	1961–1980	Digital immigrants
Generation Y	1981–1999	Millennials/digital natives
Generation Z	2000–2020	Tech savvy FANG [Facebook, Amazon, Netflix, Google] generation

Irish university students between the ages 18–25, showed that 92% of respondents want a career that 'makes a difference'.

In Irish schools, data for Leaving Certificate results (examinations taken at the end of schooling, ages 17–19) show that girls outperform boys in 26 of the 32 subjects. In science subjects, biology has a take-up female bias of 3:2, physics has a male bias of 3:1 and chemistry is approximately 1:1. Another large study (Mullaghy, personal communication, not yet published) surveyed approximately 1500 15–17 year-old students from schools all over Ireland. Her data showed that they considered enthusiastic teachers, workshops, projects and doing experiments the best methods for learning science. In terms of careers there were gender differences. Higher frequencies of boys chose engineering, science and business, whereas more girls selected nursing and teaching. An indicative comment about careers from a female student shows some of the tensions surrounding STEM career choices:

> There are some great careers in STEM but I am sick and tired of being pushed into STEM careers as a girl. If I want to do them I will. I think that pushing girls into STEM is actually turning them away. Furthermore, STEM careers are not as well paid as we're told. If you look at most wealthy people around your parents' generation they did medicine, business and law. The Head of Facebook in Ireland did Business!

Focus on Bridging Informal and Formal Science Learning

To accommodate the pedagogical changes required to develop twenty-first century skills, such as those illustrated in Fig. 1, researchers and educators are moving towards bridging formal and informal science learning (e.g., Hung, Shu-Shing, & Lim, 2012; Leonard, Fitzgerald, Kohlhagen, & Johnson, 2017). Some of the key extreme characteristics of informal and formal learning are summarised in Table 3.

However, it can be argued that there is no gap between formal and informal science learning if students are provided with a range of tools that expand the learning environment. Conceptually, Vygotsky (1978) developed the zone of proximal development (ZPD) which describes the interactions (social and material) that need to take place for the learner to move from one level to the next. The idea of the ZPD is frequently reduced to learner assistance from a teacher or more knowledgeable peer.

Table 3 Characteristics of formal and informal learning

Formal	Informal
School curriculum focus	Less structured activities
Extrinsic motivation	Exploration, experimentation, intrinsic motivation
Strict assessments measuring specific learning outcomes	Learning outcomes not explicitly foregrounded & less formal assessment
Decontextualised, more explicit knowledge	Contextualised & more tacit knowledge
Non-authentic	Authentic
Less verbalisation	More verbalisation

Brown et al. (1993) expanded the ZPD to include "people, adults and children, with varying levels of expertise, but it can also include artefacts, such as books, videos, wall displays, scientific equipment and a computer environment needed to support intentional learning" (p. 191). We would expand the ZPD further to offer more learning opportunities in terms of promoting dialogue with scientists and experiencing science as it happens, and a focus on the affective aspects of science and scientists, in environments such as Science Gallery. Vygotsky's theory foregrounded the interaction of the use of 'tools' and 'symbols' in the roles played by participants in the learning process. This foregrounds the idea of "divergent classrooms" as learning communities in which each participant makes a significant contribution to an emergent understanding between them, despite having unequal knowledge (Palincsar, Brown, & Campione, 1993, p. 43).

In a large study of different forms of informal science learning (informal science experiences at home, e.g., science kits, TV and other media; visits to science centres, etc. away from home; outdoor nature experiences, e.g., forest parks and lakes; and semi-formal science experiences, e.g., summer camps, after-school science clubs), Lin and Schunn (2016) concluded that there are unique benefits from students' informal science learning experiences across the different forms. They suggested that each form offers particular affordances and that the challenge is to create equitable opportunities for students to experience the broadest possible access to informal as well as formal science learning. This variety of learning experiences might also feed well into the recent development of STEM to STEAM.

Conclusion: Science Gallery's Changing Values

Brunswick (2017) questions whether the success of Science Gallery is a manifestation of societal change, due to its being "in the right place at the right time", or whether it is an "originator" of changes in the way society perceives science, museums and public engagement. It is most probably a bit of both. Michael John Gorman suggested that the public engages strongly with *contemporary* research. In addition, Science Gallery holds the capacity to offer emerging scientists a transformative experience. He remarks on the evolution of the goal, from "we need more scientists; we need more engineers" (in the early rhetoric of framing Science Gallery) into "we need a new kind of scientist; a new kind of engineer" (Brunswick, 2017, p. 174).

Science Gallery's evolution indicates changing goals, from engaging young people with science, towards trying to foster connections between experts and non-experts, and facilitating dialogues across disciplines and traditional power hierarchies. Thus, Science Gallery has evolved to encompass the wide mission: "to ignite creativity and discovery where science and art collide" (Brunswick, 2017, p. 174), bringing the focus on to individual agency, cultural relevance, and social impact. The internationalisation of Science Gallery will go some way towards demonstrating whether there is a gradual pedagogy shift in informal science education to encompass increasing interdisciplinarity, to include cultural studies and public health as well as communicating science.

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Using Biotechnology to Develop Values Discourse in School Science

Cathy Buntting and Alister Jones

Introduction

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

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

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D. Corrigan et al. (eds.), *Values in Science Education*,
https://doi.org/10.1007/978-3-030-42172-4_7

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

Background

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

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

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

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

An Online Portal as a Window into Biotechnological Practice

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

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

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

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

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

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

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

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

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

An Ethics Thinking Toolkit

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

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

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

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

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

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

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

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

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

A Futures Thinking Toolkit

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

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

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

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

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

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

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

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

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

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

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

Concluding Comments

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

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

Acknowledgements We thank Dr. Kathy Saunders for generously sharing unpublished data from her PhD research with us. The Biotechnology Learning Hub, Science Learning Hub, ethics thinking toolkit and futures thinking toolkit were all developed by expert teams of educators and education researchers with funding from New Zealand's Ministry of Business, Innovation and Employment and its predecessors.

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Part III
Values of Science Education Practice

Angela Fitzgerald

The teaching of science and the values that inform this practice is the theme unifying this collection of chapters by Shirley Simon and John Connolly (Chapter "What Do Science Teachers Value? How Can Values Change During Professional Learning?"), Tetsuo Isozaki (Chapter "Exploring the Professional Learning Values Inherent in Japan's Lesson Study"), and Justin Dillon and Alan Reid (Chapter "Changing Context, Shifting Values? Science, The Environment and Citizenship at Minstead Study Centre 12 Years On"). It is teachers who make decisions about which values are and are not represented in their embodiments of science education. These decisions are unavoidably guided by their own attitudes, values and belief systems. This is not the end of the story, however, as along with this influence comes responsibility—a responsibility to their learners to question and critically reflect on the nature of these values and how as teachers they will support their students in becoming scientifically informed and literate citizens. In achieving this, professional learning plays a pivotal role in shaping and refining the values that teachers enact through their science education practices. Professional learning opportunities support teachers to take ownership of what they value and find ways to change what they do in the classroom to be more congruent with these values or to maintain what is valued in the face of contextual change. Importantly, there is no one correct set of values to hold in regards to science education practices and a diversity of views will always be represented. What matters, however, is that teachers reflect on what they value, understand why this is the case, and carefully consider the implications for their practice.

Professional learning and its impact on science teachers' values over their careers, from initial teacher education through to the classroom and classroom-based research opportunities, is the lens that Shirley Simon and John Connolly bring to their chapter. They highlight from the outset the importance of value congruence if professional learning is to bring about change, which is to suggest that if the teacher doesn't value the learning focus then they are unlikely to embed it in their practice and vice versa. Drawing on three examples spanning the teaching career spectrum, they explore the impact of reflection and research in shifting professional values and altering personal beliefs. The understandings emerging from this chapter tease out the conditions required if the values that teachers hold about science education practices are to be challenged and extended in the name of professional growth and development. But it also highlights the fine line that is navigated between values being contested and value congruence. Too far either way—values being under or over challenged—and practice may start to stagnate and lose relevance. The opportunity then lies in conceptualising professional learning in ways that will reflect the values of both those providing and participating in the experience to best enhance science education practices.

The historically embedded and professionally ingrained practice of Lesson Study is brought to the fore in Tetsuo Isozaki's chapter as a way of examining the values underpinning what matters in science education in the Japanese context. He takes the reader on a journey through the characteristics of science lessons in Japan before unpacking the components contributing to and features of Lesson Study as a highly structured and regular form of classroom-based professional learning. This exploration highlights that the Japanese traditions and practices informing Lesson Study are a powerful means for teachers to question and reflect on what they value in their approaches to science learning and teaching and, perhaps most importantly, why. The insights provided by this chapter are not intended to tell the reader what should or should not be valued as part of science education practices. Instead they have been shared to illustrate a possible approach that can be engaged with by teachers to better understand the values that drive what happens in their science lessons. By doing so, a more nuanced understanding of the values of science education practices can emerge, one that takes greater account of the educational, social and cultural context in which the science learning and teaching is positioned.

Justin Dillion and Alan Reid's chapter takes us back to the Minstead Study Centre in southern England, a residential environmental organisation that readers were introduced to in the first book (Dillion & Reid, 2007). Twelve years on, Chris and Jane, the two educators, are still at the Centre and were willing to explore the extent to which their values and those they promote to their visitors had changed in that time. Emerging from the interview discussion was the stark reality that the socio and political worlds around Minstead have changed substantially. Anecdotally, this seems to have directly resulted in children who are less resilient and independent as well as an increasingly demanding regulatory environment. Despite these challenges, the values that Chris and Jane strongly connect with for themselves and their work haven't shifted, which may account for the survival and success of Minstead. The longitudinal perspective provided by this chapter highlights the tensions inherent in the decision making that informs science education practices. A key question to consider is: do you shift values to respond to changing contexts or do you maintain them with convictions of a greater good? The answer isn't necessarily easy or straightforward, but is important to reflect on in light of the long-term impacts on both science learning and teaching.

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What Do Science Teachers Value? How Can Values Change During Professional Learning?

Shirley Simon and John Connolly

Introduction

In this chapter we focus on what teachers perceive has value in the teaching of science, and how values might change during the process of professional learning. In discussing values a distinction can be made between beliefs and values, though these are often used interchangeably. Beliefs are assumptions that people believe are true about the world based on their knowledge (Pajares, 1992); values stem from these beliefs and are what people consider important. Thus a belief that science education involves learning established knowledge through transmission would lead a teacher to value transmission methods of teaching. Much has been written about beliefs and values in science education (e.g., Poole, 1995) and the distinction is a fine one. In this chapter we focus on what is valued as important by science teachers and student teachers, as a result of their belief systems. Poole (1995) suggests that values typically involve thinking, feeling and what he terms 'willing' (volition).

Twenty years ago Harland and Kinder (1997) wrote an account that highlighted *value congruence* as an important feature of professional development programmes, this being defined as the "personalised versions of curriculum and classroom management which inform a practitioner's teaching" (p. 73). For instance, though science teachers might learn about investigative group learning they may not value it in favour of their whole-class teaching. In other words, they do not believe it to be sufficiently important to affect their teaching approach and it is unlikely to be implemented. In analysing the potential outcomes of professional development, Harland and Kinder suggested that a focus on *value congruence* needs to be a key part of teachers' professional development.

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D. Corrigan et al. (eds.), *Values in Science Education*,
https://doi.org/10.1007/978-3-030-42172-4_8

The focus on personal beliefs and values that stem from those beliefs is embedded in a number of models of teacher learning, development or growth that continue to be cited and used in ongoing research and development programmes (Bell & Gilbert, 1996; Clarke & Hollingsworth, 2002; Fraser, Kennedy, Reid, & Mckinney, 2007). We argue that the role of values in teacher learning continues to have importance, from the learning journey that begins with initial teacher education and is carried on through in-service professional development; wherever innovation and change is sought, *value congruence* continues to be relevant. In drawing on examples from our own work, we include an account of how values are addressed and considered in a pre-service programme for beginning science teachers, and point to the challenges that can be experienced as personal values may be in tension with school ethos and culture.

Once qualified, teachers can experience professional learning opportunities in a variety of ways, and we draw on examples to show how different kinds of experience can influence values. First, the opportunities for critical reflection on practice and personal values can be gained through study for a higher degree through engagement with the research literature and theoretical perspectives; such an experience can radically alter personal beliefs and professional values. At our University, the pre-service programme begins this process as student teacher assignments involve engagement with such literature and are assessed at Masters level. This system allows them to build up Masters level (M-level) credits that can then be supplemented to complete a full Master's degree once they have qualified as teachers. For example, a Post-Graduate Certificate of Education (PGCE) typically includes 60 M-level credits. To complete the 120 credits needed for a full Master's degree, teachers would need to register and complete the course of M-level study at University. One of us (John) has engaged in such a course of study and experienced changes in his knowledge, beliefs and values, and we include his account of learning that shifted his values as a practicing teacher. Second, engaging in research and development as part of a research project in partnership with researchers can provided stimulating new ideas and analysis of practice that can broaden what teachers value in their teaching; we draw on a research project that provides an example.

Before proceeding with our focus on values, it is important to clarify some distinctions concerning the terms used for professional learning that are found in different countries and contexts. Bell and Gilbert (1996), drawing on a study undertaken in New Zealand, derived a model of what they termed 'Teacher Development', which is in essence about teacher learning. Their study was concerned with how teachers changed as they implemented new teaching approaches, which had implications for teachers' roles and activities in science classrooms. The model outlines teacher development as taking place in three inter-related domains—the personal, professional and social—and identifies how progress occurs in each of these three domains. Such a progression would be indicative of an individual's learning, and what makes this model so relevant and enduring is that it arose from a study where teachers *reconstructed* their understanding of what it means to be a science teacher in fundamental ways. Bell and Gilbert use the term teacher development interchangeably with teacher learning, yet a distinction between the terms 'development' and 'learning' has since been problematised, for example, by Hoban (2002), who rejects the term 'development' as conveying a mechanistic, linear view of learning characterised by one-off workshops that tend to reinforce existing practice.

The durability of the Bell and Gilbert model is evidenced by its continued use in more recent attempts to theorise the nature of teacher learning and how professional practice can be changed in sustainable ways (e.g., Fraser et al., 2007). In drawing on the model, Fraser and her colleagues make a distinction that we find useful between what is meant by 'teacher learning' and 'professional development':

> teachers' professional learning can be taken to represent the processes that, whether intuitive or deliberate, individual or social, result in specific changes in professional knowledge, skills, attitudes, beliefs or actions of teachers. Teachers' professional development, on the other hand, is taken to refer to the broader changes that may take place over a longer period of time resulting in qualitative shifts in aspects of teachers' professionalism. (pp. 156–7).

Similarly, Loucks-Horsley, Love, Stiles, Mundry and Hewson (2003) refer to professional development in addressing broader issues of designing programs, and to specific strategies for professional learning of teachers. Clarke and Hollingsworth (2002) also draw on both individual and professional aspects of learning in their account of 'professional growth'. Viewed from a cognitive perspective, teacher growth involves construction of knowledge in the personal domain of the individual teacher, and from a situated perspective teacher growth is constituted through the evolving practices of the teacher (the professional domain). In taking a situative perspective, Borko (2004) emphasises the need to consider both individual teacher-learners and the social systems in which they are participants. The recognition of both cognitive and situated perspectives is important for understanding teachers' professional learning, which can be conceptualised as a complex combination of the individual teacher's knowledge growth, the professional teacher practicing in a particular setting, and the social teacher working collaboratively with others in that setting. In summary, we are concerned with teachers' professional learning and values, that is, the knowledge and understanding they gain and put into practice that demonstrates what they to be consider important based on that knowledge. Professional development programmes can be designed to advance that learning, so where these are referred to as 'professional development' in the literature, we use that term. For example, all UK teachers know the meaning of 'CPD', a shortened term for 'Continued Professional Development' that is constantly used to refer to opportunities that are available to advance professional learning.

How Do We Understand Science Teachers' Values?

Much of the literature on teachers' professional learning, and also on innovation and change in education, makes reference to the ways in which teachers can be seen to value certain aspects of school practice and become aware of different sets of values as they undergo professional learning. Studies that have sought to bring about changes in teachers' beliefs and values highlight the different ways in which teachers report what is important to them. For example, in a study on teacher learning (Bakkenes, Vermunt, & Wubbels, 2010) one teacher reported "I don't often do that in my class: gearing my teaching to students' everyday lives" (p. 9). In enhancing science teachers' professional knowledge, Berry, Loughran, Smith, and Lindsay (2009) note which aspects teachers' value regarding learning outcomes, for example, "being open and sensitive to noticing aspects of one's environment" (p. 590). Changing values that are reflected in aspects of changing practice can arise from an awareness of existing behaviours and their impact on students. As Clough, Berg, and Olson (2009) observe, teachers can and often unknowingly

> convey the message that they do not value students' ideas in a number of ways—by the kinds of questions they ask, the little time they provide students to think and formulate answers, their unintentional negative body language, ignoring unwanted student responses, and only acknowledging or using desired answers. (p. 827)

Raising teachers' awareness of how their values are reflected in practice and in student outcomes can usefully be part of teachers' professional learning programmes to promote *value congruence*.

As mentioned earlier, many researchers have built models of professional development or growth that encompass a personal aspect of teacher learning, alongside the professional and social (Bell & Gilbert, 1996; Clarke & Hollingsworth, 2002; Fraser et al., 2007). The personal dimension includes beliefs, attitudes and values and is seen to influence how different practices and teaching outcomes are valued. Clarke and Hollingsworth's (2002) interconnected model of professional growth in particular highlights the consequences of teachers' beliefs and practice when teachers change what they view as salient outcomes. Clarke and Hollingsworth's examples show how teachers come to see different outcomes as important in the light of practice, which in turn impacts on their personal values. The interconnectedness of this model is particularly powerful as it demonstrates the mediation between personal beliefs, salient outcomes (i.e., valued outcomes) and practice; each of these change 'domains' influences the other two domains through the processes of enactment and reflection. 'Reflection', for Clarke and Hollingsworth, is modelled on Dewey's definition of reflection as "active, persistent and careful consideration" (p. 954). Our own perspective of critical reflection is that it involves looking back over time to interrogate accepted routines (Ghaye & Ghaye, 1998), and looking beyond the specifics of the individual classroom and the particular institution to the wider socio-political context (Brookfield, 1995; Dinkelman, 2000; Hatton & Smith, 1995). Critical reflection can be nurtured through interaction with the ideas of peers and through engagement with literature and research in the field.

As Bell and Gilbert (1996) and Southerland, Sowell, Blanchard and Granger (2011) show, a trigger for change can be dissatisfaction with some aspect of practice, or personal goals and strategies. The teachers cited by Clough et al. (2009) would thus require sufficient self-analysis to become aware that there was a problem and recognition of a need to change. Professional development programmes that provide opportunities for teacher learning through the introduction of ideas for innovation, can help teachers respond to feelings of dissatisfaction through providing a stimulus for change and opportunities for collaborative reflection that aid analysis of personal values and practice.

Teachers' values are developed early on in their careers from previous experiences of education and their pre-service school practice. Teaching practice situations can be an important influence on emergent values through a semi-conscious socialisation process through which "norms, values, perspectives and interpretations of events are shaped by the local workplace culture" (Eraut, 2004, p. 254). Real problems can ensue for teachers when they recognise that their own values are in tension with those of the school, as Evans (2002) pointed out in her account of her own developing practice. Evans left teaching due to the frustration she experienced as she perceived the "irrationality which underpinned most of the decision-making… and because the values and educational ideologies that I held were seldom shared by colleagues" (p. 125). Such tensions were also apparent in Roychoudhury and Rice's (2013) study of student (i.e., pre-service) teachers: those who were most committed to student learning and interest, and who demonstrated agency, were more likely to feel tensions and conflicts between their values and the normative practices and policies they encountered in schools. In contrast, pre-service teachers with content-oriented values experienced fewer tensions and were less likely to question their assumptions.

Teaching and school culture can play an important part in an educational reform (Gess-Newsome, Southerland, Johnston, & Woodbury, 2003), in particular where collaboration is fostered within schools, and also during offsite experiences when managers are encouraged to provide opportunities for teachers to see how the context influences values (Hodkinson & Hodkinson, 2005). As Lovett and Gilmore (2003) point out, "The success of teacher learning and development rests on school cultures that value learning" (p. 207). While this discussion of teachers' values is one that is relevant to all teachers, including science teachers, the examples we provide below focus more specifically on science teachers' values.

Addressing Values in an Initial Teacher Education Programme

This section draws on our experience as teacher educators on a 1-year pre-service programme called the Post-Graduate Certificate in Education (PGCE). On this programme, science graduates enrol for 1 year as pre-service teachers (PSTs) and spend one third of their time on a university-based programme, and the other two thirds in a partnership school on teaching practice. Each PST is assigned a personal tutor in the university who supports their work throughout the year and observes them on teaching practice. In school each PST has a mentor, who oversees the teaching programme, observes, supports and assesses the PST's progress. There are a number of opportunities for PSTs to analyse their own practice, while navigating the space fashioned by their own expectations as well as the expectations of their learners, the learners' parents, their peers, their mentors and other teaching staff, including school leaders, the government and the media, and their university tutors.

The PST experience is initially captured by Bandura's (1977) notion of vicarious learning, which is learning derived from their observations of teachers in school, as well as their tutors and peers in university-based activities. This exposes the PSTs to learning behaviours and, therefore, inherent values that they may not have noticed or experienced before starting their teacher training. In their study of pre-service teachers' reflections, Roychoudhury and Rice (2013) focused on teachers' dispositions, for example, moral dispositions, as an awareness of values and the ramifications of these in teaching. They explored how cultural and moral values became evident in PSTs' practice and reflections and how these were evident in their rationales about their actions. While they did not find any reflection or action that they could clearly categorise in terms of moral or specific cultural values, throughout the period of the study and through the course of the pre-service teacher year, they were able to characterise 'value-based dispositions', i.e., values that became evident through pedagogical choices, and these became indicators of how the PSTs might develop as teachers.

While pre-service teachers will hold personal beliefs about teaching and learning and have a sense of the professional values, on the whole these professional values will not be properly formulated. Adoption of professional values and adaptations to personal values from experienced others is important but can be viewed through the lens of a deficit model (a deficit of values as well as a deficit of agency) whereas if PST growth is going to occur there has to be a process of internal negotiated adoption of values, i.e., mediating new values that will sit within their own value framework.

PSTs' personal attitudes towards, and beliefs of, teaching and learning are formulated by their own experiences as a learner in school. When PSTs accept a place on our PGCE course we ask them to write an account of what makes a good teacher. Typical responses of PSTs include mentioning being able to 'deliver knowledge' in a way that 'holds their learners' attention', and they must 'have deep subject knowledge to explain material' to learners. These responses highlight a view that the PSTs believe they should have the 'learning hegemony' in a science lab/classroom where they consider themselves to be the agents of the pupils' learning. In a constructivist context, it is the aim of teacher educators to adapt the 'power structure' of the lab/classroom from being teacher-led to learner-led, in order to facilitate student learning.

Often, PSTs starting out can view science as being a fixed body of knowledge and, as such, have fixed views as to how it can be taught. By exploring the possibilities provided by investigations, and the relationship between school science and how science works in the 'real world', PSTs' initial views of science education and how science can be taught are challenged (see also Cooper & Loughran, Chapter "Exploring Values of Science Through Classroom Practice", this volume).

The broad themes that we focus on with our PSTs during their PGCE course are:

- subject knowledge,
- wider contexts in science education (including global dimensions, cross-curricular dimensions and citizenship),
- working scientifically, and
- assessment in science.

Development and enhancement of subject knowledge is aided by subject specialist sessions that focus on the big ideas (Harlen, 2010) in Biology, Chemistry and Physics. As well as a focus on subject knowledge we also require PSTs to focus on varieties of pedagogical methods to be able to teach various topics. We encourage PSTs to use concept mapping to find links between topics and explore how mid-term planning could be conducted. Further, we draw on Pedagogical Content Knowledge (PCK) and specifically Content Representations (CoRes) (Loughran, Berry, & Mulhall, 2012), which provide prompts for the PSTs to consider the main scientific concepts for topics as well as the multitude of aspects of teaching and learning when planning to teach. The development of a CoRe on a particular topic is something that the PSTs find extremely challenging but it does allow them to reflect on a wider range of considerations about teaching and learning a scientific topic than they would typically be aware of without such an exercise.

A range of taught sessions allow our PSTs to explore various facets of science education including primary science, maths for scientists, socio-scientific inquiry based learning (SSIBL), argumentation, controversial issues, differentiation, using technology in science, and outdoor learning in science where they get the opportunity to teach Year 7 students (aged 11–12) in the grounds and glass houses of the Royal Botanic Gardens at Kew (Simon & Davies, 2015). The aim of these sessions is not only to showcase the links between science and other curricular subjects but also the potential for using science to promote citizenship, and to demonstrate science as being inherently value-full as opposed to value-free.

Often, a PST's experience of learning outside the classroom would be in a more pastoral or supportive capacity if they are able to participate on a school trip. The chance to teach 11 year-old students in an environment such as the Royal Botanical Gardens at Kew empowers the PSTs to seek and lead opportunities for outdoor learning when they begin to teach, even if it is just in the school grounds or the local surroundings that exposes their students to real world contexts and elevates their engagement in science lessons. As they undertake the Kew experience, the PSTs change their perspective on what is important from organisational aspects to being more focused on student learning and what this particular learning environment offers (Simon & Davies, 2015).

When tasked with developing activities linked to socio-scientific inquiry based learning (SSIBL) and developing cross-curricular opportunities in their teaching, PSTs tend to find it difficult to understand how to fully integrate these activities into their lessons, and to view them as interesting one-off type activities or lessons. This can be due, in part, to not observing these styles of activities being used by other teachers whilst in school, or if they have an overly prescriptive scheme of work to follow which may lead to them to consider the restrictive nature of the science curriculum. However, these aspects of science education are discussed and nurtured through the university-based sessions and via subject tutor visits to PSTs to observe them teach in school. The aim is to help the PSTs see that the science curriculum is just a starting point for the engagement of science for their students.

Planning for lessons where students are invited to engage in scientific inquiry directly challenges previous held views about science being a fixed body of knowledge that the teacher delivers, as mentioned earlier. Differentiation is an aspect of teaching that many PSTs find challenging when they begin to teach during their professional practice placement. They often reflect on how it is easier to teach more able learners in a top set class but more difficult to engage some learners in mixed or lower ability groupings. They are invited to share their varying experiences of how classes are structured in their schools and critically assess ways of engaging all learners in school and their views on an engaging science curriculum for all. This encourages the PSTs to value the importance of inclusive science education where all young people, no matter what their cognitive ability or their proficiency in the English language, have the right to a good science education that will be of benefit to their lives during and after school.

As discussed earlier, Clarke and Hollingsworth's (2002) examples show how teachers come to see different outcomes as important in the light of practice. Once PSTs begin to plan and teach lessons, they are invited to reflect and evaluate their teaching and discuss this with their mentor and other teachers who observe them at their placement school and with their university-based tutor. It is during this practical cycle of planning, teaching and evaluation that the majority of PSTs begin to re-evaluate their prior held beliefs about teaching, challenge their views about being the perceived locus of control of learning, and develop their critical reflection skills. Through this process they learn to value a range of student outcomes.

To encourage more criticality in the reflective process in order to expand value dispositions (Roychoudhury & Rice, 2013), our PSTs are also expected to complete two Masters level written assignments, one in each of their placement schools. The first assignment focuses on learning about science and looks at the nature of science, its moral and ethical dimensions and its place in a cultural context. The preparation for this assignment is typically the PSTs' first foray into science education literature, and they are asked to critically reflect and compare their initial teaching experiences with the literature. This is something that most find challenging but ultimately rewarding when the objectives of the assignment become clearer as they progress through the course. The second assignment focuses on the PSTs' use of creativity in teaching outside of their subject specialism as well as using assessment to be able to discuss how and why their students learn. The assignment emphasises the importance of engagement and inspiration in helping learners learn potentially abstract subject content.

PSTs are encouraged to value the learning opportunities generated by their students expressing their ideas and observations of the world around them, particularly if their views run contrary to accepted scientific knowledge. This is helped by PSTs focusing on relevant literature regarding students' preconceptions and alternative conceptions. The purpose of requiring the PSTs to evaluate their own teaching is to develop their skills for becoming a critically reflective practitioner able to recognise what helps their students to learn science and what changes to their teaching and pedagogical approaches will further engender progress amongst their students. Though this can be trying and time consuming for the PSTs, it ultimately assists in developing their aims and purposes of teaching and learning in science education.

The PGCE programme thus aims to achieve value congruence. As PSTs develop personalised versions of science teaching and learning, the programme tutors and school mentors guide them, through planning, reflection and discussion, in such a way as to convey messages about good practice, so that values are shared and enacted as far as possible in student teacher practices. Once pre-service teachers gain Qualified Teacher Status and achieve success in applying for a teaching post, they become fully immersed in practice as in-service teachers. Here, many opportunities are available for teachers to continue their professional learning journey, for example, through school professional development programmes, partnership with research projects, or through higher degree work.

Professional Learning Through Higher Degree Work

As mentioned earlier, most students in our initial teacher education now gain Masters level credits as part of their pre-service teaching programme, and many wish to build on these credits to gain the full Master's degree through formal study once they are in employment as teachers. Other, more experienced teachers also enroll for a Master's degree in order to extend their thinking as well as achieve accreditation. The Master's degree typically includes modules on educational theory that problematise issues of practice, together with the study of research methods and the completion of a piece of research for a report or dissertation. For most Master's degree students this process provides invaluable insights into the complexities of teaching that would be difficult to achieve through other experiences of professional learning. Most teachers who enroll for a Master's degree want to learn more; they do not want to 'settle' into a role but to continue to question practice and challenge their thinking as learners.

Teachers can also be supported by their school's professional development budgets, as the outcomes are seen to be valued in terms of professional learning. Small-scale projects linked to practice, informed by careful reading that supports and deepens understanding of the issues that teachers' problematised in their own practice, or stimulated interest in the focus of inquiry, are invaluable sources of professional learning. Practice-based inquiry is a form of action research (McNiff with Whitehead, 2002) and can involve high levels of critical reflection (Hatton & Smith, 1995); a study on the process of critical reflection in a Master of Teaching programme demonstrates the power of reflection in Masters level work (Turner & Simon, 2013). In this research the authors interviewed teachers studying towards a

Master's degree, and show how problematisation of practice can lead teachers to question values, and undertake forms of inquiry.

Opportunities for completing Masters level study can be a valuable way to bridge the novel reflective experiences of pre-service and early career teachers, to a more informed reflective process that comes with engaging with literature and different theoretical insights on teaching and learning. John's learning account exemplifies this process:

> Studying for the MA in Science Education was a personal journey of challenging long held views of school that were forged primarily by interactions between a small pool of science teachers, and a wider teaching staff at a comprehensive school. Delving into the purpose and aims and philosophical aspects of science education, the nature of science and the importance of assessment, along with the opportunity to discuss principles with an international group of teachers and carefully considered contributions to online forums, were the catalysts to my evolving views of teaching and learning.
>
> Studying for the MA in Science Education gave me an opportunity to reflect on the purpose of science education and my own aims of science education. Ten years of teaching secondary school science and existing in teacher circles had created and maintained a focus on student achievement and attainment. The MA repurposed my view to how science and science education was perceived by my students, as well as how achievement goals could be adapted to learning goals (Dweck & Master, 2009), to develop my students' resilience skills when faced with challenges to their scientific knowledge and perceived capabilities.
>
> Having colleagues studying for an MA such as the MA in Science can also be a catalyst for fruitful discussions about education in the staff room when discussing pertinent literature such as Roth and Barton's (2004) 'Rethinking scientific literacy', which generated some heated discussions about the purposes of education. Researching for and writing a dissertation concerning the low uptake of Physics at A–level enabled me to explore feminist and other values of science education.
>
> Ultimately, having direct access to science education literature meant that the research community was effectively invited into my classroom where previously the door had been closed. This wider network meant that my reflections on teaching and learning not only considered the progress of learners in relation to the curriculum but also their social and emotional development in relation to the wider issues of science.

Engaging with professional learning, such as studying for a higher degree, enables teachers to critically reflect on their ideas about teaching and learning. The availability of and engagement with literature about science education research as well as being enveloped in a research community of fellow students and academic staff exposes teachers to a wider range of values and beliefs about science education beyond the confines of their school and the relatively small pool of colleagues. Being members and active participants of this broader education (research) community provides agency for teachers to professionally develop their practice and to seek research opportunities with colleagues in their school that can develop a school's partnership with a Higher Education Institution. Value congruence is thus achieved in a similar way to that described in the previous section on initial teacher education, through reflective writing and assignments designed to advance professional learning and values, particularly where ideas about what is valued are discussed in the form of tutor-led sessions, online forums and written assignments.

Professional Learning in Research: How Engagement in Projects Can Extend Existing Values

University-based research projects that include an element of professional development (i.e., a 'professional development' programme that provides opportunities for professional learning) enable teachers to critical reflect on practice and examine their values in teaching and learning science. Teachers involved in innovations such as argumentation, which include such development programmes, have been shown to make changes in practice over a period of time (Adey, 2004; Simon, Erduran, & Osborne, 2006). The following account briefly shows how changes in values often underpin ways in which teachers change practice.

Argumentation Projects

Professional development programmes for teacher learning are a feature of many research projects that aim to introduce innovations in school. During the last 15 years, one of us (Shirley) has been involved in projects that focus on developing argumentation in science classrooms (Osborne, Erduran, & Simon, 2004a, 2004b; Simon et al., 2006). The most recent included professional learning experiences using video (Davies & Simon, 2019; Simon & Davies, 2019): video footage of teachers and students working with argumentation activities was used in professional development workshops with primary and secondary teachers to analyse and develop practice.

The importance of argumentation in science education has become well-established and has been the focus of much international research (Erduran & Jiménex-Aleixandre, 2008; Khine, 2011). Studies have highlighted the challenges teachers face when introducing argumentation activities in their practice (Osborne, Simon, Christodoulou, Howell-Richardson, & Richardson, 2013; Sampson & Blanchard, 2012; Simon et al., 2006). For effective use of argumentation teachers need to extend their teaching goals beyond content and conceptual understanding of established knowledge to include and value epistemic and social goals that involve students in discussing and weighing up evidence to construct justified arguments. Providing specific examples to stimulate new practices and reflectivity has been central to the research and development professional learning programmes of argumentation projects, as was the encouragement to try out new activities and teaching strategies and reflect on their value.

Many teachers have deeply held beliefs that teaching established scientific content is the most important goal; switching their teaching strategies and classroom dialogue to reflect different goals requires an awareness of and value given to those goals. For example, scaffolding argumentation processes through providing a rationale for students, modelling argumentation, and/or asking appropriate questions requires awareness of the goals of argumentation (McNeill & Pimentel, 2010; Simon et al., 2006). Changing your role as a teacher to address these goals is underpinned by an understanding and valuing of how argumentation contributes to science learning through reasoning (Sampson & Blanchard, 2012). To this end, teachers involved in projects have been asked to explain and reflect (both written and orally) on their use of argumentation strategies. The following account illustrates the kinds of changes experienced by two teachers—Pritti and Emma—in the video project. The teachers in this project attended a series of three workshops at three monthly intervals, allowing time for activities to be tried in school. The workshops focused on group work strategies, the teacher's role during argumentation, and planning argumentation lessons.

Pritti and Emma Using Argumentation

Pritti was in her first year of teaching so was relatively inexperienced, but she was working in a science department that had a strong record of undertaking initiatives and working with research projects, including argumentation. She had joined the project at the suggestion of her Head of Department, and she expressed her expectation from the project in terms of building on argumentation practice already strong in her school and developing further strategies and more new ideas; she had perceived a need to develop her practice through developing a wider range of teaching strategies. Emma had also joined the project at the suggestion of her Head of Department, but was working in an environment where argumentation pedagogy was not strong. She wanted to develop discussion skills with her students as she had perceived the need in her own practice to enhance these skills, and hoped to gain techniques to enable a more open, but structured, debate about scientific ideas or theories in lessons. Both teachers had an open disposition and were ready to learn different ways of teaching. The professional learning programme was the stimulus to try out new ideas.

Pritti was proactive in planning and implementing argumentation activities in lessons with students aged 11 and 13; she was able to do this more easily than other teachers on the project as activities that had been designed and tried within her department were a source of ideas. For example, Pritti's first activity with 11 year olds involved justification of classifying materials as solids, liquids or gases using evidence cards, and the activity and its resources were already available. Pritti was able to focus on the process of justification and students' reasoning behind classifying the different materials, asking students to put forward their arguments rather than present the 'right answer'. She found the use of the evidence cards useful in prompting reasoning. Pritti had not considered using any particular group work strategies in this initial activity—she had students working in random groups to discuss the evidence cards—but she eventually used an envoy strategy seen in the workshop video. This strategy is usually carried out when students are in groups of about four. After discussing the task in groups, one student from each group is nominated by the group as an envoy. The envoy takes the group's decision or outcome and moves to another group to share it. The envoy then finds out the decision of the new group and takes it back for further discussion with his/her original group. This strategy thus involves sharing between groups and opportunities to further discussion. Pritti used envoys twice and then found the students' attention was limited. On reflection she thought she would reconsider how groups would be formed for future activities, and who would be the envoys if she used that strategy again.

Pritti tried a different group work strategy in her first activity with the 13 year olds. The class were learning about chemical reactions and she devised a plan to include the jigsaw strategy. The students formed mixed ability 'home' groups that sent a representative to different 'stations', each with a practical chemical reaction that the students had to become familiar with and classify with reasons. This meant they worked with a different group to become an 'expert' in the reaction, and then took their knowledge back to the home group for discussion. Pritti's reflections about this activity centred on the fluidity of the lesson, as some expert groups needed extra help to engage in the stations, and some home groups needed extension activity if they completed the work swiftly.

Pritti's reflective stance enabled her to identify ways forward with the changes in practice adopted as a result of ideas gained in the first workshop on group work for argumentation. Her willingness to try out new ideas shows progression along the practice strand of Bell and Gilbert's (1996) model of teacher development, as her changes in practice helped her to see new ways of working. Coupled with her reflective stance, Pritti's change empowered her to carry on trying out further changes in practice subsequent to the second workshop, and to see the potential for implementing other new ideas, such as the debate format she observed being used by one of her colleagues. Pritti's experience building on ideas from her departmental colleagues, and her interaction with the materials provided in the workshops, enhanced her personal development as she reflected and learnt ways of thinking about student engagement and learning. Through problematising her practice and extending her teaching strategies by taking on ideas presented in the video and workshops, she came to value the process of students seeing opposing views to establish their understanding of science and in particular that 'linking up to evidence is really important'.

Emma also focused on developing strategies for group work after the first workshop, trialling different group work strategies and in different contexts with 2 year groups. With 12 year old students she used an activity on smoking in a topic on health, and with 14 year olds an activity about theories of the origin of the Moon. She used envoy and jigsaw strategies, and reported back that she had focused on listening to arguments and asking for justification of ideas. She said that the activities went well as students learnt to justify and present their ideas. After the second workshop, which focused on the teacher's role, Emma stated in her evaluation that she found the guidance on how to facilitate argumentation the most useful aspect. She was interested in the videos that showed students' reactions to teachers' questioning. Emma intended to focus more on students' justification of ideas after this workshop, and reported that the workshop had made her think more about how to question her students. Her reflections were on the composition of the groups and how this worked; the groups tended to be mixed in terms of ability. As this activity worked well, Emma was willing to try a new strategy (she called this arranging the students at random) but was not sure how well it would go down using the context of drugs. However, she carried out this lesson and recorded her reflections afterwards. In subsequent lessons Emma tried different group structures to see how these worked—she was keen to develop her confidence with group work. Emma felt that the students engaged in discussion and sharing of ideas and learnt much about classification of drugs and their effects, which led her to place more value on group work. Thus, the stimulus for Emma's professional learning and extending her values regarding teaching strategies was through trying out ideas that she could see were feasible and potentially productive in her setting.

Emma's progress was in terms of her development of group work organisation and management, with a focus on valuable discussion. The materials provided by the videos and tasks in the first workshop stimulated changes in her practice. Her reflective stance was initially weaker than Pritti's, but was greatly stimulated by listening to and interacting with others in the second workshop, after which she became more overtly reflective of her practice. Change in her personal learning became more apparent as the workshops progressed and Emma felt more confident and empowered as a result of changes in her practice and sharing outcomes with others. Emma was in a less supportive environment in her school that Pritti, where she was expected to share and disseminate her learning at staff meetings rather than work with colleagues to develop practice collaboratively. In workshop two, however, she 'clicked' with Pritti and they subsequently worked closely in planning activities in workshop three on activity design. Emma became much more eager to accept ideas as the workshops progressed and also more eager to reflect on her own thinking about teaching and learning.

Both teachers showed evidence of extending their values as a result of their involvement in the project, in terms of the social and epistemic goals of working with argumentation activities. The examples above of how they learned to value the use of effective group work for argumentation show how the stimulus from focussed professional development workshops, opportunities to reflect and share personal learning, and affordances or limitations of the school context all impact on teachers' values. The programme was designed to help these teachers to develop a new set of values, that is, to promote value congruence, through addressing their existing beliefs about science teaching and learning and sharing new ideas for advancing practice in such a way that their learning within the professional development programme was in tune with the values of the programme leaders.

Conclusion

We have shown that professional learning experiences—from initial teacher education, higher degree study, and being involved in research and development as an in-service teacher—all incorporate the reflective process. Critical reflection on practice can bring about changes in values. Further, how professional learning experiences are conceptualised will reflect the aims and values of those providing the experiences and how they promote learning.

The value of reflection in understanding practice is now becoming popular in the demand for 'action research' by teachers and school leaders. Several colleagues have been asked to introduce the process of action research, research methods and modes of presentation with groups of teachers in local schools. The aim is for teachers to understand and to improve their practice, through a process of planning, action and reflection upon action. This can be thought of as an action-reflection 'cycle' and involves the gathering of evidence about practice and seeing the effects of planned change in their practice (McNiff with Whitehead, 2002). The aim is to be systematic and rigorous, but the analysis and knowledge formation in action research belong to the practitioner.

The introduction to research methods provides a basis for undertaking an inquiry, and it is recommended that the process must also involve some sharing of outcomes. For these projects to have some sustained impact on teacher learning they require school leaders to have an understanding of research, and of how sustained change comes about through the development of values and beliefs about practice. In essence, the concept of *value congruence* continues to be relevant as more professional development programmes become school based, from initial teacher education to in-service programmes. One risk in this scenario could be that teachers' values may not be challenged, if programmes are promoting the values already in existence. Good in-school professional development programmes that take on new ideas and are innovative are needed if teachers are to continue to grow through reflecting and extending their values as teachers.

Acknowledgements We thank Paul Davies and Jillian Trevethan, who took part in the argumentation video project.

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Exploring the Professional Learning Values Inherent in Japan's Lesson Study

Tetsuo Isozaki

Introduction

In international comparisons such as the Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS), Japanese children, along with those from other East Asian countries, tend to achieve higher scores than their peers in the West. Multiple factors contribute to this success, and it is not easy to identify the most important reasons. Green (1997) observed that in successful Asian countries, an inclusive learning culture "exists as a historical sediment, visible in the cultural norms and institutional practices of the 'learning society'" (p. 297). Stigler and Hiebert (1999) argued one of the reasons for Japanese success is that 'Lesson Study' is important for establishing a learning culture among Japanese educators.

Teaching, like learning, is a complex cultural activity, and the classroom can be chaotic and unpredictable (Isozaki, 2015). So what is Lesson Study, and why and how do Japanese science teachers engage in it? This chapter first describes science lessons in Japan, then considers the role of Lesson Study as part of teachers' professional culture. The place of values in Japanese science education, and the ways in which Lesson Study assists science teachers to acquire and develop these values is explored. Values, in this context, refer to the beliefs that teachers hold and develop in relation to their practice in science education. In this sense, values are considered to underpin what matters to them in relation to science learning and teaching, and why they do what they do in the classroom.

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D. Corrigan et al. (eds.), *Values in Science Education*,
https://doi.org/10.1007/978-3-030-42172-4_9

Japanese Science Lessons As a Cultural Activity

Some Characteristics of the Japanese Education System

The historical relationship between central government and teachers in Japan is different from those of 'Anglophone cultures' (Hargreaves, 2000). After World War II, the Ministry of Education created a new democratic educational system that emphasised a progressive, child-centred education modelled on the educational system of the USA. Schools and teachers are required to develop students' cognitive, physical, emotional, and social skills and educate students to become responsible individuals. The government regards the human capital of the Japanese people as the nation's most valuable resource.

Japan is a relatively homogenous country and highly centralised in terms of its education policy. The Ministry of Education has long controlled school administration, curriculum, pedagogy, and textbook content. Japan's national goals for elementary and secondary education are contained in the Course of Study, which embodies the national curriculum framework. This is a legal document, and it is revised approximately every 10 years by the Ministry of Education. Since 1958, the Ministry of Education has mandated all national, municipal, and private schools and teachers follow the Course of Study. It covers all subjects, including science, and other non-subject areas. Thus, the Course of Study focuses on developing every aspect of the child, addressing their social, physical, ethical, aesthetic, and intellectual needs.

The Course of Study stipulates the education goals, content, pedagogy, and the number of teaching hours for each subject. It includes the content that is to be taught at each grade level. Additionally, the Ministry of Education provides further guidance (interpretation guidelines on the Course of Study) on the social and educational background and policy of the revision of the Course of Study, the content to be taught, and other information relevant to the teaching content. These are very important documents for both textbook producers and practicing teachers. Like other countries' science curricula, Japan's Course of Study for science and its practical interpretation guidelines have traditionally referred to science education values and habits of mind such as honesty, objectivity, curiosity, and interest, as listed by Hildebrand (2007).

The Ministry of Education screens textbook content through its textbook authorisation system to address technical and factual errors, as well as any bias. For the government, this system is an important route through which its policy and the nation's values reach the classroom. There are five textbook companies that publish elementary and lower secondary science textbooks in Japan, each with its own philosophy within the confines of the authorisation system. Some distinguished and experienced teachers, as well as university professors, engage in editing textbooks, enabling them to reflect their values and practice in educational works. Every textbook has to include practical activities as identified in the Course of Study for science; however, many lower secondary science teachers traditionally produce their own worksheets for practical activities.

The similarity of Japanese lesson patterns based on the Course of Study, textbooks, and worksheets, is evident in comparative studies with other countries (e.g., Stigler & Hiebert, 1999; National Center for Education Statistics, 2006). Drawing on research in Australia, China, the Czech Republic, and Japan, Groves and Doig (2010) identified and examined some affordances of and constraints of the Japanese Lesson Study being implemented in the Australian context. They observed that teaching in Japan is regarded as a public activity, and teachers focus on learning as a community rather than as an individual activity. This is a social norm of classroom culture in Japan (Fujii, 2014). In addition, the Teaching and Learning International Survey (TALIS) (OECD, 2014) identified that Japanese teachers reported higher than average participation rates for continuing professional development (CPD) in terms of observation visits to other schools (51%, compared to the TALIS average of 19%). Why do they visit and observe other teachers' lessons? In Japan, even an experienced teacher is motivated to learn from others for self-improvement. According to the findings of Isozaki's (2016b) collaboration with the Department of Science Education and the Research Project Centre for the Next Generation Science Education, science teachers had participated in *in*-house Lesson Study an average of more than four times over the preceding 12 months. They had also engaged in *open*-house Lesson Study held in other schools an average of more than twice during the same time period. In other words, colleagues and senior school managers can easily access and observe a teacher's performance.

Some Features of Japanese Science Lessons

From elementary school (Grades 1–6) to secondary school (Grades 7–12), all students *must* take the subject known as 'science' (*rika* in Japanese), even if they are a non-science student pursuing a general or vocational course in upper secondary school. Since 1947, both the objectives and content of science education have been set by the Ministry of Education through the Course of Study, as described above.

The Course of Study states the goals of science education, which are broad and somewhat abstract, and not attainment targets. In the science education goals for elementary to upper secondary schools, 'nature' (*shizen* in Japanese) is the key word for understanding *rika* (Ogawa, 2015; Isozaki, 2014). Therefore, to instil (educe) a love of nature in children's minds can be regarded as one of Japan's traditional and important science education values, as well as one of our principal community values. Another key term in elementary school science, reflecting science education values in Japan, is 'problem-solving'; in secondary school science, the focus shifts to 'scientific inquiry'. To achieve the goals of science education, every teaching unit has more specific objectives derived from the goals.

The Course of Study also includes the content that should be taught in schools, and includes notes that provide guidance on the content. Comparing lessons in

Germany, the United States, and Japan, Stigler and Hiebert (1999) characterised the features of a Japanese mathematics lesson as follows:

(1) reviewing the previous lesson,
(2) presenting the problem for the day,
(3) students working individually or in groups,
(4) discussing solution methods, and
(5) highlighting and summarising the major points.

In Japan, each science lesson generally comprises three phases: introduction, development, and conclusion. Stigler and Hiebert's category (1) falls in the introduction phase; (2), (3), and (4) are in the development phase; and (5) is the conclusion phase. The National Center for Education Statistics (NCES) (2006) describes Japanese science lessons at the eighth-grade level as follows:

(1) focus on developing scientific ideas by making connections between ideas and evidence through an inquiry-oriented, inductive approach, in which data are collected and interpreted to formulate a main idea or conclusion; and,
(2) be conceptually coherent, with an emphasis on identifying patterns in data and making connections among ideas and evidence, conducting practical work as a central role in developing main ideas.

These features reflect the objectives of the Course of Study for lower secondary school science. Practical activities, such as experiments and observations, are enhanced in every revision of the Course of Study for science. In the introduction phase of a lesson, the science teacher reflects on the previous lesson with students, and inspires their interest in the day's topic. At the beginning of the development phase, the science teacher informs students of the question they will be exploring in the investigation, and asks them to formulate a hypothesis before engaging in practical activities. During and after the practical activities, students are guided by the teacher and/or worksheets to organise and manipulate the data generated through their practical activities into graphs or charts, and then to interpret the data. In the conclusion phase, based on the results of practical activities, small group and whole class discussions are conducted to pursue the development of one main conclusion. Finally, the science teacher summarises the lesson. Thus, the focal question and summary of the lesson, as well as focusing on a task and one main idea, contribute to the coherence of Japanese science lessons.

In Japan, it is sometimes derided that school science (*rika*) does not go beyond the school gate. This complaint seems to refer to two aspects: one is that students cannot apply the knowledge gained in lessons in their daily lives, and the other is that scientific knowledge taught in the classroom is isolated from daily life. The TIMSS video research survey (NCES, 2006) reveals that the nature of science, technology, and environment and resource issues rarely feature in Japanese science lessons; moreover, teachers devote only 6% of class talk time to science-related real-life issues (e.g., societal issues or students' personal experiences). On the other hand, Roth, Druker, Garnier, Lemmens, Chen and Kawanaka (2006) concluded that "the content of Japanese science lessons was organised to support the making of connections between ideas and evidence, and was presented coherently with strong conceptual connections" (p. 162). Nevertheless, science-related real-life issues tend to be used less often to develop the main ideas in science lessons. Indeed, socio-scientific issues, such as environment-related natural disasters and energy resources issues, which are embedded within political and social decision making, are rarely taught in Japanese science lessons compared with such lessons in the West. There seem to be two reasons for this. First, the Course of Study for science does not mention knowledge *about* science, but rather refers to knowledge *of/in* science. Second, science teachers are generally unfamiliar with pedagogical methods for exploring socio-scientific issues, such as argumentation and decision making based on scientific evidence.

Values and Lesson Study in Japan

Lesson Study: What Does It Mean for Teacher Education?

As mentioned above, according to the TALIS (OECD, 2014), Japanese teachers are distinguished from teachers in other countries in the following two respects. First, Japanese teachers spend 9 hours on average planning their lessons (cf. TALIS average, 7 hours) and their average participation rate for CPD through observation visits to other schools is 51% (TALIS average, 19%). These data mean that Japanese teachers spend considerable time on lesson preparation, and engaging in Lesson Study within their professional learning communities.

Lesson Study is a comprehensive and well-articulated approach to examining teaching practice, in which Japanese teachers engage as an essential part of their CPD within a defined professional learning community. The process involves a critical focus on the relationship between teaching and learning (Isozaki, 2015). Lesson Study is a literal translation of the term *jyugyou-kenkyuu,* with *jyugyou* meaning lessons and *kenkyuu* meaning study or research. The origin of Lesson Study can be traced back to the late nineteenth century, and particularly Japan's modernisation in the 1870s and 1880s. It is historically and strongly embedded in Japanese teachers' professional culture in both pre- and in-service training (Isozaki & Isozaki, 2011). Lesson Study in Japan has historically diverse flows (e.g., systems and ideology), and the teaching and learning theories which support it also differ. However, strong evidence of the value of Lesson Study lies in the fact that Japanese educators have been engaging in Lesson Study for over 100 years. In recent years, Lesson Study has also enabled practitioners to learn across cultural boundaries (Lewis, Perry & Murata, 2006).

Lesson Study may typically be divided into three phases: preparation, research lesson, and reflective meeting. In pre-service teacher education, Lesson Study takes place during teaching practice in school. Student teachers are encouraged to participate in teaching practice within a professional community that includes experienced teachers (mentors), other student teachers and the school students themselves. To bridge the gap between theory and practice, the process focuses on various essential questions:

- What is the teaching profession?
- What are students expected to gain from their learning experience?
- Why do teachers devote extensive time to researching and developing teaching materials (*kyouzai-kenkyuu* in Japanese)?
- Why do they need to make and revise lesson plans, along with *kyouzai-kenkyuu*, and how do they do so?

Student teachers observe their mentor's lessons and attend lectures on the mentor's views of teaching, classroom management, and other teaching-related matters. Student teachers collaboratively make lesson plans, and research and develop teaching materials based on discussions with other student teachers and advice from their mentors. After a research lesson delivered by one of the student teachers, they participate in a reflective meeting. This process is repeated throughout teaching practice in pre-service teacher education, with multiple opportunities for student teachers to learn about their mentor's thinking on educational and scientific values. Through this process, student teachers gradually become familiar with the processes and benefits of Lesson Study, as well as become exposed to ideas about the culture and identity connected with being a teacher, as held by other student teachers (Isozaki, 2015).

During in-service teacher education, Lesson Study can be divided into the same three phases. In the preparation phase, there are mainly three processes: goal setting, researching and developing teaching materials, and making and revising lesson plans. The goals of Lesson Study are generally identified by teachers through analysing their students' or schools' situations; recent educational trends related to the Course of Study, such as introducing active learning; or educational issues to be addressed. Researching and developing teaching materials, and making and revising lesson plans, are conducted in parallel, and the process of their completion is accompanied by teachers providing feedback to each other. The teacher who will deliver the research lesson formulates the lesson plan based on discussions with colleagues and external advisors. Teachers engage in these activities for several months. Before the research lesson, teachers sometimes check the lesson plan in a different class, aiming to review and revise it.

In regular lessons, science teachers devote extensive time and energy to lesson preparation, as well as Lesson Study. The teacher delivers the research lesson in the targeted class based on the lesson plan they developed through the above process. Other teachers then use the revised lesson plan as a guide for their comments on and critique of the lesson. In collecting data, such as on students' behaviour, and taking notes, they focus on student learning and on the teaching. The observing teachers are allowed to move around the laboratory to listen to students' discussions, to observe how students are engaging in practical activities, and to check what students write in their notebooks or worksheets. Most science teachers who deliver a research lesson are eager to use an inquiry-based approach, encouraging students to make predictions or hypotheses, conduct practical activities, obtain data, and induce a law or principle from these data. The use of video cameras for recording the research lesson enables teachers to reflect on their teaching and to analyse the students' activities. A reflective meeting is usually held later the same day and is based on the evidence collected during the research lesson. External advisors such as a university professor and/or a consultant teacher of a local board of education, who also observed the lesson, attend the reflective meeting to give comments and advice. Sharing the results of Lesson Study can be done in several ways, including writing a report or a school bulletin. These documents provide a record of Lesson Study for future use (Isozaki, 2015).

Why Do Science Teachers Devote Time and Energy to Preparing Lesson Study and Regular Lessons?

As already indicated, Japanese teachers devote time and energy to lesson preparation (OECD, 2014). In addition, a survey of Lesson Study for lower secondary school science teachers in Hiroshima (Isozaki, 2016b; Ochi, Ueda & Isozaki, 2018) found that half of science teachers (N = 177), aged from their 20s to 50s, report the research and development of teaching materials to be the most useful Lesson Study processes for their self-improvement in teaching and learning. Those in their 20s–40s indicated that they wish to learn how to conduct research into and development of new teaching materials (*kyouzai* in Japanese), and they wish to apply teaching materials produced by others, while those in their 50s wish to learn new pedagogical methods in science. Data from short essays on the Lesson Study preparation phase show that the teachers primarily concentrated on: (1) reflecting on previous teaching materials, (2) developing new teaching materials, and (3) developing a lesson plan appropriate for students' understanding and skill level.

A science teacher is not a scientist. Therefore, a science teacher's knowledge of science is organised from a teaching perspective. Conversely, a scientist's knowledge of science is formed from a research perspective. As Ausubel (1968) argued, there is a "distinction between [the] logical and psychological structure of knowledge" (p. 45): the former depends on the discipline's structure, while the latter represents a "particular learner's cognitive structure" (p. 44). Therefore, a science teacher's knowledge should be subject to a series of adaptations before being accepted for teaching in schools. Based on Chevallard's (1989) ideas of Didactic Transposition Theory (Tiberghien & Sensevy, 2015) and Anthropological Theory of the Didactic, Bosch and Gascón (2006) illustrated the four stages of the didactic transposition process. This includes 'scholarly knowledge' as produced by scientists and 'knowledge to be taught' as defined by the educational system. Chevallard referred to this latter area of knowledge as the 'noosphere', namely the sphere of those with a strong influence within the education system, such as professors, curriculum developers, scientists, and science teachers. Finally, there is the 'taught knowledge' as created by science teachers in schools and 'learned, available knowledge' as formed by students in classrooms (Bosch & Gascón, 2006).

Scientific knowledge can undergo transformation through the different actors mentioned above, based on what they think is important and valuable for students to learn in schools. Science teachers are responsible for these types of knowledge, as they determine how to teach in a manner suited to their students, and they carefully focus on and take part in what Winsløw (2007) described as 'internal didactic transposition': from 'knowledge to be taught' to 'taught knowledge', and from 'taught knowledge' to 'learnt knowledge'. The research and development of teaching materials (*kyouzai-kenkyuu*) encapsulate these processes of internal didactic transposition, involving the important process of examining teaching materials and such tasks as practical activities in lessons, incorporating scientific and educational values, as well as students' points of view. Researching and developing teaching materials and the task (being the main activity in which students engage) are inseparably related. If science teachers do not deeply engage in researching and developing teaching materials that integrate both scientific and educational values and students' perspectives, there is no meaning for students in conducting the task, which has no value to them. Therefore, examining values through researching and developing teaching materials is a very important activity for teachers, explaining why they devote time and energy to it in relation to both Lesson Study and regular lessons.

What Does the Lesson Study Planning Process Look Like?

Figure 1 outlines a template for a typical lesson plan used by teachers in regular lessons

In the study by Isozaki (2016b) science teachers reported that in the process of making a lesson plan, they primarily concentrate on:

(1) setting objectives to be achieved during the lesson and deciding a question (derived from the objectives) that identifies a task appropriate for students' current knowledge and skills, and
(2) creating the lesson's narrative and researching and developing teaching materials.

A task involving practical activities should be the main learning activity in the lesson, and should be achievable for students. In designing a task for one lesson, science teachers must consider students' learning processes with regard to both the scientific and educational value of the task, as well as anticipating students' responses and their scientific thinking. Therefore, science teachers need to understand the scope and sequence of the (spiral) science curriculum beyond their students' current grade in order to link tasks within the unit and between related units in both previous and subsequent grades.

Lesson Study and regular lessons primarily focus on students' learning. In Isozaki's (2016b) study, science teachers reported that in every phase (preparation,

[date and location, name of the teacher]

1. Unit title (Name of the unit)
2. Unit objectives: Based on the Course of Study and teacher' ideas; students should know and understand, be able to, etc.
3. Unit views: (1) Main scientific ideas of the unit and key teaching contents with scientific and educational values;
   (2) Learners' characteristics, their prior knowledge and preconceptions relating to this unit, and the classroom atmosphere; and
   (3) Teacher's views and ideas for instruction based on both (1) & (2).
4. Assessment task: Assessment criteria with methods and activities for the whole unit and each lesson
5. Overall scheme of work: The sequence of unit goals and tasks with the number of hours to be spent on the unit.
6. Today's one-hour lesson: (1) today's topic title, (2) objectives of today's lesson, (3) resources, and (4) development of today' lesson with a task.

Fig. 1 A sample lesson plan
Note 1: The one-hour lesson (the research lesson in Lesson Study) is generally divided into three parts: time and lesson phases (introduction, development, and conclusion), students' activities and learning based on anticipated students' thinking and response, and teacher's activities involving assessing the task
Note 2: For a research lesson in Lesson Study, a lesson plan generally includes other information, such as an explanation of the relationship between the focal topic and the main theme of Lesson Study

research lesson, and reflective meeting) of Lesson Study, they consider the students' perspectives. For example, in researching and developing teaching materials they consider what knowledge and skills students should gain through the lesson in order to achieve its objectives, and in making the lesson plan they create a question that will motivate students. It is noteworthy that in Japan, especially in secondary schools, science teachers belong to a subject department and are also organised into grade units that cut across subject boundaries to address common issues and management duties pertaining to a particular grade level. They also have other responsibilities in their school, such as school management, research promotion, student counselling, school sports club instruction, and communication with people in the school community. Therefore, science teachers in secondary school can form a more holistic understanding of students' characteristics, not only through their performance in science lessons but also through other school activities, for the benefit of students (Isozaki & Isozaki, 2011).

Lewis et al. (2009) argued that "Lesson Study makes various types of knowledge more visible…, thereby enabling teachers to encounter new or different ideas, and to refine their knowledge" (p. 286). As described above, not only in researching and developing teaching materials but also in making lesson plans, teachers need many types of teacher knowledge. Science pedagogical content knowledge (PCK) plays an especially important role, and the teacher's knowledge, beliefs and values are crystallised in the teaching materials and lesson plans. Although observers of another's lessons cannot see the preparation phase of Lesson Study and regular lessons, they can read the teacher's ideas and values as outlined in the lesson plan. Furthermore, TIMSS 2015 showed high rates for Japanese science teachers engaging in CPD in the areas of science content (76%), meaning subject matter knowledge related to science values, and science pedagogy/instruction (77%), which is related to science education values; the international averages for these two areas were 55% and 57% respectively (International Association for the Evaluation of Educational Achievement, 2016). These findings demonstrate that Japanese science teachers are keen to participate in areas of science content and science pedagogy that are the foundations of researching and developing teaching materials and making lesson plans.

Does Lesson Study, As a Part of CPD, Change How Teachers Value the Goals and Purposes of Science Teaching Over Time?

To investigate how teachers' science and science education values are changed through Lesson Study, an empirical study was conducted in 2015 (Ueda & Isozaki, 2016). Qualitative data were collected through semi-structured life story interviews, based on the methods of Atkinson (1998) and Sakurai (2012). The participants were five experienced secondary science teachers (each with a teaching career of more than 30 years), and the aim was to investigate changes in their beliefs about the goals and purposes of science teaching over time. Three interviews, totalling more than four hours, were conducted with each teacher. The life story interview data were analysed through the Steps for Coding and Theorization (SCAT) (Otani, 2008).

The results of the SCAT analysis show that, initially, the five teachers participated enthusiastically in Lesson Study, both formally and informally, aiming to improve their teaching. However, the data suggest difficulty in changing their beliefs about the goals and purposes of science teaching through CPD. While the results of quantitative research show that Lesson Study can provide teachers with opportunities to learn from others and improve their teaching competencies (Isozaki, 2016b), Pajares (1992) described beliefs as episodic, personalised, and difficult to change. The SCAT findings among these five experienced teachers show that their beliefs about the goals and purposes of science teaching had been affected by a range of experiences both in and outside their schools, throughout their teaching careers, such as students' reactions and achievements, and encounters with other teachers.

The results of this research reinforce what Jones and Carter (2007) and Jones and Leagon (2014) have previously noted, namely that teachers' beliefs are embedded in a sociocultural environment/context. Some teachers have retained the beliefs about the goals and purposes of science teaching that they developed before becoming teachers, even though they have taken part in Lesson Study every year. Luft (2001) previously reported that the beliefs of experienced teachers were consistent and that they demonstrated more change in their practices than in their beliefs by participating in-service teacher education programmes. Hildebrand (2007) proposed a model when investigating teachers values as enacted in the science curriculum. Her model consisted of four layers, moving from social practices such as pedagogical practices in the outermost layer, through guiding principles and signposts such as principles and metaphors, and sets of beliefs such as the philosophy of science and education; to the innermost layer of core values. It seems that whereas CPD programmes involving Lesson Study are likely to be effective in reframing teachers' teaching and learning practices (the two outermost layers of Hildebrand's model), it is relatively difficult to change teachers' beliefs (the two innermost layers of Hildebrand's model) through CPD programmes involving Lesson Study.

Conclusion

Learning to teach is a complex process for teachers, taking place across multiple formal and informal social settings. Other chapters in this volume (e.g., Simon & Connelly; Smith & Corrigan) have explored science teachers' values. The present chapter provides clear evidence that the Japanese tradition of Lesson Study provides a different and powerful approach to explore what and why science teachers value in science learning and teaching. Japanese teachers have traditionally engaged in Lesson Study in ways that is like air for them, meaning that it is taken for granted and deeply embedded in Japanese teachers' culture and seen by teachers to be of real value. It is based on collegiality and focuses on students' learning within a professional learning community (Isozaki, 2016a); however, we should recognise that the standardisation of Lesson Study leads to its stylisation and rigidity, resulting in it becoming routine work. In addition, the only attempts to theorise Lesson Study, several of which have been seen in recent years, have taken place outside Japan (Isozaki, 2015).

As Fujii (2014) asserts from an international perspective, values are located at the heart of the approach to Lesson Study in Japan. The Course of Study and educational orders and regulations issued by the Ministry of Education involve community values central to national identity. Science and education values are carefully discussed within the noosphere when the Course of Study is revised. These values are directly reflected in the Course of Study for science, together with its interpretation guideline, and are indirectly reflected in textbooks and guidance for teachers.

In the preparation phase of Lesson Study and regular lessons, especially when researching and developing teaching materials and making lesson plans, science teachers deeply consider scientific and educational values, and reflect their individual values as science teachers, from the perspective of students' learning. Consequently, they devote more time and energy to preparing lessons compared to the international average. Science and education values, as well as science education values specifically, should be brought up-to-date by teachers themselves; therefore, as international and domestic surveys show, Japanese science teachers are eager to observe other teachers' lessons and reflect on science content and science pedagogy in Lesson Study. Thus, consideration of values is the key to a teacher's role in both Lesson Study and regular lessons.

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Changing Context, Shifting Values? Science, The Environment and Citizenship at Minstead Study Centre 12 Years On

Justin Dillon and Alan Reid

Introduction, Rationale and Conceptual Framework

In the first edition of this book we drew on an interview with two exceptional environmental educators based in Minstead Study Centre in Southern England (Dillon & Reid, 2007). We chose a residential environmental study centre because values are often made more explicit in such institutions than they are in the school classroom. Indeed, values tend to form a core dynamic of the curriculum and the pedagogy of outdoor education. The 90-minute interview took place in July 2005 and formed the basis of the 2007 chapter.

In response to the invitation to contribute to this volume, we chose, after some deliberation, to see if Chris and Jane, the two educators, would be willing to be interviewed again, 12 years on. We were interested in the extent to which their core values and those that they promoted to their visitors had changed. Our assumption was that, since the world has changed in so many ways since the mid-2000s, the 'Minstead Experience' might now be quite different than it was in 2005. Public debate and media discussions about issues such as immigration and the UK's membership of the European Union have created a new values climate to which impressionable young children must adapt. Another major social issue affecting children is the impact of austerity on publically funded UK institutions such as the National Health Service and, in particular, funding for residential study centres.

Part of our deliberations about how to contribute to this volume involved finding out whether Minstead was still going and whether Chris and Jane were still there. It was, and they were, and this chapter draws on another in-depth interview with them

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D. Corrigan et al. (eds.), *Values in Science Education*,
https://doi.org/10.1007/978-3-030-42172-4_10

Table 1 Conceptual framework emerging from the interview analysis (Dillon & Reid, 2007, p. 79)

Values	Underpinning assumptions and beliefs
Metaphors	Comparison between ideas seemingly unrelated
Issues	Environmental or scientific concerns
Activities	Tasks undertaken by students
Strategies	Generic pedagogical approaches
Outcomes	The end product of the activities

focusing on their values as they are related to the environment and to notions of citizenship.

In our original chapter we used a conceptual framework to illustrate a range of themes although we deliberately devoted much of the chapter to Chris and Jane's own words. Our position then, as it is now, was that there was no need for much mediation on our part such was the clarity of our informants. However, the exploratory framework proved helpful in showing how individual values impacted on the educational experiences of young people through the mediation of a pedagogy centred on hands-on practical activities, stimulated reflection and appeal to the magic of place and time. Table 1 shows the original framework, which we will also draw on in this chapter.

Where relevant, we will draw attention to these six framing ideas by italicising them in the text.

Minstead Study Centre

When it opened in 1968, Minstead Study Centre occupied the grounds and buildings of a Victorian village school and offered accommodation for up to 30 primary age (5–11 year-old) children. The Centre is situated in a large national park (The New Forest) in the south of England and offers an ideal site for the study of a wide range of habitats in what is officially designated as an Area of Outstanding Natural Beauty.

The Centre is owned by the county council, Hampshire, which, back in 2005, provided funding for 50% of the cost of school visits—a substantial subsidy that was withdrawn in 2008. Not long afterwards, an accommodation block was opened that replaced the existing bedrooms and increased the capacity to 34 students. There is also comfortable accommodation for accompanying staff and other accompanying adults. School groups can choose from 2, 3 or 4-night stays. As well as Chris and Jane, the Centre has eight staff including administrators, cooks, ground-staff and a house-keeper.

As well as the buildings the Centre has extensive grounds covering 7 acres (3 hectares). There are extensive plots devoted to vegetables and herbs as well as areas of grassland for play and other activities. Other features that are used by visiting children include a miz-maze (a pattern cut in the turf), a willow tunnel, an astronomical circle, freshwater ponds, an armillary, a teepee and a Celtic roundhouse in which fires can be lit and stories told. It is an environment that many children who visit will never have experienced, although their parents may well have attended when they were at school.

The Centre's extensive focus on monitoring fuel consumption and minimising waste provide explicit value statements to which all visitors are expected to commit. The pedagogic *strategies* employed by the staff, at a meta-level, link the *issues* of sustainability and conservation with the Centre's *values*. The new residential accommodation was designed to be as sustainable as possible.

The Minstead Philosophy

> Minstead is a magical place where we help develop personal responsibility and nurture positive attitudes. (Minstead Study Centre website, 2017)

The Centre's website provides a considered and comprehensive introduction for teachers, parents and children and explains its 'learning philosophy' which involves:

> Caring for the Earth, working co-operatively, taking responsibility for our actions and understanding the need to live sustainably.
>
> Children are able to establish and understand their connection, influence and responsibilities towards the people, plants and animals of Planet Earth. (ibid.)

This learning philosophy exemplifies the Centre's explicit *values,* which are based on collaborative endeavour supporting individual action for the benefit of the planet and all its occupants. Personal and collective responsibility are seen as essential for a sustainable future. The personal *values* and the environmental *values* which the Centre espouses are seen as being fully integrated.

The 'unique approach', which the Centre's two key staff, Jane (Head) and Chris (Deputy Head) have established over many years, is also outlined on the Minstead website:

> We have developed a unique approach to working with children, allowing us to make learning hands-on, reflective and most of all fun. Time at Minstead enriches children and adults alike, by living, learning and working together. The experience will improve social skills and confidence to learn outside the classroom. (ibid.)

The unique approach is the Centre's *strategy*. The *outcomes* of the *activities* are made clear: improved social skills and personal confidence resulting from hands-on activities and reflection.

Magic, Fun and the Big Message

During the introductory session of a residential visit, each visitor is given a wooden badge with the Latin name of an English animal or plant. This species becomes their personal 'creature teacher', a pedagogic device to aid personal reflection. Although the core of the Minstead curriculum is *issues* in science and geography, the key *outcomes* that the Centre promotes are better team-work, responsibility for self and others, respect for opinions, and connections with the wider context within which the children live.

Schools sending children to the Centre have specific curriculum content and *outcomes* in mind. Indeed it would be difficult for a teacher to obtain permission to organise an out-of-school visit without specifying the curriculum links and *outcomes* in some detail. It is usually the case that a substantial amount of paperwork is required in advance of any school visit. However, the *values* explicit and implicit in the Centre offer a far richer experience than schools might anticipate, as Chris explained in 2017:

> I think if you've done the background work, you've got national curriculum objectives, [the teachers have] said what they want to achieve and you can tie those things to it, and that work was done [by Jane and me] several years ago. It's easy to pass that through, although you've got to go through that process of what fits where and remember to deliver it three months later, which doesn't always happen, but generally it does because they'll remind you.
>
> But I think that the whole thing of what we deliver is something else, and the 'something else' is a bit more intangible and it's to do with the visual atmosphere when you walk into the place, because people go: "Oh, this is a gorgeous magical place".
>
> And layer on top of that whatever our personalities are delivering as well—and I think that's a fairly key thing and difficult to reflect on—what you as an individual makes of, what they make of me, but there's something in that rapport building that allows the message to move more smoothly to individuals and teachers and children.
>
> [If] you deliver the objectives in a dry, dull way, you lose your audience quite quickly. If you're wrapping up big messages and very general messages about being good, kind, being effective, going out there and being in action, that storyline has to persist throughout the whole week, be delivered with a bit of heart and passion, and that's probably why it works…

'Magical' is a word that appears on the Centre's website (see above) and is clearly a dimension of the Minstead experience that Chris and Jane hold dear. It is worth noting here that the New Forest was created in 1079 to serve as a hunting retreat for William the Conqueror so it is not short of history and stories.

The Centre's pedagogy promotes fun ("most of all fun") and a sense of dislocation from children's everyday lives in one sense but with a clear linking of a take-home message that sustainable living does not just happen in a purpose-built eco building but should carry on back at home and/or in school.

Chris's vocabulary here of "wrapping up big messages" and allowing "the message to move more smoothly to individuals and teachers and children" shows the layering of a consistent values-based set of ideas throughout the experience.

Place and Pedagogy

The New Forest setting helps to promote the philosophy of the Centre, as Jane explains:

Jane: I think we're very fortunate because of the site as well. I think the site has its own intrinsic magic, because you are surrounded by forest and it's like being held in the hands of the forest, and a lot of people say that it feels very safe, it feels intimate, it feels warm, it feels friendly, and the trees are doing that partly for us. But then the rest is in harmony with them, I think.

JD: Do you have kids [coming to stay] who have never been to the forest at all?

Jane: Oh yes.

Chris: Probably the majority actually. [I was never really] into that and I didn't come to the forest till I was 15, or maybe once, but it was like a memorable event even my first time, but there are very local people who wouldn't get to the forest, let alone the rest of Hampshire …

The novelty of outdoor educational experiences has been addressed by previous researchers. Burnett, Lucas and Dooley (1996), discussing high school science students' visits to a marine theme park, opined that "teachers need to ensure that students are not distracted by the novelty of the location" (p. 63). On the other hand, Ballantyne and Packer (2002) found that "students who had not visited the particular site before were looking forward to their visit more than those who had" (p. 221). Our experience of Minstead is that the staff make the novelty safe and, indeed, magical.

Although most of the visiting schools come from within the county, for many children it must seem like a far away destination. The novelty of the location requires a residential experience for it to be more fully appreciated. Although children feel at home reasonably quickly, the real learning takes place over several days. Repetition of narrative themes (messages) and of practices helps to create a sense of familiarity and acceptance.

Issues and Values

Back in 2005, Chris explained the links between science and environment *issues*, stories and *values*:

> Going back to where science pervades and permeates: if you asked a child about the structure of the bog land they would be able to tell you, because the build-up has been talking about a layer of sphagnum moss and plants and a deep dank layer, and you could push a stick down through, and the bog bodies and the potential for bog spirits. And this kind of blend of science, non-science, storytelling, religion and faith is all there. What you make of it will vary. (Dillon & Reid, 2007, pp. 86–87)

Chris here is illustrating his understanding that while context is key to learning, it does not mean that the one experience provides identical outcomes for all students. This position might be seen to challenge the desire of visiting schools to specify common learning outcomes for every child. This is an issue for many outdoor education providers.

For us, and for Chris and Jane, the issue at focus is how best to educate young children for a future that is unforeseeable and full of unimaginable challenges in ways that encourage personal growth, collaborative endeavour and critical thinking. We believe these issues are faced by environmental educators across the world (Stapp, 1972).

In our earlier chapter, discussing the Centre's activities and philosophy, we wrote: "People need tools to be able to decide on truth and falsehood—otherwise they will be duped, hoodwinked and bamboozled in the same way that people traditionally have always been" (Dillon & Reid, 2007, p. 86). We take it as axiomatic that this situation has not changed. Indeed, the need is probably even greater now than it was in the early 2000s (see Marangio & Gunstone, this volume).

Values Drift? Doubt and Certainty

We wondered whether the *activities* that visitors carried out were still aimed at promoting general *outcomes* such as reflection and subsequent behaviour change. We also wondered whether Jane and Chris could see any long-term influence of the Centre on local schools and their students. Some people argue that the UK now is a very different place than it was in 2005: more nationalistic, less tolerant and more divided (Brown, 2017). The education system has certainly seen a more managerial approach being brought in and, like most of the public sector, it has suffered from the political focus on austerity (Pollitt & Bouckaert, 2017). We wondered about the extent to which these contextual changes had impacted the Centre's work.

One major change since 2005 has been in the relationship between the Centre and the owner, the local county council.

Jane: Well [the relationship] has changed in that we are still a Hampshire property but we're classed now as a 'self-financing business unit' and we have to pay the county council the rent and we have to pay them a re-charge, which covers any services that we're buying into, like property and business repairs and things like that. Many places [centres or other facilities] were sold off […] to private businesses. We're still here and I think we're still valued and respected [by the county].

The situation now is better in some ways, according to Jane, although the onus is on the Centre being self-financing:

Jane: There isn't that threat because there's nothing to take from us. We are now independent and have survived. So we're stronger in that way. I think you are more, I feel more at the chalk-face, the coalface, whatever. You're having to push to get the business in, keep the business running, marketing strong, fundraising all the time. My job's changed, probably three million per cent I'd say.

This change in circumstances has, over the years, focused Chris' and Jane's minds on their core purpose:

Jane: The 'Million Dollar Question' is what you want to get out of it, isn't it? And what your driving principles are and how you're going to reinforce those every day through the message that you're delivering, and I think that's been very pure by the staff we've had and good fortune and happenstance of working with Chris, and I think schools have bought into that as the whole package, and they like that strength message.

However, recent events have caused some uncertainty to enter their minds:

Jane: […] whether that message is going to endure into the future with change of leadership and the change of the world around us, I'm not sure. It's had its ascendancy, and whether it's losing—I'm not quite sure whether that's what the customer wants out of [a visit] now or whether they're just happy to go and do random […] outdoor activities, which are great fun, rather than having this deep message behind everything.

This is a critical reflection on Jane's part: there is an air of uncertainty, a sense that their underlying *values* may no longer be a message that visitors can identify with. It is not that Minstead's *values* have shifted; perhaps it is that the values climate beyond its grounds have themselves shifted in another direction.

This uncertainty did not, however, characterise the vast majority of Chris and Jane's discourse. For example, when discussing the impact of the Centre on visiting schools, Jane was certain that it has been both long-term and positive:

Jane: It's amazing. That's a lovely feeling though, that you've had that long, long term connection with a school, and a lot of schools have very deliberately taken the philosophy and they've taken Minstead and said "we want to have Minstead at our school" […] And I can think of four or five schools that have tried to put the same sort of development in their garden, a lot of it based round eco-schools in the early days, and put in systems that we have, the way we eat, the way we measure the waste, and a lot of those things are now in Hampshire schools, which is quite fun.

Jane identified another long-term impact indicator:

Jane: But it's very heartening when people come back years later to visit and say "I'm thinking of going into the world of environmental education, will you give me a reference or can I come and talk to you?" Or Chris will put them in contact with a job network, and they say "it was going to Minstead that made that difference to me", and that little jewel has lived with them.

Chris identified another indicator of the impact of their work. He pointed to a specific example of how Minstead had supported local schools looking to take up more sustainable practices:

Chris: … schools, all fairly local, […] approached the idea of what energy was and how, using smart meters, basically they could monitor their own schools with remote metering, a sense of what your energy bill translates into and the amount of carbon and the amount of money, the amount of pollution. So that was fairly effective to get some of those schools going. Some were up in it well already, because they had just incorporated solar panels on all their roofs. Others had no idea that they could even have solar panels. There was a big range.

This work eventually led to a shift in policy across the county:

Jane: Well, I think [we] managed to shift policy so that all schools had smart meters fitted, so that was quite a major move in Hampshire, and then Chris does a great piece of work introducing all the children to their smart meter, what it looks like on the white-board and how you use it, and nobody uses them do they, until you show them.

The smart meter approach also appeals to Minstead's visiting students:

Jane: Well having the big smart meter up there, the kids get quite obsessive about it […] sitting there in the dark so we don't use any electricity [laughs].

On the one hand Minstead has this magical, other-worldly appearance steeped in long-forgotten history and myth, and yet it promotes cutting-edge scientific monitoring of fuel use not just in the Centre itself but in schools across the whole county. At some point the value of living more sustainably expresses itself in hard cash terms, which is a message that schools can understand and which, one assumes, leads to Minstead itself being seen as adding value.

Shifts in the Values of Visiting Staff and Students

Much of the success of a school's visit comes down to the willingness of accompanying teachers to embrace the Minstead values approach. Over the last 12 years Jane had seen changes:

Jane: I think we've noticed a change in that. So [there] used to be full buy-in [from teachers] and there was a lovely sort of match with our values, their values and the whole principle of what you come away for.
I feel it's harder for the teachers to settle into it now. They're coming in with a very much more sort of business attitude, the way they dress and everything's different. It's a different breed of person, and we've found there's been more mis-matches and a little bit more discomfort, because it's not quite what's happening at school anymore. This is quite different. [To Chris] Do you think that?

Chris: I haven't noticed that dramatically. I think we had one week where the teachers didn't get it. It was very uncomfortable from arrival to departure, and the review was pretty poor. The kids were brilliant. We enjoyed their company, they enjoyed our company. The kids got it. The teachers didn't. Bad review. That was a one-off, very much a one-off actually.

This difference in perspective of Chris and Jane likely reflects their different personalities and, perhaps, their different roles within the Centre.

Other changes in the behaviour of teachers reflect the rise in social media over the last 12 years.

Jane: I think back to technology, that the big difference is that the teachers are on their phones the whole time, whereas that wouldn't have happened in the past, which is a bit of a curtain between us and them, and sometimes it feels you want to say "give it up" [laughs].
JD: "The rule applies to you as well!"
Jane: Yeah.
Chris: And there's probably a few things, some teachers are blogging, some teachers are writing down, they're going to repeat the session and I'm always aware of that, but […] there's probably things that we can do in planning, [such as] leaving a note in their bedroom. "These things work well when you're on the trip. Please don't or please do…", and keep it positive as well.

Despite working together for more than 20 years and sharing so much in common, Jane and Chris have different views about a number of issues. This duality perhaps explains the Centre's ability to live, seemingly effortlessly, in the concrete everyday and in a spiritual, magical world into which children become almost instantly immersed. Perhaps the lack of access to social media encourages children to be more social and more reflective?

The Changing Context of Young People's Lives

In the intervening years since our first visit to the Centre, the UK has become a different place. These changes reflect political events as well as the rise of social media. We wondered what changes Chris and Jane had seen beyond the rise of social media.

JD: Have the kids changed, do you think?
Jane: It's interesting, isn't it? I think we're a bit protected here because we don't allow them to bring any of their technology and they don't do any gaming while they're here and they don't spend any money, so in a way we've built a bit of a wall around ourselves to make that bubble.
I think in general I might say kids are a little bit more namby-pamby, a bit over-protected from home, a bit less resilient, maybe not quite so, I don't know, quite so independent. I just feel it all the time. They don't know how to use their knives and forks or they can't tie their shoelaces or they come

in here and they eat food, "Oh what's that, somebody's not giving me exactly what I want". I don't know, it's a bit more molly-coddled I think.

And that might be all I would notice about them, because we're setting this new norm and they tend to just fall into it [laughs], because they're quite responsive at that age I find.

Chris: Yeah, I probably haven't noticed any changes in children for 20 years actually, but again that might be because I have a way of interacting with them that allows a response, and the response generally is honed, because you're trying to, again, win rapport so that you can move off physically with the group, or win rapport so that you're getting verbal responses.

And when I do my little introduction, I'll thumbs up for all the good things, think of one good thing, one problem facing the world from this age, from seven years old up to even teacher trainees, the list of things that comes up from 30 children hasn't changed enormously. Pollution is still [identified], wars …

Jane: How long have you been doing that?

Chris: A good decade. Maybe a decade, thumbs up, thumbs down, and that is a summary of the word sustainability, which I hardly ever use, but I try to squeeze it in now and then, sort of keep the good things, sort out the problems, and scaling that from the personal community to sort of global. Their list of what their problems might be facing the world hasn't changed enormously in the decade.

And they're quite hard hitting, everything from war, terror, well, terrorism is mentioned now, but it wasn't that mentioned 10 years ago.

Again it is interesting to note the differences between Chris' and Jane's perspectives. Is it the case that Chris' pedagogy works at a different level than Jane's? Is it that Chris is looking for an inner-child, an expression of childhood, that has changed little over time whereas Jane sees them with a different lens?

Chris' admission that he rarely uses the word 'sustainability' might appear surprising given that it is a key element of the Centre's *strategy* and appears on the Centre's website: "understanding the need to live sustainably". There may be no need to use the word 'sustainability', which is hardly part of the discourse of children aged 5–11 who are much more used to the notion of 'caring for the Earth'. Others have written about the inadequacy of sustainability and sustainable development, without suggesting what terms environmental educators could use.

Ethnic Diversity

Back in 2005, the catchment area for the Centre had little ethnic diversity. Times, though, have changed and the UK supports many immigrants including newcomers from Central Europe. We were interested as to whether this demographic shift had manifested itself at the Centre.

JD: And do you notice kids from different parts of the world now, different countries that you wouldn't have had 10 years ago?

Chris: Yeah [there] probably are actually.

Jane: Yes I think so. I mean the girl that's here this week […] is from Pakistan and she's never been in a forest like this before, which is amazing.

Chris: And we […] tend to do the Latin names, the badge name given out as names of other animals. So all the Polish kids, until they say "I know the name of an animal in Polish", you wouldn't have known because they haven't got a Polish accent […]

Jane: I think the only time we've found there's a bit of segregation is when we had the Southampton school, and there was a very big Polish element and they did tend to stick together, because I suppose they were speaking Polish, and then there were the other kids. So that has been more noticeable that there's more foreign children.

Our feeling is that the fact that the Centre works only with primary school children means that some of the issues UK society is facing may not manifest themselves as much as they might if the visitors were secondary-aged.

Pedagogy, Change and Taking Risks

While there are clear advantages for Chris and Jane of working at the Centre for more than 20 years there may also be some disadvantages:

JD: Isn't there a danger though that you, because the feedback is generally positive, that you don't change, you don't experiment or take risks?

Jane: Yes, I think that is a fear.

Chris: I think it's not just the feedback. It's being able to drive change and drive the experiment and the *ad lib* and how to do that when you are repeating it twice a week, groundhog day scenario basically, because you know certain things work, they're going to work again and if you find something new, whatever that new thing is and repeat it 10 times, it's just part of your package.

So I'll have phases of a year or so where I'll deliberately not plan something, but I've never yet done something like, okay kids, half an hour in the woods, over to you and let them play in the woods. I've not done that. And that's, why wouldn't I?

Give them the liberty […] If I see somebody doing something dangerous, I'll tell you [to stop] or trust them. It's a bit like playing in the back field. Why not liberate and [relax about] the risk taking bit.

And that's just one example of all the risks we don't take because we're not quite brave enough. We're not sure it's going to work, or we're wasting our time or the teachers' time. But by taking those risks, you open up whole new territories.

Jane noted an increase in regulations related to safeguarding children over the last decade:

Jane: I think the job has changed me. The job has changed me. The culture of health and safety has sat heavy a lot and it makes me more cautious. I didn't think like that when I started the job, so I'd have been much more willing to try any sort of experiment. I think you get so obsessed by it that it changes your attitude to things.

JD: And is that part of the safeguarding agenda?

Jane: Safeguarding and health and safety, yes, are the two big things.

Chris: But what I do out in the woods is such a low level danger, there are no injuries. In a decade it's one or two ambulances for a bash on the head. So my risks are very [small], very simple, go explore […]

We wondered how Jane and Chris felt that they themselves had changed:

Jane: I'm less of a risk taker, from what I was saying before. The responsibility sits on you a bit sometimes.

Chris: And I'd just like to be more of a risk taker and I'm taking the very smallest, little variations. Won't even call them risks [I'm] obliged to take those challenges and just try something new a bit more.

I would say I haven't changed dramatically over the last decade. I might even say I haven't changed at all in that the manner of delivery, separate from the content of delivery, is much the same. Make sure it's funny. It has to be funny because if it's not funny then it can get really dry, so making jokes for the children is a good part of it and a really good way of assessing what their level is as well, if they get a joke or don't get a joke.

Similarities with Other Pedagogical Approaches

Over the past decade the Forest School movement has become increasingly popular in the UK. We wondered whether Jane and Chris saw their approach as very different from Forest School (Morgan, 2018) or other approaches.

Chris: [Well we] do and we don't. I think I've been tempted to go on, be sent on training, two weekends and see what the Forest School package is, and it's kind of that child centred and it's bush craft orientated, and it's also regular repeat visits to a site that you know well, so there's aspects of Forest Schools that we, because we've got changing children that…

But also, you know, if we take a Forest School approach to show schools what they can do with their kids in their own grounds, and I haven't got my head around what Forest School fully entails in order to say we do or don't do, what they are, but there's elements of it.

And the teachers from Montessori schools come here and go, "Oh this is so like our school", but I wouldn't say I'm anywhere near knowing what a

Montessori school's full ethos might be, but there's an element of that magical quality, exploring, colourful, diverse, holistic going on.

Huberman's (1989) long-term studies of Swiss teachers showed that those who frequently tinkered with their pedagogy were more content than those who adopted a more conservative approach to their work. Both Chris and Jane seem to have made tinkering their default pedagogy and seem satisfied with their approach to the extent that they have not actively engaged with other educational approaches to any great extent.

Dealing with Difficult Issues

In the weeks before the 2017 visit, the UK had faced several terrorist attacks and had experienced a major fire incident in a block of flats in which at least 80 people had died. The UK was also (and still is) in the midst of political turmoil following from a snap general election and the aftermath of the Brexit vote. How, then, did Chris and Jane deal with these challenging issues?

JD: Has [Brexit] had any impact on you or the Centre?

Jane: Well, we were discussing this before. Nothing really tangible at the children's level.

Chris: During the vote and after Brexit, a few children would mention it, but you tend to have to cut those conversations short, because are you prepared to launch into a conversation with a group of children in front of their teachers about whether we should or shouldn't leave the EU?

And it just doesn't, like Trump, the children will say something negative or positive, negative about the Trump situation, but you can end up just having a bit of a slanging match, so unless you're going to construct that as a good debate, which is unlikely here, because there are other places for it. So that's probably, no it hasn't had a big impact.

Probably the biggest impact is fires and terror attacks, and the minute's silence which suddenly became—every week over the last few months there's been a minute's silence, a few which we did, but then the last few we didn't or [they] slipped by.

JD: Because?

Chris: It didn't seem an appropriate thing to do. It didn't feel like it was coming from the right place to have that minute for that event for those children at that time, in that the schools may or may not have done something.

Jane: We're quite protected from the news here. We don't tend to talk about current events that much, do we? You know, if there are big national disasters, they don't, I don't think they should come from us necessarily. They're not watching telly and they're not listening to the radio, so it's going to be from parents when they get home.

Chris: But there's a rightness and a wrongness in that. It's finding the way of breaking news to everybody or referring to something.

Part of the magic of the Minstead experience, in other words, is that it is cut off from everyday life. This suspension of the everyday is a powerful pedagogical tool that opens up spaces for reflection. We tend to use silence to show respect for the dead and dying rather than to focus on valuing life and the living.

Religion and Evolution

We commented back in 2007 that it would be difficult to imagine that the parents of visiting students would not want their children to value the planet, resources, or other people, but we wondered whether there may have been values that are implicit in activities carried out in the name of science in schools or study centres that parents might wish to be informed of in advance. This visit we asked specifically about the teaching of evolution and a rise over the last 20 years or so of creationist views emerging in schools:

Chris: I talk about [evolution] most weeks because I've been reading a few books on Darwin. It's a bit of a revelation, so I'm taking the moths out of the moth trap, as moths are evolving as we speak. It's not 10,000 years, it's hourly that things are happening.
And I would refer to who made the world or how did the world come to be, and the children will say "God made the world" fairly regularly. I'll sort of refer to trolls and fairies and do you believe in them, and they don't […]
So it's not talking about creationism or Darwinism, but it's referring to, "Oh there's different views of the world", and again it dips into that sort of atmosphere of what's the world made up of […]

JD: So what's your philosophy then? There are just many ways of looking at the world and explaining the world and they're all equally valid? Is that what you want kids to think?

Chris: Yeah. I'd go for that one […] you can view the world in so many different ways. Personally I don't think there's any god or a sentient being.

The UK is an increasingly irreligious country with church attendance at record lows (British Religion in Numbers, 2017). The particular ethnic groups that are most associated with fundamental Christian beliefs tend not to live in rural Hampshire. It is not surprising, therefore, that strong opposition to scientific explanations of the origins of the universe has not emerged among Minstead's visitors.

Final Thoughts

Jane: I think I've become increasingly saddened at how disconnected the children are to the planet, and how discordant some visiting groups are. And how much you have to do to, sometimes, even to become a working group before you can start to entertain any of the wider environmental thoughts that we have been talking about today. It seems a sad situation that children are so out of sorts with themselves and their environment that our week needs to spend such an amount of time trying to socialize a group before moving on any further.

This statement was made in 2005 not 2017. Things haven't changed; they probably have not worsened but neither has much improved. What is impressive is that Minstead has survived despite other centres closing. It is resilient, it is sustainable. Minstead's unique approach, driven by Jane and Chris's unshakeable values, has provided thousands of young people with inspiring insights into science, geography and the environment.

While both Chris and Jane are aware of the changing contexts affecting the lives of their young visitors, their strong values, which are manifested in all that they say and do, have remained intact over the last 12 years. They do, though, see the world through different eyes, but together this plurality of perspectives on a number of issues may well make the Centre more flexible and more resilient.

We finish with a quote from Jane from 2005. To us it is as current now as it was then. And it is a call for arms that still remains unheard.

Jane: It makes me think whether we should be more actively political. Whether your best tool of change is to work with individuals and hopefully make some small personal change or whether we should be lobbying more at parliamentary level and having a voice in that way. It is a constant frustration to me how little focus has been given to education for sustainable development at a national level.

Methodological Note

As before, we regard this study as both an *intrinsic* and an *instrumental* case study (Stake, 2000). It is an intrinsic case study in that it is carried out:

> because one wants better understanding of [a] particular case. It is not undertaken primarily because the case represents other cases or because it illustrates a particular trait or problem, but because, in all its particularity and ordinariness, this case itself is of interest. (p. 237)

It is an *instrumental case study* in that it provides "insight into an issue or refinement of theory" (p. 237). As we explained more than a decade ago:

a case study of the particular is drawn upon to address and/or elucidate more concisely some essential, underlying principle, issue or point the author seeks to highlight, even to the extent that general features or lessons may be drawn. It is about deepening understanding and knowledge of the issue at focus. (Dillon & Reid, 2004, p. 26)

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Part IV
Values of Science Education Systems

Cathy Buntting

It would be short-sighted to consider ways in which to enhance the role and place of values in science teaching and learning without also being cognisant of the socio-political context in which the science curriculum is constructed and enacted, whether in formal or informal settings. Perhaps this is one reason why the chapters that contributed to our first values book—*The re-emergence of values in science education* (Corrigan, Dillon, & Gunstone, 2007)—were grouped into sections relating to the intended, implemented and attained curriculum. More than a decade later, the place of values in the intended curriculum for school and out-of-school science programmes seems to be shifting towards more open, explicit inclusion of values discourses (see Parts 1 and 2 of this volume), and some professional learning programmes deliberately set out to identify and explore teachers' values in relation to their practice (see Part 3). However, it is only when the wider education system, including assessment practices, authentically recognises the development of students' values discourses that wide-scale change will occur.

The final section of the book therefore turns to the values of science education systems, adopting a more wide-angled lens than the one used in the earlier chapters. Here, the socio-political context of curriculum construction comes to the fore. This is important, since:

> The curriculum is never a neutral assemblage of knowledge, somehow appearing in the texts and classrooms of a nation. It is part of a selective tradition, someone's selection, some group's vision of legitimate knowledge. It is produced out of the cultural, political, and economic conflicts, tensions, and compromises that organize and disorganize a people. (Apple, 1993, p. 1)

In Chapter "Intended, Achieved and Unachieved Values of Science Education: A Historical Review", Gillian Kidman and Peter Fensham present an historical review of societal changes and the impacts that these have had on the aims of school science, and therefore the value that is attributed to science education. Using examples from the US, Britain and Australia, they trace the pendulum swing from an early curriculum that emphasised the history of science and its applications to society (pre-1950s), through to a focus on the concepts and principles of science for growing scientists (1950s–1970s), back towards notions of ‘science for all’ (1980s) and (more recently) specific inclusion of values and the human elements of scientific endeavours. The burgeoning STEM movement, however, tends to be fuelled at the system level by economic arguments and Kidman and Fensham predict that linking STEM education tightly with future employment objectives is likely to lead to a science education that values

> (a) the content knowledge relevant to the solving of S&T problems, and (b) the skills of problem solving, communicating, creativity, metagcognition and critical thinking, and the practices of working individually and collaboratively—skills that have not previously been emphasised in school science. (p. 183)

Specific examples of each pendulum movement are provided to demonstrate the different value that is attributed to science education based on the socio-political and economic context at the time, and the implications any shifts in the aims of science education have for curriculum as well as pedagogy and assessment. Specifically, Kidman and Fensham note that implementation of changes in curriculum goals are most effective when the curriculum changes have status, there is sufficient professional learning available for teachers, and assessment authentically supports the aims of the curriculum.

In Chapter “The Place of Values in the Aims of School Science Education”, Jennifer Mansfield and Michael Reiss also explore the aims for school science, through the lens of updating Michael’s original presentation (Reiss, 2007) of a range of possibilities, which depend in the first instance on the aims for education in general. Possibilities for education in general are broadly grouped into those where the intention is to develop the individual for their personal benefit; and those where the intention is to develop individuals so that they may collectively contribute to wider national goals. The possibilities Mansfield and Reiss then outline as aims for school science include the supply of future scientists, scientific literacy, individual benefit, democracy, social justice and socio-political action, and criticality. Although this categorisation is an over-simplification, and the categories are clearly not mutually exclusive, Mansfield and Reiss use them to open up space for readers to critically reflect on their own values for science education, and the values inherent in their local educational context. This critical reflection is important, since “The place of values in the science curriculum depends critically on one’s views of the aim(s) of science education” (p. 206).

The book concludes with Chapter “Exploring Values Through Lived Experiences of the World Heritage Site of Petra: A Case Study” by Angela Fitzgerald and Diana Abouali, about the complexities inherent in the notion of values. The narrative is set in the rich context of Petra as a World Heritage site where multiple stakeholders hold many and varied values in relation to the use and (or) preservation of this historical, cultural, scientific, educational treasure. For instance, UNESCO’s designation of World Heritage status in 1985 led to a dramatic increase in visitor numbers, eliciting concerns about dangers resulting from heavy human traffic. However, the increase in international tourism has had significant economic benefits for the local community, and Jordan more broadly. For locals, five of whom were interviewed for this chapter, there are values around identity and emotional connection (being proud of their home, upset when visitors don't appear to value its significance or beauty), livelihoods (the economic benefits of tourism), and aesthetics, history and culture. For those charged with managing the site, there can be tensions between short-term economic gains and long-term preservation goals. When considering the values of the various stakeholders (including local inhabitants, Jordanians, visitors, archaeologists, UNESCO), questions arise around whose values should be prioritised, and why. At its simplest level, the chapter raises awareness of the different value sets that may exist, and could be used as a case study to explore with students the importance of science-rich locations, and the impacts of visiting them. More deeply, the narrative highlights the importance of considering values as influenced by the lived realities of stakeholders. Such an approach highlights the role context plays in meaning-making, and may lead to more just engagement in socioscientific issues. It is this kind of science education that is promoted by many of the chapters in this book.

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Intended, Achieved and Unachieved Values of Science Education: A Historical Review

Gillian Kidman and Peter Fensham

Introduction: Societal Change and Science Education

This chapter is about how major societal changes can lead to changing demands on schooling. Commonly, when such a demand is recognised and Science is seen as being a key to it being met, a science expert group is often established to determine the role or purpose that science education could play in response to the demand. In articulating its advice, the expert group argues for the value(s) that changes to the content for science will have for the learners to achieve learning outcomes that meet the demand. This advice is then tends to be transferred to the government bodies responsible for Education (and the School Curriculum) to respond to the recommendations. Their implementation response will indicate those recommendations that have value for the Government.

In this chapter we review a number of examples of these societal demands involving science education since the 1960s. Our examples are drawn from the United States of America and Britain, influential external sources for the case of Australian science education, the context for our final example. We assess the educational responses in each case and show that they have resulted in mixed success. Our assessment is used to ensure that more of the intended recommendations become general practice in science classrooms.

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D. Corrigan et al. (eds.), *Values in Science Education*,
https://doi.org/10.1007/978-3-030-42172-4_11

1950s–1970s: Societal Demand for More Scientists

Context

With the end of the Second World War in 1945, there was a strong awareness of the decisive role that the sciences, particularly physics, had played. The rapid emergence of the Cold War meant there was an urgent political demand on both sides of the Atlantic for more scientists. University science departments quickly began to reform their teaching of the sciences, so as to bring it up to date.

At this time, as a consequence of the economic depression in the 1930s and the years of the Second World War, there had been little or no reform of science courses in senior secondary schools, although these were seen as essential preparation for the further study of the sciences at university. Academic scientists in both the USA and in Britain recognised this disjunction as inhibiting the increased demand for more scientists and began to campaign for a reform of the school teaching of the sciences to ensure academic maintenance across the two sectors.

The emergence of the Space Race and the successful launch of the Sputnik flight in 1959 added extra political support for these reforms, and funds were made available in both USA and Britain on an unprecedented scale for projects to design and produce support materials for the necessary changes in school science education. The National Science Foundation in the USA and the Nuffield Foundation in Britain administered these funds, and they encouraged scientists to work with school science teachers in developing new school science courses, together with texts and other teaching materials that exemplified what scientists deemed necessary in the science classroom (de Hart Hurd (1969) for the USA, and Waring (1979) for Britain). The initial projects in both the USA and Britain were aimed at the minority of school students who potentially would go on to university studies in the sciences.

Intended Value of Science Education

At a defining meeting for the American reforms in 1959, at Woods Hole Massachusetts in USA, the intended value for science education was summarised as "a desire to examine the fundamental processes involved in imparting to young students a sense of the substance and method of science" (Bruner, 1966, p. vii). This meant that a more conceptual introduction to the knowledge of the disciplinary sciences was valued, along with a greater use of laboratory exercises designed to support the learning of this knowledge. The basic concepts and principles of the sciences became the content for teaching, almost entirely supplanting the previous emphases on descriptive science, the history of science, and its applications in society (Fensham, 1973).

Education Response

In both the USA and Britain, bodies responsible for school science education greeted these new science courses positively and reinforced their introduction in schools by adapting their assessment. The introduction of these new school science courses was successful for the following reasons:

- the new curricular content had the authoritative status from the science academies,
- new high quality texts and teachers' guides were available, and
- interested university scientists and teachers from development projects were influential on the curriculum and assessment committees for these school science subjects (Fensham, 1980).

These contributing factors are not evident in subsequent sections. In addition, since the target student group of more academically oriented students was not large, only a relatively small number of existing science teachers needed professional development for these new courses. Teachers adapted quickly to what became the accepted form of senior school science education, not only in its countries of origin, but also in many other countries who followed their educational lead. For example, the state authorities in Australia had, by 1970, moved to using the overseas support materials, or local adaptations of them, along with professional development of the teachers.

Developing and changing science curricula on this scale does, nevertheless, take time and during the subsequent decade of the 1970s, a number of other societal changes were coalescing to create new demands of science education.

1980s: The Demand for a Science for All

Context

In the 1980s, technologies were rapidly changing the processes of economic production, with implications for how young people needed to be prepared for work. Technological products were impacting on the social and personal lives of citizens (e.g., personal computing, the Internet). Furthermore, there was a growing awareness of the ways in which science and technology (S&T) were impacting both positively and negatively with the health of the environment.

In many industrialised societies, such as in Europe, where this S&T impact was most evident, positive economic conditions had enabled increasing numbers of students to undertake more years of secondary schooling. For most of them the conceptually heavy approach to teaching of the sciences was proving either unattractive or unsuitable for their needs as future citizens.

Table 1 The common societal demands that call for a *science for all*

Demands	Aust.	USA	Canada	Britain
Basic and essential skills	✓	✓	✓	✓
Economics and prosperity	✓	✓	✓	✓
Everyday life	✓	✓	✓	✓
Whole population	✓	✓	✓	✓
Limitations	✓	✓	✓	✓
Impact of S&T	✓		✓	✓
Applications	✓		✓	✓
Effectiveness of education	✓	✓	✓	
Working life	✓		✓	✓

The prevalence of S&T in everyday life called for a study of science that would meet the needs of all students—a *Science for All*. Scientific committees were established in USA (1983—National Science Foundation), Canada (1984—Science Council of Canada), and Britain (1985—The Royal Society), while in 1978, Australia established the Curriculum Development Cooperation, to elaborate on the demands and the values that an education in Science needs to meet the demands.

The resulting reports each linked S&T as a duo affecting the prosperity of the economy and the everyday personal and working lives of students and citizens. Table 1 indicates the commonality of these committees' understanding of the demand.

The committees all refer to the need for the population at large, as individuals and citizens, to have some understanding of S&T in order to effectively manage the tasks they must perform and the decisions they must make with respect to the environment and human welfare. Three of the reports refer to a need for both the power and the limitations of S&T to be appreciated. Each of the reports assume that the continuing societal need for science-based professionals will be met by more specialised education in the sciences in the senior years of schooling.

Intended Values of Science Education

The reports go on to list the values that an S&T education would have in equipping all students for these societal demands. There is significant overlap in how these values are expressed so the comprehensive Canadian report, *Science for Every Student—Educating Canadians for Tomorrow's World* (Science Council of Canada, 1984), can be used to summarise these values in its 'goal of scientific literacy for all'.

Science is taught to:

- Encourage full participation in a technological society—students need to learn about S&T's influence on contemporary society so that control of these potent forces are not left to a technocratic elite. This learning should enable everyone to understand the ways in which they can change their environment;

- Facilitate entry to the world of work—students' learning needs to include technology —the application of disciplinary scientific knowledge to achieve a desired result. Technology is a key factor in the future employment of large numbers of students and, they must learn how it affects the workplace, influences the nature of work and opens new careers;
- Promote intellectual and moral development of individuals—students' intellectual development can be divided into the acquisition of knowledge and the development of intellectual skills, but the two must not be divorced from each other. Science education needs to encompass both these aspects in order that students can share in the development of ideas that explain and can be used to control how things work in the physical environment; and.
- Train those with a special interest in Science and Technology fields—Science education, at all levels of schooling, should be a preparation and encouragement for students to learn about science throughout their lives. It should be linked to other areas of study to avoid premature specialisation that tends to isolate subject areas. It should enable students to question the basis of their own scientific knowledge (p. 10).

The reports all suggest changes that would be needed in both science content and pedagogy related to the age of the learners as they proceed through the years of schooling. In the primary or elementary years, the S&T education should focus on phenomena in the local environments of the students so that students can collect and process primary data. In the secondary years the focus should be on investigating applications of S&T in both the local and wider society, including a growing awareness on how S&T and society have, and do, interact to make a cultural heritage. More generally, the curriculum at each stage should develop knowledge of science and scientific problem solving skills, an appreciation of science's strengths and limitations, and personal and community decision making about real life S&T issues.

Education Response

Not surprisingly, the educational authorities did not immediately respond to these detailed suggestions for changing the nature, content emphasis, and pedagogy of a school science education to meet the needs of all students. Nevertheless, in a number of countries science teachers and their professional associations saw merit in the proposed changes and initiated responses that reflected the new values. Their responses quickly became known as the *Science/Technology/Society (STS) Science Movement,* and with private funding some exemplary materials were developed for teaching versions of the new *Science for All* in the secondary school years.

For example, in The Netherlands, the **PLON** project[1] for physics used an approach that aimed to assist students to see relevance of physics content because it was related to familiar real life S&T contexts which, in turn, allowed the physics content to better understood (Eijkelhof & Kortland, 1988). In Britain, the Association for Science Education (ASE) launched a similar project entitled *Science and Technology in Society (SATIS)* and its materials assisted interested teachers to make some of the recommended S&T links to students' current and future lives (Holman, 1986; Hunt, 1994).

Before the formal educational responses to the *Science for All* challenge arrived, other societal demands concerning mass primary and secondary education were looming. For example, in Britain the Conservative Government became committed to encourage a 'free market' in school education, which would allow parents to choose schools based on their measured performance. This led to the need for a National Curriculum with standardised content for teaching that would lead to students' learning that could be assessed and made public in 'league tables' of each school's performance. In this curriculum for England and Wales, Science and Technology were identified as separate statutory subjects. This recognition of Technology as a distinct subject grew out of a link that could now be seen between hitherto less academic subjects like Art/Craft, and Design and Information Technology. This alternative view of 'Technology' meant that Science in the National Curriculum could no longer be explicitly linked with its *'Applications of Science'* in the STS initiatives. Science was, however, now mandated for teaching and learning for all levels of compulsory schooling, but with a form of content that simply stretched down across the conceptual knowledge of the established disciplinary sciences. It was because of these wider social influences that Layton (1994) subsequently described STS as a movement overtaken by history.

The partial response in England and Wales influenced how the *Science for All* recommendations fared in Australia and other countries. They elevated the status of the teaching of the technical arts with IT elements into a subject called 'Technology' and mandated the teaching of Science across all the compulsory schooling years, giving it the status of a *literacy* that hitherto had only been associated with language and number learning.

The term *scientific literacy* quickly became associated with a number of quite different learning outcomes. For some it gave *Science for All* a more operational sense, for others it was about confident knowledge of the disciplinary sciences, and for yet others it meant the inclusion of more *Nature of Science (NOS)* (Gräber & Bolte, 1995). A decade later Roberts (2007), a much earlier discussant of the term, clarified this debate by making a distinction between *Scientific Literacy 1 (SL1)*—a literacy in the scientific disciplines—and *Scientific Literacy 2 (SL2)*—a literacy in the science associated with real life S&T situations and issues. This distinction between *SLI* and *SL2* will be used in the **Discussion** section of this chapter.

[1] PLON is an acronym for Project Leerpakket Ontwikkeling Naturkunde (Learning package for the development of Physics)

Late 1990s: A Societal Demand Revisited

Context

As the 1990s progressed a number of science educators in Britain became increasingly concerned about the inadequacy of the science education in the National Curriculum and its failure to respond to the values suggested by The Royal Society (1985). They set out these concerns and a number of recommendations for further reform in *Beyond 2000—Science Education for the Future* (Millar & Osborne, 1998). They reiterated the general demand of the 1980s that all students need to have a broad general education that includes Science and enables them to gain good communication skills, adaptability, and a commitment to lifelong learning. In view of this demand they argued that the current form of science education was outmoded and urgently needed to be reformed. The present focus on conceptual scientific detail too often meant that the major themes and ideas of Science have been missed.

Beyond 2000 recognised the importance of schools for preparing future research scientists and other science-based professionals and it proposed the needs of students interested in these careers could be met by offering this minority additional, specialised education in the sciences. The report's primary concern was, however, again with the ever-growing importance of scientific issues in everyone's daily lives. This demands a populace who all have sufficient knowledge and understanding to follow science and scientific debates, and to engage with the issues S&T poses for them individually and for society as a whole.

Intended Values of Science Education

Beyond 2000 (Millar & Osborne, 1998) presented the values that the reformed science education should have:

- Since science and technology are commonly seen as paired as a single entity in society, they should likewise be linked in science education as Science and its technological applications;
- It should deal with major themes in which people are already interested, or can readily be interested—*life and living things, matter, the Universe, information,* and *the "made-world";*
- In the early school years, Science's primary importance is to provide a framework for developing children's innate curiosity about their natural environment; and.
- For older students it should provide (a) a greater awareness and experience of how scientific inquiry is conducted and (b) some understanding of the social processes internal to science itself, which are used to test and scrutinise science knowledge claims before they are widely accepted.

In relation to the pedagogy of science teaching and learning, *Beyond 2000* recommends that much greater use should be made of the narrative form—the world's most powerful and pervasive way of communicating ideas, but not often used in science classrooms.

Education Response

Anticipating that a response to *Beyond 2000* would require substantial and hence unlikely changes to the national curriculum, a group at York University (with the help of funds from The Salters' Company) established a project for a new approach to science education for 14–16 age students, an age group that was free of the constraints of the national curriculum. This approach, entitled *twenty-first Century Science* included a number of the *Beyond 2000's* suggestions for new content and pedagogy and, importantly, solved the persistent problem of the needs of the two different groups of students. A mandatory Science course was offered for all students and optional courses of further science study (including the separate disciplinary sciences) were available for students to choose. At this senior level of schooling in England and Wales, assessment was the responsibility of several examination boards so that the project was able to achieve a type of assessment that authentically supported its intentions. Since its inception, the number of schools offering *twenty-first Century Science* has expanded rapidly (Millar & Osborne, 2006).

2000s: The Demand for an Australian National Curriculum

Context

Demand for a national curriculum for Australian schools had been on the political agenda since the late 1980s. A number of factors drove this demand, including increasing mobility of families across state boundaries, and employers' concerns about what different states were certifying as students' learning. However, with states having constitutional responsibility for school education developing a national curriculum was not going to be straightforward. Meetings of a Ministerial Council (MCEETYA) comprising the state ministers of education and the federal one issued the *Hobart Declaration* in 1989 that affirmed that Australia's social and economic future demands that every citizen, through high quality schooling, has the necessary knowledge, understanding, skills and values for a productive and rewarding life in an educated, just and open society. Its outcome was an aborted attempt in the mid 1990s to develop a national curriculum. In 1999, however, the Council then issued the *Adelaide Declaration*, which reaffirmed its intentions and the demand for a more national approach to the curriculum was again on the agenda.

Table 2 Australian curriculum: science rationale and aims

Rationale	Aims
Science is a:	Science aims to:
way of *answering interesting and important questions* about the biological, physical and technological world	provide opportunities for students to develop an understanding of important science *concepts* and *processes*, the *practices* used to develop scientific knowledge, science's *contribution to our culture and society,* and *its applications* in our lives
reliable basis for action in our personal, social and economic lives	
dynamic, collaborative and creative human endeavour arising from our desire to make sense of our world through exploring the unknown, investigating universal mysteries, making predictions and solving problems	support students to develop the scientific knowledge, understandings and skills to *make informed decisions about local, national and global issues*
valuable pursuit in its own right	
source of critical and creative thinking skills	encourage students to participate, if they so wish, in science-related careers
challenge to identify questions and draw evidence-based conclusions using scientific methods	

Source: National Curriculum Board, 2009, p. 5

Finally, in 2008 there was enough agreement across the political spectrum for the national Labor Government to make the decision to develop a National Curriculum (MCEETYA, 2008). Science was designated as one of its four priority Learning Areas, along with English, Mathematics and History and as a mandatory subject for all students across the compulsory years of schooling (Years 1–10). Expert groups were convened to provide a *Rationale* and *Aims* (or *Values*) for these priority areas. For Science, the Expert Group consisted of leading science teachers, science educators, and representatives of the academic Science community.

Intended Values of Science Education

The resulting *Rationale* and *Aims* for the Australian Curriculum: Science are summarised in Table 2 (emphasis added by authors).

The Expert Group recommended that the content of the Australian Curriculum: Science be organised around three interrelated strands: Science Understanding, Science Inquiry Skills, and Science as Human Endeavour. The titles of the first two strands had a somewhat familiar ring, but the third strand was new and intended to enable the rather wider aspects of Science that are intended in the Rationale and the Aims. Furthermore, it suggested that this content for learning across the strands should be drawn from S&T issues that were relevant for each year of schooling.

Education Response

In 2011 MCEETYA adopted a Science curriculum for each year of schooling, in which the three strands had separately specified learning content. In contradiction to the suggestion for S&T issues to define the science content, the *Science Understanding* strand was set out in the established form of a conceptual introduction to four disciplinary sciences (Biology, Chemistry, Earth and Environmental Science and Physics). Because the second and third strands are now not linked to specific science knowledge, their ability to support learning in the intended wider senses of *Nature of Science (NOS)* that are emphasised aspects in Table 2 has been seriously weakened.

Elsewhere, one of us has outlined the bureaucratic processes that led to this disjunction between the Expert Group's intended values of science education and a content for teaching and learning that maintained a familiar status quo (Fensham, 2013).

Late 2000s: A Demand for a Twenty-First Century Workforce

Context

At the same time as Australia's national curriculum was being developed, the twenty-first Century became synonymous with international changes in society, in the economy, the nature of work, and in personal life, not least because these changes are linked with the digital age, including the emerging role of social media. These new demands for an educational response have crystallised into the acronym STEM (standing for Science, Technology, Engineering and Mathematics). This latest societal demand relates not only to the education of these fields in schooling but also to tertiary education beyond school. The demand is regularly expressed in terms of sets of skills that STEM learning should offer—skills that are argued to have increasing value in many different occupations and industries.

In Australia, the Government announced a long-term strategic view for developing these skills in all school students and for broadening the social spectrum of STEM professionals (Office of the Chief Scientist, 2013). To meet these demands the Australian education system was called upon to provide the broad base of STEM skills required for the workforce of the future (Siekmann & Korbel, 2016) and to increase student interest in further studies in the STEM fields.

Intended Values of Science Education

For science education in Australia, the authoritative intentional changes to meet the demand for STEM professionals have been expressed as three broad aims:

- All students to develop a positive attitude towards science,
- More students to be encouraged in their study of these subjects and to continue them in tertiary education to meet the increasing economic demand for such skilled professionals, and.
- All students to acquire from these school subjects, knowledge and skills and attitudes that relate to their future employment in a more general sense. (MCEETYA, 2008, p. 8–9).

At the more detailed level, what follows from this link with the needs of employment as valued in science education is (a) the content knowledge relevant to the solving of S&T problems, and (b) the skills of problem solving, communicating, creativity, metacognition, and critical thinking, and the practices of working individually and collaboratively—skills which have not previously been emphasised in school science.

Education Response

Following the general support for STEM by MCEETYA and by the Office of the Chief Scientist, there has been a burst of responses and a flow of funds for a variety of STEM activities—projects, professional development, and STEM conferences. Several Australian universities have appointed senior staff to have a responsibility for promoting STEM. This is not dissimilar to the outbreak of activity the STS movement generated in the late 1980s, but now with more authoritative backing but a more opaque sense of educational direction.

Ritchie (2018), in a review of these STEM initiatives, pointed to a number of uncertainties concerning the original demand and the uncoordinated responses. For example, in the current state of science education, the first two aims above pose major problems. The attitudes of the majority of students to Science in western countries is currently by no means positive, and a number of demographic groups of students are not currently aspiring to tertiary scientific studies. Furthermore, although it is a fact that graduates in Science are employed in a diverse range of positions, the expanding demand is not yet evident. The third aim would require a considerable number of changes in the current practices of science education, since its emphasis on teaching *science content that is associated with the solving of S&T problems* harks back to the earlier intentions to value this type of science teaching and learning. As discussed earlier in the chapter, this shift in content has proved to be elusive internationally and indeed, was rejected just a few years ago in Australia's National Science Curriculum. Finally, skill learning in science education is still largely confined to a narrow sense of scientific inquiry, leaving a very large gap in relation to the skills identified above.

With respect to the skill of *working together collaboratively*, Ritchie, Rigano, and Duane (2008) and Rennie (2007) have reported good examples in the primary and middle school years, but at the more senior levels of science education, the practice, learning and assessment of science are almost always very individual activities. The state of Queensland in Australia is an exception, encouraging and rewarding cooperation, communication, and higher order critical thinking (Fensham & Bellocchi, 2013). Kidman and Casinader (2017) describe the values for Queensland science education in the lead-up to the Australian curriculum, in which Science students completed up to four extended experimental investigations (EEIs) during their final 2 years of schooling. In the compulsory years of schooling, Queensland students were encouraged to think creatively and work cooperatively in classrooms where the teachers' locus of control was varied—thus facilitating the inquiry learning process. Despite their conjunction with the STEM aims, the maintenance of these features in Queensland is now under threat following an attack by some traditional academic scientists. In 2020, Queensland will require its secondary school students to undertake an external examination—50% of the final grade in the Sciences and Mathematics. The last external senior examination in Queensland was in 1972 following the recommendations of the Radford Committee (Department of Education and Training, 2019). It is to be hoped that the Queensland's teaching and learning does not suffer as a result of the assessment practices reverting back 50 years.

As the demand for STEM intensifies and responses to meet it gain momentum in a number of countries, it is salutary to note that Zeidler (2016) has pointed out that STEM's valued aspects need to be appraised not only on their own terms but also in terms of other hard won and valued aspects of science education that they could displace, ignore or downplay.

Discussion

The above examples of intended new values of science education have all come from authoritative scientific bodies charged with recommending how the science education being practised needs to change to meet a new societal demand. In each example, they have been accompanied with suggestions for changing the teaching and learning of science to achieve these new values. The recommendations about changing the science content, the role of the practical laboratory, and the pedagogical link between them were substantial. In the first example from the 1950s to the 1970s, the national and state educational bodies responsible for the school's senior science curriculum responded positively, so that the new values fairly quickly became the norm for the teaching of the sciences to more academically-oriented students in secondary education. In each subsequent example, the student population target for receiving these new values has been the whole student body at all levels of compulsory schooling. This means an education response of an order of magnitude different from the first example, when only a small academic group of students and their teachers were involved.

For each of the *Science for All* examples the intended content for Science was to be drawn from the interactions of science and technology with society, rather than the disciplinary sciences. This means inter-disciplinary concepts as well as the disciplinary ones became part of the required content. Instead of laboratory experiences that support conceptual science, the students' practical experience is to develop their sense of *the processes of scientific thinking, the skills of inquiry, problem solving, decision making,* and of *the reasoning that underpins scientific knowledge claims.*

The Challenges

The various intended changes in the values of science education, and the target scale of their relevance, has proven very difficult for educational authorities. In many countries, the most they have achieved is to institute Science as a mandatory course of study for all students throughout compulsory schooling. Almost without exception they have, however, shied away from the recommended changes in science content, practical experience, and pedagogy, that would enable all students to have the benefit of the new values. Without a more substantial response from educational authorities, it is not surprising that the change to mandatory disciplinary Science has proved difficult for many teachers. Elementary or primary school teachers have trouble, as they often have weak Science backgrounds. Those teaching the secondary years tend to have stronger Science backgrounds, but have trouble making the unsuitable content motivating to their students. Even exemplary science teachers can find the wider recommendations about content, practical experience and pedagogy raise major epistemological and practical difficulties. The wider recommendations give a priority to aspects of science knowledge that are unfamiliar to even well qualified science teachers. They are based on real life S&T contexts that have not been a focus in these teachers' own science learning. In addition, they expect a familiarity and confidence about scientific processes of inquiry and problem solving that is beyond what most qualified school science teachers have personally experienced (Kidman & Casinader, 2017).

As noted earlier, Roberts (2007) used *Scientific Literacy 1 (SL1)* to characterise the science familiar to science teachers through their undergraduate studies in the disciplinary sciences and *Scientific Literacy 2 (SL2)* for the science of S&T interactions that all students now need to know. The paradox of this difference between science teachers' knowledge of Science and the S&T Science knowledge their students need, is still essentially unresolved internationally. After 30 years it might almost be concluded that these new values are not possible to teach.

The Possibilities

The case literature of science education, however, provides considerable evidence to the contrary. Over the period we have reviewed, some science teachers have welcomed the new values, and taken up the challenge and opportunity to modify their teaching of science accordingly. Often these innovative teachers have worked with the support of their Science Teacher Associations, and of science education researchers, who have then shared these initiatives more widely by publishing what had been achieved in these classrooms. Above, we referred to how, in a number of countries, the STS movement inspired teachers and science education researchers to begin to teach in a way that values students' need to learn about S&T's influence on society so that control of this influence is not left to commercial forces. For instance, soon after the *Beyond 2000 report,* Driver, Newton, and Osborne (2000) provided a basis for teaching the role of argument in science. This was quickly followed by a number of reports of teachers, at different levels of schooling, enabling their students to gain "some understanding of the social processes internal into science itself which are used to test and scrutinise knowledge claims before they are widely accepted" (p. 8). Likewise, following leads from Sadler and Zeidler (2005) in the USA, and Ratcliffe and Grace (2003) in Britain, a number of science teachers have extended this value of science by introducing socio-scientific issues (SSIs) into their science teaching. Such issues include themes in which students are already, or can be, interested in so that a fuller sense of the use and abuse of scientific evidence can be developed.

These positive responses from science teachers provide evidence that, with adequate support, they can offer their students at least some of these intended new values of science education. The students in these innovative classrooms have, indeed, been fortunate, but the majority of their peers in other classrooms and schools remain untouched by these valued aspects of science education. Buntting and Jones (Chapter "Using Biotechnology to Develop Values Discourse in School Science" this volume), outline the case of the Biotechnology Learning Hub in NZ, which illustrates again, how the new science values the Hub offers, have been taken up by alas, only a minority of innovative teachers.

The Contemporary Educational Context

In the light of this positive, albeit small scale, evidence for the practicality of teaching the new values, it is time to take up the issue of the persistent inability of educational authorities to respond to the repeated recommendations for the interactions of real world S&T, etc., to become the central focus of school science education.

Four critical factors enabled the successful adoption by educational authorities and teachers of the new values demanded in the 1960s. These were *(a) the status of the new Science content, (b) the education of existing and new science teachers in the new Science content, (c) professional development in the pedagogies for the new values,* and *(d) the development of forms of assessment that authentically supported the new science learnings.* These are now considered in turn in relation to the contemporary educational context.

The major source of status for school Science is the academic scientific community. In the 1960s it came from interested academic scientists whose standing in the disciplines of Science gave the new content status and value (*factor a*). These scientists also ensured that all new graduate teachers for the target minority of students would, on account of their undergraduate studies in the sciences, become familiar with the new content and values (*factor b*). Thirdly, they also raised very large sums of money from industry and government to produce high quality support materials and programmes of professional development to assist existing and new teachers (*factor c*). In this example, the educational authorities had, thus, almost nothing to do, except to adopt what was offered, and to institute new assessment modes that were emerging at that time for the learning of this conceptual science (*factor d*).

Since the science education of the whole population of students is the target for all the subsequent sets of recommended new values, this is clearly a responsibility of authorities within Ministries of Education, but we suggest our examples provide the evidence that such bodies lack the resources to undertake it seriously. As educational bureaucrats they cannot provide status for the new Science. Its status and sense of worth among teachers has, as in the 1960s, to come from the community of Science. Fortunately, there are now large numbers of academic and applied scientists who work on interdisciplinary issues, and whose research is directed to real world S&T issues—*Roberts' SL2*. These types of scientists have hitherto only been sporadically linked to school science education, compared with the continuing influence that disciplinary scientists have had on the curriculum and the assessment of Science-bound students from school to university—*Roberts' SL1*.

A Way Forward

Accordingly, it is time for educational authorities in Ministries of Education to establish quite new relations with scientific bodies (such as the National Science Foundation in the USA, The Science Council of Canada, The Royal Society in the UK, and the Office of the Chief Scientist in Australia) to enable these S&T engaged scientists to authenticate the status of the new science values (*factor a*). Similarly, faculties of Education in universities will need to collaborate with staff from the faculties of Science and Engineering to ensure that all new teachers for school science will learn the valued Science as undergraduates (*factor b*).

The systematic professional development in the new Science values that all existing teachers would need could again be achieved through involving scientists, familiar with the Science of S&T issues, to work with teachers to produce supporting materials and to provide short courses in the new Science, as occurred in the 1950s–1970s example above (*factor c*). For professional development in the pedagogical changes needed, Education ministries are, again, not a strong source. Rather, the expertise for this other component of *factor c* lies within the ranks of the international research associations for science education (e.g., Australasian Science Education Research Association, etc.), whose members have worked with innovative teachers to change their classroom practices in these intended directions. There is thus great potential for contracted out partnerships between scientists and teachers, and between science education researchers and classroom teachers, if Education, as a state entity, authorises and funds it.

The last facilitating factor (*factor d*) is authentic assessment of students' learning of the new values. The assessment modes of multiple choice or short answer test items which were introduced in the 1960s as a convenient and sufficiently authentic way of assessing senior students' SL1 knowledge for further university science, are now very entrenched for school science as a whole, but they are largely inadequate for assessing the learning of the new values.

In the Re-emergence of Values in Science Education, an earlier book in this series, one of us (Peter) described two international assessments of science learning—IEA's Trends in International Mathematics and Science Study (TIMSS) and the OECD's Program for International Student Assessment (PISA). Although constrained by the use of a single, short time, paper and pencil mode of assessment and administered externally, they do reinforce differently valued science learnings (Fensham, 2007). For the former, these are the recall of the conceptual knowledge of science and its simple applications, as these commonly occur in science curricula for the 9 and 13 year olds (SL1 knowledge), and for the latter, the ability of 15 year old students to apply their science knowledge, from whatever source, to real life S&T contexts—identifying scientific issues, explaining phenomena scientifically, and using scientific evidence (more SL2 knowledge).

A number of the key intended values of contemporary science learning are not amenable to such simplistic and external modes of assessment. They now require assessment modes that are much closer to the classroom contexts and practical experiences that promote the new values. This means classroom teachers and their peers have to assume a major assessing role. Fensham and Rennie (2013) discussed a number of such modes for use in context-based science education, in decision-making about SSIs, and in integrated science education. Black, Harrison, Lee, Marshall, and Wiliam (2004) provide evidence that teachers can be assisted to use modes of assessment appropriate for new science values, provided they have the support of systemic guidelines for their design and administration. Peer moderation from other teachers can provide consistency and accountability, and as Black (2013) pointed out, such an approach to assessment, when it has been tried, has proved to be not only authentic for the values, but also a very powerful form of professional development for the teachers.

The scientific groups responsible for the 1980s *Science for All* reports and for *Beyond 2000* suggested that different aspects of their new values of science education were more appropriate for students at different stages of their schooling. This is consistent with Roberts' (1982) reflection that a science curriculum needs to focus on a quite limited set of learning emphases at any one stage of schooling. Teachers and students cannot achieve a number of different learning emphases at the same time. If the emphases are not confined, the hitherto, most familiar one will dominate. Roberts used the term 'emphasis', which we see as close to our use of 'intended value' or 'aim'. The more recently intended values of science education are set out as a number of content and process aims. As Roberts pointed out, it is not the number of values that is the problem. It is wanting to achieve them all at the same time. The models that have been used for national science curricula in most countries over the last 25 years have expected the same science aims or values to be achieved across each stage of schooling. If the educational bodies could encourage fewer and more targeted science learning intentions for the different stages of schooling, then more of what is recommended would immediately become possible.

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The Place of Values in the Aims of School Science Education

Jennifer Mansfield and Michael J. Reiss

Introduction

Debates about the aims of school science education are perennial (e.g., Reiss & White, 2014; see also Kidman & Fensham, Chapter "Intended, Achieved and Unachieved Values of Science Education" this volume), particularly in Western cultures. In this chapter we review some of these arguments about the aims of school science education, and look at what has changed in the last decade since one of us (Michael) considered a similar debate (see Reiss, 2007). We have situated this review of arguments in current global circumstances including rapid technological advances, a continuing demand for workers with STEM (Science, Technology, Engineering and Mathematics) qualifications and the increasing acknowledgement of the deeply worrying effects that humans have on the Earth's ecology, and indeed its future. Part of our argument is that decisions about the aims of school science education are inevitably decisions about values in education in general and values in school science education more specifically. This means that for a country, a group of schools, an individual school or a classroom teacher to come to a view about the aims of science education in the classroom is to have made a judgement, implicitly or explicitly, about values.

One of the intentions of this chapter is to make more explicit the role of values in decisions that are made about the nature and content of school science. We note that a person's understanding of what should be the aims of science education depends on whether you give more weight to the overall aims of education, with science education playing a part within that, or to the aims of science, with science

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D. Corrigan et al. (eds.), *Values in Science Education*,
https://doi.org/10.1007/978-3-030-42172-4_12

education playing a part within that. We place ourselves firmly in the camp that sees science education as playing a part within the overall aims of education.

We pay particular attention to the science education provided by schools during the compulsory period of education. We are mindful of the fact that much learning of science takes place elsewhere and at other times of life—and we are passionate about the importance and potential of these out-of-school sites for science education. Nevertheless, in many international contexts, schools are in a unique position: in an increasing number of countries they typically cover 90% or more of each cohort for 10 or more years, are staffed by learning experts and exist in a social structure that presumes that these learning experts have the right to undertake their jobs so as to enable learning about a broad range of knowledge, skills, and dispositions. This is in contrast to the focused and highly contextualised experiences that other sources (e.g., science centres, zoos) might additionally provide.

Current Global Circumstances

The current global landscape is characterised by rapid technological advances within a highly connected and globalised world that is nevertheless deeply fragmented. Increasing numbers of people in a rapidly increasing proportion of the world's countries are able to communicate almost seamlessly in real time across the globe and an increasing proportion of the world's population has virtually instantaneous access to information, goods, services and each other via the internet. With such advances comes increased accessibility, travel, job mobility and the rise of technologies such as Artificial Intelligence. But at times it seems that our cultural evolution is unable to keep pace with this rapid technological change, which manifests, as has long been noted (Beck, 1986/1992), in greater uncertainty about what the future might look like and increased concern at these changes. Such concern is indicated by a rash of dystopian novels such as Margaret Attwood's The MaddAddam Trilogy (published in 2003, 2009 and 2013) and Naomi Alderman's *The Power* (2017), and such films as *The Hunger Games* series (2012, 2013, 2014 and 2015), *Under the Skin* (2013), *The Divergent Series* (2014, 2015 and 2016), *Interstellar* (2014) and *Ex Machina* (2015).

Increased technological advances and the movements of goods, services and finance have escalated competition at local, national and global scales, which has placed increased emphasis in education on comparing national capacities with measures such as TIMSS and PISA as well as national standardised testing, such as NAPLAN in Australia and SATs in England and Wales and the USA. Greater pressure from political and economic forces on education has repeatedly returned to the question of what education should be preparing students for and therefore what the aims of education in general, and school science more specifically, should be.

Government agendas provide insights into the political and economic aims of nations and how these aims might affect educational aims and practices. For example, Australia's National Innovation and Science Agenda aims to "drive smart ideas that create business growth, local jobs and global success" (Australian Government, 2017) because

> innovation and science are critical for Australia to deliver new sources of growth, maintain high-wage jobs and seize the next wave of economic prosperity … Innovation keeps us competitive. It keeps us at the cutting edge. It creates jobs. And it will keep our standard of living high. (p. 1)

Furthermore, there is a presumption that

> too few Australian students are studying science, maths and computing in schools—skills that are critical to prepare our students for the jobs of the future. We also need to create an environment that attracts the world's best talent to our shores. (p. 4)

In the USA,

> the nation's capacity to innovate for economic growth and the ability of American workers to thrive in the modern workforce depend on a broad foundation of math and science learning, as do our hopes for preserving a vibrant democracy and the promise of social mobility that lie at the heart of the American dream. (Achieve, 2009, p. 1)

STEM Curricular Responses

Many governments are responding to these global developments by placing greater emphasis on school STEM courses in what seem to be increasingly desperate attempts to fend off competition from beyond their country's borders. Bencze, Reiss, Sharma and Weinstein (2018) argue that:

> STEM sales campaigns rely on a common neoliberal tack; namely, disaster capitalism (Klein, 2007). In other words, in order to infuse neoliberal priorities, capitalists may capitalize on natural or manufactured disasters. STEM education promoters often, for instance, appear to adopt salvationary rhetoric—claiming that STEM education should allow individuals and jurisdictions (e.g., states/provinces, countries) to be saved from economic disaster; and, indeed, to prosper, especially in terms of jobs and associated products and services, in the face of increased international economic competitiveness from other countries, like India and China ... (p. 74)

In the UK, and despite consistent economic data on the importance of the service and creative industries, there is a government fixation on the importance of STEM education for manufacturing and future prosperity. For example, in 2014, the Education Minister, Elizabeth Truss, in the staccato prose that seems to be favoured by certain UK politicians, said:

> We're one of the top countries for research citations in subjects like physics or maths. We have one of the strongest science research communities in the world. And we know this is vital for our national future. Maths is becoming ever-more important to the economy. More and more sectors rely on technology—and more companies require people with advanced analytical and research skills if they're going to compete. So we need a strong education system. Because tomorrow's world relies on today's pupils. (Truss, 2014)

In this and similar government pronouncements from other nations, education and innovation are seen as a means of economic survival and transferability. Political agendas speak of education as a way of preparing students as 'marketable commodities', able to enhance national economic and innovative competitiveness in a global climate.

Education is feeling the pressure of such a view of students. Indeed, the next generation of students are facing an uncertain future with suggestions that a large proportion of jobs in the future are yet to be invented or designed, as present ones disappear, in large measure as a result of increasing automation (Rainie & Anderson, 2017). As a consequence, education systems will need to adapt to prepare students for change in the workplace. This increased pressure can be seen in the political agendas for a number of nations. Rather than a focus on preparing 'scientists', the focus is on preparing students for the jobs of tomorrow by enhancing students' STEM capacities. For example, from the USA:

> Our nation needs an educated young citizenry with the capacity to contribute to and gain from the country's future productivity, understand policy choices, and participate in building a sustainable future. Knowledge and skills from science, technology, engineering, and mathematics—the so-called STEM fields—are crucial to virtually every endeavor of individual and community life. All young Americans should be educated to be 'STEM-capable,' no matter where they live, what educational path they pursue, or in which field they choose to work. (Achieve, 2009, p. vii)

In Australia, *The Melbourne Declaration* specifies the broad goals for schooling in Australia and suggests that:

> In the 21st century Australia's capacity to provide a high quality of life for all will depend on the ability to compete in the global economy on knowledge and innovation. Education equips young people with the knowledge, understanding, skills and values to take advantage of opportunity and to face the challenges of this era with confidence. (Ministerial Council on Education, Employment, Training and Youth Affairs, 2008, p. 4)

The goals for education suggested by the Declaration argue for a youth that is confidently equipped for the contemporary challenges of a globalised world. This aim aligns with the National Innovation and Science Agenda, referred to earlier, which advocates increased innovation for sources of growth, creation of jobs, economic prosperity, global competitiveness and the maintenance of high standards of living (Australian Government, 2017).

The Aims of Education

Despite the recent emphasis on STEM for national prosperity, a number of aims continue to be proposed for education (cf. Biesta, 2009; Reiss & White, 2013). For all that, there is now less confidence that we know what makes for a good education. Indeed, Kress (2000) argued that whereas the previous era required an education for stability, we now require an education for instability. Such a scenario would require considerable provisionality and open-endedness about any precise, subject-specific set of aims. Generally, in writings about the aims of education and in curriculum documents, we can discern two broad groupings (Reiss, 2007). First, those where the intention is to develop the individual for her/his own benefit; second, where the intention is to develop individuals so that they may collectively contribute to making the world a better place, though in recent years this global aim has shifted more towards national interests.

Acknowledging the historical and cultural context of any attempt to discern the aims of education, contemporary philosophers of education have examined what these might be. Chief among the suggestions are: autonomy, well-being and justice.

Autonomy as an Aim in Education

To be autonomous is rationally to decide things for oneself. It may be objected that no person is an island, that our decision making is influenced by our historical past and social present. While this is true, the argument for autonomy still holds. If you choose to read philosophical writings rather than popular romance fiction, for example, the reasons are likely to be due in large part to your parents, schooling and friends but that doesn't mean that you lack agency or act with diminished autonomy in reading them.

It is widely accepted within liberal traditions of education that education should intend students to achieve autonomy. Of course, there are degrees of autonomy and different conceptions of autonomy. It is generally held that rational autonomy is displayed by individuals who act intentionally, with understanding and without external controlling influences that determine their actions (e.g., Haworth, 1986). Although there is increasing sensitivity to the Eastern and feminist positions that too strong an emphasis on rationality may be both discriminatory and illusionary. Nonetheless, an optimistic belief in rational autonomy would mean that a society in which a sufficient proportion of its citizens had achieved rational autonomy would function successfully. For example, it is not rationally autonomous for us to routinely choose to deceive and steal as even a cursory analysis should convince us that this is neither fair to others nor likely to lead to a flourishing society.

Other terms, such as self-determination or authenticity, have much in common with rational autonomy. To be self-determined is to make personal decisions that are authentic, or true to oneself. This argument might be taken as assuming that we are born with a self that is waiting to be unveiled and that social and cultural conventions constrain or distort an individual. From this perspective, the purpose of education would include challenging social and cultural constraints of the authentic self.

However, social and cultural constraints are powerful, and education is fundamentally a product of societies. An educator may urge students to pursue their dreams and exercise self-determination and authenticity, and yet the students are still to be 'measured' and 'judged' by an education system that replicates the hierarchical structures of the society in which it is embedded. The students are still constrained by the system that educates them in terms of standardised testing and academic rankings. This complexity is challenging for students and educators alike.

Education for autonomy should therefore aim to balance rationality with authenticity and self-determination. It is possible to lead a self-determined or authentic life by devoting time to consuming chocolates or playing video games online 24/7. However, rationality would temper these desires with pragmatic decisions about one's health as well as social and cultural conventions such as employment and the need for social engagement. This raises questions about the relationship between what is good for an individual and what is good for a society and, in particular, how individuals make decisions about their well-being in the light of societal paradigms.

Well-Being as an Aim in Education

The idea that education should try to enhance people's well-being (sometimes expressed as human flourishing) is closely allied to the notion that education should enable people to act autonomously. However, we can easily imagine situations, such as are found in introductory textbooks on medical ethics, when well-being and autonomy are opposed. Suppose, for example, an adult injured in an accident urgently requires life-saving medical treatment that can only be delivered by injection but attempts to reject it because they are terrified of needles. Most of us would favour trying to persuade the person to accept the treatment, but if that proved unsuccessful giving the treatment without the person's consent (i.e., overriding the person's autonomy) on the grounds that there is a greater good than autonomy in this case, namely the preservation of life.

This example further highlights the complexity of decision making for well-being due to uncertainty (cf. Rennie's chapter "Communicating Certainty and Uncertainty in Science in Out-of-School Contexts" in this volume, where uncertainty in science takes a different meaning). Values exist within and outside an individual. However, uncertainty complicates decision making about an individual's well-being due to competing values. As an aim for education, what role do schools play in preparing individuals to be aware of this complexity and the problematic nature of decision making, such as what is 'right' or 'wrong' for a given situation related to a person's well-being?

Justice as an Aim in Education

Education can also be seen as striving for justice. There are various conceptions of justice but they have in common an emphasis not only on the actions of individuals but also on the consequences of individuals' actions and social structures on relationships between individuals and on the distributions of resources between individuals. Here, values play a complex and important role in determining which resources or actions are valued, for and by which people (cf. Fitzgerald & Abouali, Chapter " Exploring Values Through Lived Experiences of the World Heritage Site of Petra: A Case Study" this volume). This raises issues about whose values matter more than others. Recent years have seen an increasing acknowledgement of the importance of environmental justice, helping to decentre humans, thus giving more consideration to the interests of other species.

Social justice is about the right treatment of others (what Gewirtz (1998) characterises as the relational dimension of social justice) and the fair distribution of resources or opportunities (the distributional dimension). Yet, complexity exists in determining what counts as 'right' treatment and also what might count as fair distribution when competing sets of values exist. For example, it may be accepted by some that an unequal distribution of certain resources can be fair provided other criteria are satisfied (e.g., the resources are purchased with money earned, inherited or obtained in some other socially sanctioned way—such as gambling in some, but not all, cultures). At the other extreme, it can be argued either that we should ensure that all resources are distributed equally or that all people have what they need. Such distributions might be achieved through legislative coercion, social customs or altruism on the part of those who would otherwise end up with more than average.

Justice as an aim of education is complex, despite educators' widespread enthusiasm for 'social justice', especially when the values which influence decision making are not explicit or cannot be examined with much objectivity. What role do teachers and schools play in educating for justice and how can teachers be supported to think about their own values and the way these values are portrayed to their students (cf. Cooper & Loughran, Chapter "Exploring Values of Science Through Classroom Practice" this volume)?

The Possible Aims of School Science Education

The above arguments are about the aim(s) of education in general. We shall now attempt to demonstrate the implications of these arguments for determining what the aim(s) of science education should be. Of course, categorising possible aims of school science is problematic. Although separated here into discrete aims, this classification is not without limitation as there is considerable overlap and interdependence between categories. In addition, different stakeholders bring individual lenses and values to bear on decision making about what school science should look like and consist of. Global and national values also play a major role in what become 'new expectations' for how teachers and students 'should ideally' work in classrooms. Teachers and students need to reconcile top-down imperatives with their own values and aims for school science. Therefore, changing global and national prerogatives has serious implications for schools, teachers and students through the potential misalignment of respective stakeholders' values. What does this mean, then, for the way teachers and schools plan for science learning and teaching? The answer depends on whose values are considered.

Supply of Future Scientists

In revisiting the aim of school science as way of supplying future scientists, we need to consider the changing face of scientific work in the twenty-first century. A professional scientist can be considered to be one who is employed in a science or science-related career. As a global citizenry, we value the role scientists play and thus place value on students choosing science as a vocation.

The practice of scientific research has seen dramatic change over the last few decades. This has presented opportunities and challenges for scientists, such as: increases in interdisciplinary collaboration (Luke, Carothers, Dhand, Moreland-Russell, Sarli, & Evanoff, 2015); a rise in team-based work on large projects, geographic distribution and virtual communities; new organisational structures (Cummings & Kiesler, 2014); and a rise in new and alternate approaches for funding, such as entrepreneurial and crowdsourcing (e.g., Wood, Sullivan, Illiff, Fink, & Kelling, 2011). Also on the rise is the emergence of an emphasis on STEM 'capacities', 'skills' and/or 'attributes' as ways of working towards an uncertain future. As a previous Australian Chief Scientist argued: "Our nourishment, our safety, our homes and neighbourhoods, our relationships with family and friends, our health, our jobs, our leisure are all profoundly shaped by technological innovation and the discoveries of science" (Office of the Chief Scientist, 2013, p. 5).

Indeed, the need to provide pathways for future scientists (and people with expertise in mathematics, engineering and technology if STEM in its interdisciplinary form is truly valued) still persists as an imperative of many science courses. However, the nature of this preparation may be changing. With the emergence of policy agendas, such as the examples offered early in this chapter, in addition to the changing accessibility to information via the internet, we see an increased emphasis on teaching 'skills' and 'capabilities', such as the capacity to find relevant information, critical thinking, and problem-solving skills to comprehend scientific concepts and to enable the ability to work with data and evidence. Greater emphasis has been placed in learning theory on the student as the constructor of knowledge, rather than as a passive recipient of facts and concepts; however, whether this is a reality of schooling is another matter.

The broadening of science education to focus more on skills, capabilities and dispositions may also be in response to the calls for more humanistic approaches to science education, such as the 'science for all' movement (see Kidman & Fensham, Chapter "Intended, Achieved and Unachieved Values of Science Education" this volume). And it could also be in response to criticism towards science education that caters for the few (who may become scientists) at the expense of alienating a large majority (who are unlikely to).

With the suggestion that three-quarters of the fastest growing occupations will require STEM skills and knowledge (Becker & Park, 2011), school science courses will need to prepare students for a range of skills and capacities rather than just aiming to develop conceptual understandings. However, the increased focus on STEM in education policy does not necessarily translate into greater development of capacity, partly due to the lack of consensus as to what STEM teaching, STEM skills and STEM capacities might look like in a primary and secondary setting and how to develop them. While there is a growing number of STEM schools and STEM centres in schools, they often feel and look a lot like traditional sites of school science. This illustrates the problematic way in which global imperatives, such as the push for a greater focus on STEM, might translate into practice within schools when there are different values at play.

Another argument for the development of more skills-based rather than overly conceptual-focused science curricula is the changing state of career progression. A person may have several career changes over the course of a lifetime, and it is difficult to see this tendency reversing. The movement to skills- and capacity-based science courses, particularly in a climate of rapid technological evolution, could be a way of indirectly preparing students for a multiplicity of potentially different future careers in science-related fields, as well as creating a citizenry with skills and capacities to survive and diversify in an uncertain future. However, the nature of what these courses might ideally look like is unclear. For example, what sort of practical work is most appropriate for specialised (e.g., biomedical sciences) or generalised science degrees? How much should science degrees teach about the nature of science?

Furthermore, there may be a danger of going too far the other way, of alienating or not adequately preparing those with a fascination (or at least interest) in the content of science who might have otherwise chosen to pursue a career in science. We admit that this possibility is under-researched but we want to acknowledge the possibility that there is a minority of students who do not want anything other than an overly conceptual-focused science curriculum. There is also increasing acknowledgement that skills, like conceptual understandings, need to be developed within specific contexts; science courses that focus on the process of science and on building up generalisable skills (e.g., Warwick Process Science, developed in the 1980s) may do their students a disservice compared with courses that retain a solid grounding in scientific knowledge and understanding.

Scientific Literacy

Emerging from the ‘science for all’ movement has come a desire to embed science learning in relevant and authentic contexts in order to nurture a greater awareness of the nature and uses of science in students’ everyday lives. The notion of ‘scientific literacy’ has emerged as a common aim of school science curricula, and although debate as to the meaning of the term persists (Roberts, 2007), sufficient agreement allows for it to be used beneficially.

Goodrum, Rennie, and Hackling (2001) have suggested several qualities of scientifically literate individuals—people who:

- are interested in, and understand the world around them
- engage in the discourses of and about science
- are sceptical and questioning of claims made by others about scientific matters
- are able to identify questions, investigate and draw evidence-based conclusions
- make informed decisions about the environment and their own health and well-being.

This definition aligns with that of Hodson (2008), who further elaborates the importance of an individual’s capacity to use their scientific literacy for future individual and societal benefit, by suggesting that the:

> Use of the term “universal critical scientific literacy” carries with it a commitment to a much more rigorous, analytical, skeptical, open-minded and reflective approach to science education than many schools provide and signals my advocacy of a much more politicized and issues-based science education, a central goal of which is to equip students with the capacity and commitment to take appropriate, responsible and effective action on matters of social, economic, environmental and moral-ethical concern. (p. 2)

Internationally, many curricula are becoming more sensitive to developing this kind of scientific literacy, through explicit inclusion of strands that require consideration of the nature of science—for example, the nature and history of scientific knowledge development, the nature of scientists’ work, the tentativeness of new scientific knowledge and the social, cultural and value-laden nature of science. This way of thinking is perhaps becoming more evident through the use of the word ‘science’ to describe ways of thinking, knowing and doing, rather than just a static body of knowledge.

Perhaps the argument that to be an educated person in the twenty-first Century is to understand something of science should also be included within the scientific literacy category. This ‘science as culture’ argument proposes that science is as worth studying in itself, as are, for example, literature and the arts (cf. Kind & Osborne, 2017). Most school science courses unfortunately do not do a very good job of introducing science as culture as they are short on history and culture and they typically omit, beyond the mundane, some of the parts of science that the cultural argument would surely deem important. Such examples might include the origin and end of the Universe, the theory of relativity, the uncertainty principle and quantum theory, nanoscience, what it is to be human, feminist science, and ethnosciences. Omission appears to be principally on the grounds of difficulty—as if school literature courses would omit Shakespeare and Emily Dickinson and school art courses Duchamp and Picasso on the grounds that they were difficult.

Individual Benefit

Another aim of school science is for individual benefit or utility. Elmose and Roth (2005) caution that we live in "a risk society, characterized by the unpredictable consequences of techno-scientific innovation and production and by increasing complexity" (p. 11). Hence, science education should equip and benefit students in ways that have positive impact on their lives and help them navigate an uncertain future. This might include gaining employment and understanding how to maintain and make decisions about their own health and wellbeing through, for example, healthy eating (e.g., knowing about the nature of nutrients, composition of foods and the science of food preservation and cooking) and health care (e.g., being able to understand the nature of illness, especially in light of issues like increasing antibiotic resistance and increased incidence of diseases such as cancer, diabetes and dementia). More broadly, educating for utility across the STEM subjects could also benefit students who need to make decisions about which goods and services to purchase, be able to discern potential 'scammers', especially in an online environment, and make other informed decisions that could influence their wellbeing.

The capacity for science education to help individual students may be greater than is sometimes supposed. In a moving account of a science programme they introduced in an orphanage in Rwanda, Perrier and Nsengiyumva (2003) used 'hands-on' approaches to connect the manual, emotional and intellectual dimensions of the young people with whom they worked. These children had lost their parents as a result of the 1994 genocide; almost all of them had witnessed extreme violence and the great majority had thought they too would die. Perrier and Nsengiyumva's paper is full of accounts of young people developing (recovering is probably a better word) self-esteem, confidence and curiosity while undertaking such comparatively routine scientific activities as: building the five Platonic solids; studying the ascent of water when a candle is placed above water, lit and covered by a plastic mineral water bottle; and identifying insects. This study is particularly salient given the world-wide increase in the number of refugees and refugee camps since it was written.

Citizens who are able to make informed decisions make them not just for individual benefit, but also in light of their role in the greater global economic marketplace. Can the components of this electronic device be recycled? Does buying this brand of clothing support ethical production standards? Are the workers paid an appropriate salary? Do they have good working conditions? Is the fabric sourced from sustainable or low impact materials? Does the palm oil in this product contribute to the extinction of wild organisms? Does buying these eggs support ethical chicken farming? Do I need new shoes or can the old ones be repaired? What will happen to them when I throw them away?

In a review of the knowledge actually used by members of the public (i.e., non-scientists) to function effectively in particular settings, Ryder (2001) concluded that the amount of formal scientific knowledge needed was relatively limited. How much content knowledge should young people be equipped with to enable them to face an uncertain future? Which values will determine the conceptual emphases? These questions are not unproblematic. Constructing a science curriculum on the basis of what science members of the public need may result in less emphasis being paid to content knowledge and more to ways of accessing and evaluating scientific knowledge, including procedural knowledge, than is typically provided by school science courses.

Democracy

Decision making about one's actions impacts on the wider community in which a person exists, and thus the two are interconnected. Longbottom and Butler (1999) put forward the argument that "the primary justification for teaching science to all children is that it should make a significant contribution to the advancement of a more truly democratic society" (p. 474). Longbottom and Butler seek to steer a path between positivism and post-modernism: in common with most science educators they would have students appreciate that scientific knowledge is reliable, indeed "the best we have" (p. 487), but fallible. They go on to argue that, in a way reminiscent of inquiry-based science, "children should adopt many of the critical and creative attributes of scientists (giving students the skills to seek and evaluate evidence and to take part in reasoned debate)" (p. 487).

The argument that school science education should promote democracy is related to the argument that it should be for citizenship (Sadler, 2011). In both cases there is what we might term 'weak versions' and 'strong versions'. The weak versions consist of learning about what a democracy is and what it is to be a citizen. The strong versions entail using such knowledge in action to bring about change. These strong versions are closely allied to claims that the aim of school science education should be to effect social justice or socio-political action, which we discuss below.

Building an educated citizenry is good for democracy but can be uncomfortable for certain politicians who would probably benefit from a more ignorant populace. The public may be distrustful of certain scientific 'advances' (e.g., fracking, GM crops, the use of embryonic stem cells), for all that it may be positive about others (e.g., cheaper renewable energy, new medical treatments). Levinson (2010) suggests that "distrustful publics will respond negatively to the introduction of new technologies thereby threatening the nation's competitiveness as a knowledge economy" (p. 70).

A more democratic society needs greater equity in education and discussion about the nature of knowledge development. To wade into some major scientific issues, such as nuclear power, GMOs and climate change, requires the ability to understand the nature of evidence, the social and cultural embeddedness of knowledge and what it is that constitutes a valid argument. Many issues impact in different ways on different interested parties; being able to understand different points of view and the interplay of different forces is beneficial for informed decision making. Levinson (2010) contends:

> Not only are the technical details of scientific and technological issues frequently at a level of complexity that would confound any layperson, but the interweaving of social, economic, political and ethical matters attendant on most contentious issues deepens the problems of what democratic participation can realistically mean. (p. 71)

Sinatra, Kienhues and Hofer (2014) conclude that "At a minimum, the public should be enabled to make thoughtful decisions that are informed by science. They should have the skills necessary to apply scientific evidence to science-related issues that affect their lives" (p. 135). But on whose values do we draw when selecting these skills and how do we decide which skills will be of most value for students in moving forward, particularly in contexts of uncertainty?

Social Justice or Socio-political Action

Recent years have seen a growth in the idea that school science education should serve to achieve social justice. Rodriguez (1998) was one of the earliest to argue for this by exploring the potential of science education to serve as a platform for resistance. Calabrese Barton, who worked with homeless children in the USA to develop more appropriate science learning, has shown that active participation in science lessons, and authentic learning about science, happens when children believe that their work can enact change and improvements for themselves, their families and their friends (Calabrese Barton, 2001). Drawing on feminist approaches, she demonstrated that many of the students with whom she and her colleagues worked, although seen in school as not achieving in science, were actually perfectly capable of high quality science work provided they were given real choice in the science they worked at.

Akin to science education for social justice is the notion of science education for socio-political action, as described by Roth and a number of his collaborators. For example, Lee and Roth (2002) provide a case study of a community-based activist project, the Henderson Creek Watershed Restoration Project, in which decisions were made about how to reduce erosion and increase the oxygenation of the water. Lee and Roth carefully discuss the issues that arose in the work. While some of these were narrowly scientific, many were not. There were, for example, the interests of landowners to consider; horse owners and home owners have their own interests aside from those of anglers and others. Lee and Roth concluded:

> As part of living and doing research in this community, we have come to realize that not only are our lives enmeshed with research, but that in everyday pursuits of people, science is irreducibly enmeshed with politics, farming, activism, and so forth. (pp. 44–45)

Larry Bencze and Steve Alsop (2014) have edited a collection of accounts that focus on exploring activism within science and technology education. There is also now a journal *The Journal for Activist Science & Technology Education* and a growing number of progressive authors are being used to frame science education for activism, including John Dewey, Michael Foucault, Paulo Freire, Antonio Gramsci, Jürgen Habermas, Dona Haraway, Sandra Harding and Ivan Illich. Alsop and Bencze (2014) argue that there are four main ways in which a more radical approach to science and technology education should be framed:

- Science and technology education should be critically reworked in relation to contemporary economic, social, ecological and material conditions;
- Science and technology education should be critically reworked as political practice;
- Science and technology education should be critically reworked to support learners as subjects in change and not objects of change;
- Science and technology education should be critically reworked as moral and ethical praxis.

The broadening of the aims of science education to include social justice and socio-political action has gone hand-in-hand with a reconceptualisation of scientific literacy. Roth and Lee (2002) argue that scientific literacy can be conceived of as a property of collective activity rather than individual minds; indeed, that it characterises interactions irreducible to characteristics of individuals. Roth and Calabrese Barton expand on this vision and through a range of case studies argue that “critical scientific literacy is inextricably linked with social and political literacy in the service of social responsibility” (Roth & Calabrese Barton, 2004, p. 10).

Criticality

Internationally, there is a growing focus on the value of critical thinking, where ‘critical’ can be taken to mean being analytical, logical, open-minded, rigorous and questioning, along with having a degree of scepticism. Critical thinking enables greater awareness and reflection about issues through the ability to rationally analyse and make judgements about arguments and evidence to formulate reasoned decisions. *Criticality*, however, situates the learner as an active participant within their environment as one who is required to: think critically with analytical reasoning (critical reason), understand oneself critically (critical reflection) and act critically (critical action) (Dunne, 2015). Criticality as an aim of education therefore would ideally lead to critically thinking individuals who are able to act with purpose and autonomy within the world around them (Barnett, 1997).

Given the uncertainty of the global landscape, especially in the context of climate change, increasing human population, global connectedness and rapid technological evolution, criticality appears to be an essential capacity. Development of critical thinking skills is often touted as an essential aim for higher education but is seldom an outcome (Arum & Roksa, 2011; Dunne, 2015). Increasingly, the push for developing capacities such as critical thinking is filtering down into schools (see, for example, the General Capabilities of the Australian Curriculum). However, developing criticality requires thinking about one's epistemology and recognising the impact of values, social and cultural influence, and personal bias. Developing this capacity to take a critical look inwards and self-reflect is difficult for most people.

The notion of criticality in education as compared to critical thinking draws on the work of Freire (1972), who saw teachers as agents of praxis who were capable of helping transform conditions in society through nurturing students to think and act critically. Hildebrand (2001) likewise argued in favour of what she termed 'critical activism' in science education, urging participation in science (doing science) and participation in debates about science (challenging science).

Socio-scientific issues, argumentation, consideration of ethical issues (see, for example, Buntting & Jones, Chapter "Using Biotechnology to Develop Values Discourse in School Science" this volume) and the role of values (see, for example, Corrigan & Smith, 2015) have been encouraged in science education to "foster critical thinking skills, decision-making, argumentation, reflective judgement and moral development" (Tidemand & Nielsen, 2017, p. 44). However, including such apporaches may be daunting for teachers if they feel they do not have sufficient knowledge or capacity to respond to student questions. Furthermore, Tidemand and Nielsen suggest that teaching of SSIs in secondary school contexts may not lead to enhanced critical thinking skills as it requires teachers to move beyond content. Yet doing so is challenging and problematic as it requires criticality of, and within, the education pipeline in which teachers operate. For example, how does one balance curriculum coverage with skill development in the light of increasing standardised testing and examinations along with increasing teacher accountability, etc.?

Teaching for student criticality also requires of teachers the capacity to reflect "critically on their own stance and recognize the need to avoid the prejudice that comes from a lack of critical reflection" (Oulton, Dillon, & Grace, 2004, p. 420). Yet, if criticality is not being nurtured in pre-service teacher education and is not necessarily required of teachers with regards to working within their own educational contexts (how many teachers lament the overemphasis on administrative tasks in faculty meetings as compared to robust and critical discussions about learning and teaching within the school?), when might capacity for criticality be nurtured and valued?

The examples in the sections above on science for social justice, socio-political action and criticality may inspire but they may also overwhelm or even dishearten. After all, not all science teachers work in ways that allow the inclusion of extended projects. Neither do they all feel they have the capacity or confidence to engage with socio-scientific issues in the classroom, for example. Furthermore, even the most enthusiastic attempts to make a science curriculum relevant for one's students may fail (e.g., Tobin, 2002). However, it is possible that much classroom-based teaching and modelling may, and over shorter time spans than extended projects require, contribute to science for criticality.

Conclusions

As with any attempt to categorise, the above updated analysis of the aim(s) of school science education simplifies; things are generally messier than when they are reduced to arguments on paper and will not capture the complete picture. Indeed, the greater risk and complexity that exists in today's society will provide challenges for the validity of such classification. Our purpose in classifying the aims of science education into categories that may be discrete or overlapping, albeit problematic, is to open up discussion and invite critical reflection about one's values for science education.

Moreover, the various positions outlined above can be mapped reasonably well onto the tripartite classification of autonomy, well-being and justice discussed at the start of this chapter in relation to the more general aim(s) of education, situating our values position of science education playing a part in realising the aims of education. For those readers who like to think in terms of n-dimensional graphs, one can imagine each of the aims of science education as a cloud mapped in a space with the following axes:

- From benefits for selected students to benefits for all students
- From benefits now to deferred benefits as adults
- From individualism to communitarianism
- From knowledge to action.

The place of values in the science curriculum depends critically on one's views of the aim(s) of science education. For example, as Hodson (2003) points out, there will be barriers and resistance to a science education predicated on socio-political action:

> Traditionally, science education has dealt with established and secure knowledge, while contested knowledge, multiple solutions, controversy and ethics have been excluded. Accommodating to what some teachers will perceive as loss of teacher control and direction will be difficult. Indeed, to teach this kind of issues-based curriculum science teachers will need to develop the skills and attitudes more commonly associated with the humanities and language arts. (pp. 664–665)

But then all curriculum reforms meet resistance. As Hodson and many others (e.g., Ogborn, 2002; the whole Action Research movement) point out, successful change only happens when teachers are active participants in the change process.

Finally, although we are of the view that school science education needs more education for social justice, socio-political action and criticality to deal with a global context with increasing risk and complexity, we have some sympathy with more conservative analyses. Teachers, as well as students, have zones of proximal development. As others have put it:

> … it takes an inordinate amount of time—years rather than days or months—for science teachers and scientists to re-examine their own experiences, principles, and practices about science and science education and to implement coherent and consistent strategies to combat the inequalities that currently exist at all levels in our educational system. (Bianchini & Cavazos, 2001, pp. 286–287)

Part of our argument is that decisions about the aims of school science education are inevitably decisions about values in education in general and values in school science education more specifically. This means that for a country, group of schools, individual school or classroom teacher to come to a view about the aims of science education in the classroom is to have made a judgement, implicitly or explicitly, about values.

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Exploring Values Through Lived Experiences of the World Heritage Site of Petra: A Case Study

Angela Fitzgerald and Diana Abouali

Positioning Ourselves in Petra

When I moved to Jordan in the Middle East at the beginning of 2013 to take up a 2-year volunteer role in a local non-governmental organisation—Petra National Trust (PNT)—I had been working in science education as a teacher, teacher educator and researcher for almost a decade. At first glance, the links between being an education and youth engagement advisor for an organisation that advocated for the World Heritage site of Petra and my previous work did not seem at all obvious. But over time two clear connections emerged.

The first connection was in relation to the role and presence of science in my work. The phrase 'science is everywhere' can at times sound like a cliché but in the case of Petra it is very much true. The geological features, such as the narrow gorge that draws you into the site and the incredible coloured rocks, alongside the architectural achievements, realised as monuments carved into the sandstone, are what make Petra famous. While most people don't tend to think about these features through a scientific lens because the aesthetics are overwhelming, when you scratch below this rather beautiful surface you start to realise that a wide range of scientific principles and concepts played an important role in being able to convert notoriously harsh desert conditions into a fully functional, thriving city. This played out in a number of ways, including complex water harvesting techniques, using metallurgy to develop carving tools and sophisticated approaches to making ceramics. What I came to realise is that while I didn't necessarily form an instant association between Petra and science or my education-focused work in both spaces, I was very much experiencing science in ways that were applied and relevant, and that genuinely contributed to an improved way of life.

The second connection played out in the notion of privilege and whose values, or perspectives of what should be valued, are credited with mattering. This might seem quite abstract in terms of links with Petra, but over time it certainly struck a chord with me. I have

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D. Corrigan et al. (eds.), *Values in Science Education*,
https://doi.org/10.1007/978-3-030-42172-4_13

> found the tensions that play out between scientifically accepted ways of knowing phenomena and culturally specific ways of making sense of the world to have had a significant influence on my thinking. I have had opportunities to experience science learning and teaching in different parts of the world, including the Cook Islands, Nepal and India, which has caused me to be more attuned to the tendency for school science to be enacted in ways that privilege scientific approaches. In the context of Petra, this privilege is realised through the ways visitors to the site are prepared to engage with and make sense of their experience. This is usually through lenses provided by 'experts' such as international archaeologists and global organisations such as UNESCO (United Nations Educational, Scientific and Cultural Organization). The more time I spent with the local communities connected with Petra, the more I recognised that their ways of valuing and making sense of the site were markedly different, and sometimes at odds, with what I had been educated to consider as important. (Angela)

> When I started working for PNT in 2014, my experience with Petra was limited to two visits I made to the site in 1997 and 2013, which were done with little understanding of the history of the place since efforts were underway to list it as a World Heritage Site. It was only after working at PNT that I learned of the various and sometimes conflicting interests held by the different stakeholders and how they impacted—or didn't—decisions pertaining to the management of a historical site like Petra, one that, though ancient, still remains home to a small community known as the Bdoul. I admit I had always given priority to the need to preserve the site in a manner consistent with standards set by UNESCO and heritage management best practices, but I soon began wondering why the positions and demands of external bodies were always given precedence over local needs, and why locally-held values were deemed less important than those that informed the World Heritage platform. If a community sees Petra as its home, should it not continue to be so even though the act of daily living might damage a historically valuable and arguably unique site. Why shouldn't sites like Petra remain living sites? Why should they be turned into museums? Perhaps the answer lies less with the power and influence of international bodies like UNESCO than with the Jordanian authority's inability to desist from patronising its citizens rather than actively including them in the decision-making processes. (Diana)

This chapter seeks to probe the complexities inherent in the notion of values by positioning this work within the context of our experiences and knowledge of the tensions that play out at the UNESCO World Heritage site of Petra situated in Jordan. Petra becomes a case study of sorts with the voices of various stakeholders at this site becoming the informants in what these tensions are and what impact they have (see Dillon & Reid, Chapter "Changing Context, Shifting Values? Science, the Environment and Citizenship at Minstead Study Centre 12 Years On" and Roche & Murphy, Chapter "Changing Values in Science Education and the Emergence of Science Gallery" this volume, for other context-rich chapters). Parallels can be drawn to the tensions that play out between scientifically-accepted ways of understanding and valuing science phenomena and more culturally specific ways of making sense of and connecting with the world. Connections will be made to highlight what this means for the work and thinking of science educators.

Science and Petra: Where Are the Links?

At first glance, the links between scientific understandings and practices and the World Heritage site of Petra may seem tenuous. That the S in UNESCO stands for 'scientific' is a clue. The more obvious link, however, is that Petra is a classic site for archaeological research and discoveries. While there is some debate about whether archaeology should be defined as fitting into the traditions of history or science, it is more broadly understood to be a bridge between these two ways of making sense of the world. Archaeology draws upon a range of evidence and techniques to study human activity. This focus may be of interest to science educators and their students as it brings a contemporary understanding of the work of scientists. It showcases that science can exist outside of the traditional paradigms often enacted in schools—biology, chemistry, physics, and earth and space science. Archaeology draws on the conceptual and theoretical ideas existing in these strands and uses them in applied ways to make discoveries and solve problems out in the world.

Beyond being of archaeological interest, Petra can also be considered as science rich through its impressive geological and hydrological features. Geologically, the site is famed as the '*Rose Red City'* for its various hues of red sandstone. Sandstone rates as a 6–7 on the Mohs scale of hardness, which ranges from 1 (talc) to 10 (diamond). This suggests that while the rock is durable, it is possible for it to be shaped and moulded. The geological structure of Petra proved to an ideal canvas for carving elaborate features and facades. The red colour is caused by the presence of iron oxide in the rock, which results in reddish tints ranging from pink to terracotta. Across the site, it is also noted that the sandstone has yellow and purple features caused by the presence of feldspar and manganese respectively. Hydrologically, the site achieved an incredible feat of sustaining a significant population in desert conditions. This was through sophisticated water harvesting techniques such as the use of dams and cisterns and a system of channels to store and transport water around the site. To maintain the quality of the water for human consumption, terracotta pipes were created. These features were engineered to make use of the mountainous catchment areas as well as the natural slope of particularly the Siq, the naturally occurring narrow gorge that provides a protected entry point to the main city area. Evidence suggests that Petra was so abundant with water that it was possible the city had water features, such as waterfalls and ornamental moats.

Petra is not the only science-rich site in this region. Other UNESCO World Heritage listed locations in the Middle East that highlight the application of scientific understandings and practices include the Pyramids in Egypt, the irrigation systems in northern Oman and the Socotra Archipelago off the coast of Yemen. In fact, of the 1073 listed sites located across world, most have some scientific underpinnings or connections. Of all of these sites, 832 are identified as cultural, 206 as natural and 35 as mixed properties. Although a science-rich site, Petra falls into the cultural designation alongside other sites such as the Sydney Opera House

(Australia), the Great Wall (China), the Taj Mahal (India) and Stonehenge (United Kingdom). While a place of interest to scientists, particularly archaeologists, the main group of people visiting Petra is tourists who tend to be intrigued and mesmerised by the cultural, historical and aesthetic aspects of the site. However, we should not lose sight of the potential that a science-rich site such as this offers. It provides evidence that scientific phenomena are based on real things and have an application to what is happening (or has happened) in the world. It is a type of authenticity that is highly valued in science education and has the capacity to engage the hearts and minds of science teachers and learners alike.

Positioning Petra and Our Work

The ancient city of Petra served as the capital of the Nabataean kingdom (4th century BCE–107 CE), which extended through southern parts of modern-day Jordan, Palestine and north-western Saudi Arabia. Today, the remains of ancient Petra are part of the Petra Archaeological Park (PAP) and are surrounded by six communities with a total population of approximately 19,000 (Hashemite Kingdom of Jordan, 2015).[1] Petra is Jordan's most popular tourist site and receives hundreds of thousands of visitors each year. Consequently, tourism and related services are the region's main avenue for economic growth and its main employer apart from the public sector. After peaking at almost one million visitors in 2010, the number of visitors to Petra has since decreased significantly, with 410,000 in 2015 and 464,000 in 2016 (Petra Development and Tourism Regional Authority, 2016). Visitor numbers are highly sensitive to external events, both regional and global. The shrinking of tourist numbers since 2010 is related to the ongoing political and humanitarian crisis in neighbouring Syria, which has negatively impacted the tourism sector nationally and regionally. Conversely, following the World Heritage designation in 1985, visits that year more than doubled and when Petra became one the new Seven Wonders of the World in 2007 in a global competition, numbers increased by 50% the following year.

Management of Petra has been a source of some regional strife over the years. Competing interests and conflicting disputes over land rights and access by the former Bedouin dwellers of the site have created an atmosphere of mistrust and, sometimes, outright antagonism (Farajat, 2012; Ma'ayeh, 2010). Other concerns about its management have had to do with the prioritisation of development and investment over preservation of the site and in contradiction with sound cultural heritage practice. Petra's designation as a UNESCO World Heritage site in 1985 led to a dramatic increase in visitors, which elicited concern about dangers posed by heavy human traffic. It was this concern over potential threats to the ancient site as well as

[1] The PDTRA, however, puts the population of the Petra region at approximately 31,000; see http://www.pdtra.gov.jo/page.aspx?page_key=key_people

concerns over poor management that led to the establishment of the Petra National Trust (PNT), an Amman-based non-governmental organisation, in 1989 (and where the authors worked 25 years later). PNT initially limited itself to advocacy and monitoring through "promot[ion] and coordinat[ion of] Jordanian and international efforts to preserve the unique combination of antiquities, natural environment and human traditions in the Petra region" (Petra National Trust XE "Trust", n.d.). Through various archaeological and preservation projects carried out over the years under PNT's aegis, by securing funding and enlisting the efforts of archaeologists, engineers and local and national authorities, Petra is now a safer and better understood site (Petra National Trust XE "Trust", n.d.). PNT has also monitored decisions made by the various managing authorities, most recently the PDTRA, to ensure that they were aligned with best practices and World Heritage expectations.

Beginning in 2010, PNT supplemented its role as an advocacy and watchdog agency by branching into youth awareness and outreach programs. It is this renewed vision that brought both of us (the authors) to the organisation with Angela in a voluntary capacity as an education and youth engagement advisor in 2013 and 2014, while Diana was the Director of Education, Outreach and Awareness from 2014 to 2015. Buoyed by the idea that Petra's local community was the archaeological site's best advocate, PNT developed popular and successful youth engagement programs aimed at raising awareness among children (from ages 7 to 18) of

> the *cultural and natural value* of Petra by underscoring the inextricable link between good practices in cultural heritage management and long-term economic gains… PNT's programs *aim to instil those values that render Petra a World Heritage site* and the importance of its preservation for the benefit for [sic] the community, Jordan and the world at large. (Petra National Trust XE "Trust", n.d.)

As we can see here and by the organisation's own admission, PNT's education focus is guided by the values that have rendered Petra an UNESCO World Heritage site.

Inscribing Values: The Role and Vision of UNESCO

UNESCO was established in 1945 as one of the arms of the newly established United Nations, which was created in the aftermath of the Second World War. UNESCO seeks to promote mutual understanding among member nations by promoting international collaboration on educational, scientific and cultural initiatives as a means toward ensuring world peace and avoiding future armed conflict. In 1972, UNESCO adopted the Convention Concerning the Protection of World Cultural and Natural Heritage, and created the World Heritage Fund to assist member states in identifying, preserving and promoting World Heritage sites with the intent of getting those sites inscribed onto the World Heritage list (Keough, 2011; UNESCO, 2008).

Inscription onto the list results when a state that is party to the World Heritage Convention submits an exhaustive file on the merits of the site in question, pushing forward the case that the site—whether cultural or natural—is indeed worthy of special status as a heritage site that can be considered part of the world's patrimony. For a successful submission to be made, a site must possess what UNESCO calls "Outstanding Universal Value" (OUV), which is acknowledged if the site fulfils at least one of the ten criteria that may render it as having such value (UNESCO, 2008). As mentioned previously, Jordan succeeded in placing Petra on the World Heritage list in 1985, and did so by demonstrating how the site—both the ancient monuments and its natural habitat—possesses the following characteristics (numbers correspond to the position of each criterion in the list):

i. Represent[s] a masterpiece of human creative genius
iii. Bear[s] a unique or at least exceptional testimony to a cultural tradition or to a civilization which is living or which has disappeared
iv. [Is] an outstanding example of a type of building, architectural or technological ensemble or landscape, which illustrates (a) significant stage(s) in human history. (World Heritage Convention, 1985)

It is worth noting that in the context of this book, these OUVs could be linked to values that are considered relevant and meaningful to science and science education in the forms of creativity (i), human endeavour (iii) and innovation (iv), respectively.

As one can see from the list above, the criteria are rather vague and broad, prompting one scholar to wonder how it is that every historical or culturally significant site in the world has not already made it onto the list (Shepherd, 2006). The 1972 Convention defines cultural heritage sites as "works of man or the combined works of nature and man, and areas including archaeological sites which are of outstanding universal value from the historical, aesthetic, ethnological or anthropological point of view" (UNESCO, 1972). In her critique of the World Heritage program, Keough (2011), quoting Boer, notes that even the definition of "outstanding universal value" as it appears in the Operational Guidelines of the World Heritage Committee—"cultural and/or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity" (p. 601)—does not clarify things much further. With no qualifications for what "exceptional" or "importance" are meant to signify, except that they are universally so, Keough explains that this vagueness gives the World Heritage committee member states (there are currently 21) "incredible latitude… in choosing which sites are suitable for inclusion" (p. 602). She also says, "As a practical matter, this leaves open an equally incredible opportunity for misuse of this latitude, as there are no sequential criteria that a site must pass through on the journey to inscription" (p. 602). Nations are free to choose which sites are worthy of nomination, and there is no official UNESCO body that is mandated with that duty.

Furthermore, the notion of heritage and how it is acknowledged, appreciated, and valued in the way that UNESCO does, is very much a modern (Western) construct. De Cesari (2010) describes how "[a]t the intersection of nationalism and colonialism, a concept of heritage developed between the nineteenth and the twentieth centuries as the shared past of the nation-state, along with the infrastructure required to manage it" (p. 305). The concept of "world heritage," she continues, took shape as something that needed protection from the "disruptive effects of modernization," namely the unprecedented levels of physical, economic, cultural and human destruction that two successive world wars wreaked upon the European continent. De Cesari cites other cultural heritage scholars who are critical of the UNESCO World Heritage system, calling it "a case of Western imperialism because Western languages, values and practices of the past, genealogically related to the nationalist and capitalist projects (Gamboni, 2001), are subtly imposed at a global level as best standard practices" (p. 306). These critiques suggest a call for action in terms of finding and documenting different ways of valuing World Heritage by showcasing the perspectives of the stakeholders themselves.

Grassroots Values: Perceptions from the Local Community

We consider ourselves as 'inside outsiders' to this story. Our work has involved us advocating for Petra through a significant education, outreach and awareness programme focused on the children and young people living in the six communities surrounding the site. While much of that work has been guided by UNESCO's perspectives of how the Petra site should be valued, for this chapter we feel that it is important to take a step back from this association and to capture the perspectives of those more directly connected with the site through their lives and work. In the spirit of breaking through the layers of politics and privilege that exist to capture the lived experience, we are enabling a number of stakeholders to speak for themselves to give voice to the values that they associate with and ascribe to Petra.

In achieving this, five conversations were held around the key question, *what value does Petra have to you*? The five people who contributed to these discussions have various connections and interactions with the site and were either been born in the Petra region or had lived in one of the communities for a significant amount of time (over 15 years). In brief, these individuals were:

- *Abdullah* – shop owner (souvenirs), located at the entrance to the site;
- *Hisham* – tour guide for the Petra site and regional attractions;
- *Hani* – manager of a hotel positioned close to the Petra site;
- *Amira* – principal of a primary school located in one of the communities; and
- *Ahmed* – works with Tourist Services and Protocol for the Petra Development and Tourism and Regional Authority (governmental body).

Each conversation is captured in the following snapshots and is intended to highlight the perceptions of five individuals, who have a lived experience of Petra, by emphasising the values they identify with or place on the site.

Abdullah: Weighing Up Historical Value Against Dollars

To Abdullah, a shop owner, Petra is of historical and economic importance. "Its historical value means a lot to us, for the people here, Petra means a lot. It [also] means a source of income." In capturing the historical importance of the site, he used words like "civilisation" (*hadara*) and "existence" (*wujud*), which suggests a significant and ongoing connection. The following quote captures how the historical value of Petra means more to Abdullah than its economic potential:

> It's more than a source of income, and maybe, what can be more important to a human being than a source of income?

Equally, the historical value that he places on the site is underpinned by a deep emotional connection:

> For example, many visitors who come, and especially Arabs, they are the people who affect us the most. That person who, when he returns [from visiting the Petra site], says to you, I'm never coming back. Petra, it's just a bunch of stones!

Abdullah shares a sense of being "annoyed that these people don't value me, [and] the region's history and civilization". Interestingly, he believes that visitors to the Petra site from outside the Arab nations seem to value the site more than local visitors.

Hisham: Beauty and Culture Go Hand-in-Hand

Hisham, a tour guide, connects with Petra on a historical and aesthetic level. Initially, in the conversation, he focused on the historic worth of the site.

> Its value is great for those who understand its historical value. Petra has a long history, which goes back more than 2500 years, when the Nabataean Arabs first settled it.

However, Hisham goes on to express adamantly the aesthetic importance of the site:

> Whoever goes to Petra is dazzled … with its wonderful colours. In addition to its aesthetic value stemming from the colours, there is the aesthetic value of the rock carvings.

For him, these two values are interlinked in that you cannot truly connect with the aesthetic elements of Petra if you don't understand the site from a historical perspective. The following quote helps to illustrate this viewpoint.

> One day, for instance, there was this Arab man who wanted to visit Petra but he found the entrance ticket too expensive. He said, I don't want to see Petra. Why should I go see a bunch of rocks? Of course, this person knows nothing, he thinks it's a bunch of stones. A lot of visitors come and don't hire a tour guide; they visit and look and don't know/understand anything. That's why we encourage [visitors] to hire tour guides so that they learn about Petra's history. If you don't know the history of place, you won't enjoy it.

As a counterbalance, Hisham admitted that as a boy and even as a young man, before becoming a tour guide and having to learn about Petra's history in detail, "we'd look at the rocks and we wouldn't know what it all meant." He also touched on an interesting point—"Petra came in second place in the New Wonders of the World competition in 2007"—which provides insights into the value of the site in terms of increasing the profile of the region as a place to visit as a tourist, which has economic overtones.

Hani: Local, National, International

Like Hisham, Hani, a hotel manager, connected with Petra on historic and aesthetic levels. Both of these factors are at play in his use of the term "unique" which he used several times to describe the site:

> It's something distinguished, not only unique. Distinguished. I mean, the wow-factor once you reach the end of the Siq, and you see the greatness of the Treasury, it is something that I would not exchange it with money of x, y, z. Petra is unique, yes.

Through the conversation, Hani went on to highlight the role that local people have in maintaining this uniqueness and the factors that are threatening this. "Petra has a lot to offer, but we have to upkeep Petra. There are certain things that need to be somehow eliminated in order for Petra to be able to give as long as we live." For him, the upkeep of Petra isn't about spending money to restore or fix things, but about changing attitudes and expectations of local people to ensure the longevity of the values of the site as well as long-term economic sustainability.

> This is what we have been taught and learned over the years. Values differ according to, maybe to [one's] own benefit, let's say. And I always say, people of Petra, yes they do value but not the way, but they don't give Petra the real value.

Hani's comments get at the tensions that exist between the historical and aesthetic aspects of Petra that essentially bring people to the site and the economic values, which sustain the livelihoods of the local people. His insights have been gathered through his contact with international guests visiting the site. To Hani, the profile of Petra as a New Wonder of the World again highlighted the tension between a tourist versus local view of the site. For tourists, it is about valuing the historic and aesthetic aspects of Petra, while for some locals it is about the economic benefits that flow from an increase in tourist numbers:

> It means something to them in terms of it is a money factory-destination. They generate revenues out of it.

He was acutely aware of the repercussions of these things on how people may then represent Petra, the country and the region when they go home. For Hani, the value that Petra gives to the country and its people is much more than economic, it is about reputation and in many ways Petra becomes the spotlight that shines a light on this for better or worse.

> I value it for what's giving; for what Petra is giving to Jordan. I mean, people would, maybe they would not know Jordan unless they know Petra. Or they come to Petra to experience Jordan, and sometimes it's the other way around; they come to Jordan to experience Petra. So Petra is something unique. Unique in culture, unique in destination, unique in place, unique in everything.

Amira: Beauty Amongst the Instability

Amira, a school principal, valued Petra historically, economically and aesthetically. Similarly to Hani, she held an awareness of what the site meant not only locally, but at an international level because of the "ancient cultural heritage" of the site. Amira identified that "this heritage calls upon us, young and old, to preserve it and hold onto it". Somewhat different to the others, she held a bigger picture insight of the economic value of the tourism that Petra attracts as a "source of income, let's say, for Jordan or one of the Jordanian economic channels" rather than for individuals per se.

For Amira, Petra had been a key influence in the "recovery/resurgence of the Jordanian economy because it was able to attract so many foreign tourists" even though the instability of the region has reduced the numbers coming to the site. "The reason is not Petra itself, or Jordan; it might in fact be due to the Arab Spring and the effect it had on the whole Arab world". Emotions also have an underlying role in the ways she believed people value the Petra site because despite the unrest and uncertainty active in the area "Petra still carries this special place in all our hearts". This is an interesting comment considering Amira had only visited Petra once. Despite this, she was very clear in differentiating her visit to Petra from when a tourist (essentially an international guest) visits the site.

> Look, a tourist comes to Jordan, truly, I mean, he hears about Petra and he comes to enjoy Petra and to discover what this cultural heritage is that everyone enjoys. Indeed, the tourist [is able to] enjoy Petra. As for me, I went as a visitor, not for enjoyment—the first kind of visit (e.g., tourism) is for enjoyment—I went on an exploratory visit.

Amira has lived in one of the communities surrounding Petra for 16 years. She has noticed that when she mentions that she lives near Petra, this conjures up images of "generosity, quality, history, something ancient" from the others living outside the region. The beauty of the site was not lost on Amira, but she had not returned because she has children and she feels that "when you want to admire beautiful scenery, when you want to enjoy/experience things as a tourist, it's best not to bring your children with you because they really hinder your movement". Regardless, Amira had a way to poetically articulate how beautiful the site was despite her lack of experience in engaging with the site directly, which is many ways seemed spiritual in nature.

> When you go to Petra you want to enjoy it because it contains [within it] the meaning of sublimity, beauty and grandeur. All of this is embodied in Petra, and if you really want to enjoy it you shouldn't take children with you.

Ahmed: Respect and Pride

Cultural components are what connect Ahmed, the Head of Tourist Services and Protocol, to Petra. He exuded a sense of being very fortunate to have a site such as Petra in his country and part of his cultural heritage. For Ahmed, in thinking about the site in this way, it seems “priceless” and above being just about how it is valued or what its values are. Interestingly, he talked about his connection with Petra as being a “relationship” being borne out of “respect”. It seemed that the site has given Ahmed the opportunity to not only share his culture, but to learn a great deal about cultures from all over the world without needing to leave the region.

> It’s because of Petra that [people of] different cultures from far away places, from all over the world, pass through either Taybeh or Wadi Musa, two of the six communities around Petra, it’s because of their visits to Petra that I was able to get to know these various cultures. Now, these cultures have their positives and negatives, and based on what one can acquire from [these encounters], it’s either positive or negative.

Ahmed held a sense of pride about the site and his ability to provide tourists with a good experience. This was captured in an example he shared about enabling visitors with special needs easy access to the site, so thinking about what their needs were and finding solutions to some of the issues they faced (e.g., difficult terrain and long distances if using a wheelchair, etc.). This pride was also sensed in Ahmed’s understanding of the international reputation of the site through being recognised as a New Wonder of the World, a place that the King of Jordan draws attention to and that other agencies want to be connected with.

> This means that it is an honour to be here, in this place that is important to every eye that has seen it, every ear that has heard [about] it, and everyone who has visited it.

‘More Than Just Stones’: What These Narratives Tell Us

What emerged from these conversations in response to the question—*what value does Petra have to you?*—was a convergence around three key values as identified by these community members in relation to the Petra site: historical/cultural, economic and aesthetic. While these values will not be explored in detail, they will instead be juxtaposed against the values UNESCO ascribes to the Petra site, with comparisons made between the stakeholders’ ways of expressing the value of this site to local people and ways a Western organisation articulates what matters.

Over 2000 years ago the Petra site started to take the shape that it is famous for today and in doing so became a key location for rest, renewal, commerce and trade on the camel caravan trails crisscrossing the deserts of the Middle East. As the snapshots above capture, Petra remains a place of refuge for quiet reflection, for escape, for wonder and awe, and for being reminded of cultural and historical connections. Arguably commerce and trade also still exist in the form of tourism. The creativity, human endeavour and innovation that made Petra what it is, as named by the OUVs ascribed by UNESCO, make the site a tourist drawcard to the region in its own right. With close to a million people visiting the site at its peak, the desire to experience Petra has not been without its pitfalls, with short-term economic gains and long-term preservation goals often at odds with each other. The snapshots above give voice to members of the local community and start to get at these tensions. A range of points emerge from these conversations, but for this collection two particular messages are considered in more detail in relation to the nature and role of values more generally and specifically with links to science education: perceived value and balance.

The designation given by an international organisation, like UNESCO, has a significant influence on how something is valued on the global stage. Petra is a case in point with visitor numbers doubling within a year of being inscribed on the UNESCO World Heritage list. Interestingly, this doesn't register with stakeholders in the same way as experiencing success in a commercial popular contest (naming the New 7 Wonders of the World) did. This labelling of status is juxtaposed against the significant differences in how international tourists regard the Petra site in comparison to regional Arab visitors. What we sense is coming to the fore is the role of perceived value and the complexities that exist when we think we should value something in a particular way because others tell us that it is important or that it matters. This is perhaps most evident in the narratives, and becomes increasingly complex, when notions of identity and connectedness start to get tangled up with the economic value of Petra for both local communities and Jordan more generally. The snapshots captured in this chapter speak to the messiness of a values-based approach to understanding a site such as Petra because what matters plays out differently in relation to need.

The notion of perceived value can play out in relation to science when we consider the divide that can exist between scientifically-accepted ways of making sense of the world and other more culturally-derived ways of understanding. Equally this notion may play out when weighing up problems and considering where scientific resources (human and material) would be best used. For example, should priority be given to solving developing world issues (e.g., eradicating malaria) over more first-world issues (e.g., obesity)? Both of these scenarios start to raise questions about whose values should be prioritised in these circumstances and why. Coming to a definitive answer is not easy and perhaps not even necessary. Recognising that it is not about prioritising whose values matter more starts to become important alongside acknowledging the validity in different ways of valuing knowledge and its application.

It has become evident to us as this chapter has unfolded that there are more similarities between the ways that Petra is valued internationally and locally than there are differences. Notions of cultural importance and aesthetic qualities are similar threads running through the snapshots we have shared and our documented understandings of how UNESCO values this World Heritage site. However, it seems that the differences lie in the reality of how the site is lived and experienced by the various stakeholders. In particular, the role and contribution of economics to Petra, in terms of livelihoods both locally and nationally, is where some key differences and even tensions lie. It is important to note that these things aside, whether internationally positioned (big picture) or locally connected (little picture), both parties have valid ways of valuing Petra. Viewing the site in this way brings opportunities to strike a better balance by creating a more holistic and inclusive approach to considering what matters and why.

The notion of striking a balance between values systems in science may not always be appropriate or achievable, but it does provide a pause for thought in terms of weighing up different ways of connecting with the world. It proves to be particularly useful when grappling with contentious issues (e.g., the use of uranium as a sustainable energy solution). Using a different lens can help us to be mindful of possibilities and to make more informed decisions about the science we encounter. But like our discovery regarding the values connected with Petra, there are possibly more similarities in the values systems embedded in the science community than there are differences. Despite differences in opinions and perspectives, the values connected with creativity, human endeavour and innovation—three important components underpinning science practice and thought—and their connection to scientific understandings and knowledge are typically unwavering.

Concluding Thoughts

This chapter may not connect cleanly with science education, but what we have tried to achieve through sharing these snapshots is to explore the values that emerge from lived experiences of a science-rich site. By positioning this against the values held by an international organisation like UNESCO, we were highlighting where tensions might exist in terms of the values associated with the Petra and how, and whose, values might be privileged. What this chapter does offer science education is an opportunity to consider what we think about values in terms of how they may play out in lived experience (rather than in theory or on paper) and what multiple and diverse perspectives can do to provide more nuanced understandings. By considering values in action in this way, it is possible to engage in more open dialogue around the importance of values and to promote thinking about the role context plays in making meaning.

This chapter also offers science educators with an authentic case study that highlights two key considerations that can be integrated into science learning experiences. Firstly, it provides insights into a real world example of how science can be applied to help make sense of the world, in this case, through archaeology and all that it has uncovered about the science concepts and practices at play in Petra. And secondly, through raising awareness of the tensions that can exist between different stakeholders and their value sets, this work provides a contentious issue for discussion: by visiting a World Heritage site like Petra, are we helping or hindering the preservation and protection of this science-rich location?

In the end, whose values matter when it comes to Petra? Our work highlighted three characteristics that UNESCO ascribed to Petra, which are largely cultural values. We also made connections with three values that are important in the science community—creativity, human endeavour and innovation—all of which have relevance to what has been achieved at this site over time. Through discussion with local stakeholders, we discovered three common values that are important to the people of Petra—historical/cultural, economic and aesthetic. Through our own grappling with the inherent complexities, we recognised a number of overlapping similarities in the values that stakeholders connect with this site. For example, the beauty of Petra was captured in expressions such as creative masterpiece, innovation and aesthetics. Where differences did exist, and this was mainly in the name of economics, they did tend to drive a wedge between stakeholders and the values they connected with Petra.

This work highlighted for us that a site like Petra will naturally mean different things to different people. While there will be core values that will act to bring stakeholders together, the challenge will exist in being able to find respectful ways to balance out the differences.

Acknowledgements The authors thank Huda Amarin for her invaluable assistance in facilitating interviews with stakeholders in and around the Petra site.

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D. Corrigan et al. (eds.), *Values in Science Education*,
https://doi.org/10.1007/978-3-030-42172-4