The Challenges and Opportunities for Embracing Complex Socio-scientific Issues As Important in Learning Science: The Murray-Darling River Basin As an Example

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Abstract Socio-scientific issues present a great challenge to science educators that are charged with equipping students—as future adult citizens—with the knowledge, skills and attitudes to understand and respond to them. These issues, such as climate change and over-exploitation of resources, are increasingly prominent in our lives. Complex socio-scientific issues are often defined by an interrelated set of smaller issues, they can have vast social impacts and their scientific basis is often uncertain or contested. The increasing global conflict around water, in particular in rivers that flow across territorial or national boundaries, is a notable example of one of these issues.

In Australia, the management of the Murray-Darling River Basin, which underpins a large part of the nation's agricultural economy, became the focus of intense public debate in all forms of the media between 2010 and 2012. At the same time, a new national curriculum for school science was being developed. In this chapter, we use the Murray-Darling controversy as a context to investigate how this science curriculum might facilitate teaching and learning of socio-scientific issues (SSIs) by considering this SSI. We adopt the analytical tools of frame theory and boundary work to assess:

(i) the role of science in the controversy surrounding this SSI;
(ii) the strengths in the science curriculum to make a contribution to understanding the science involved; and

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(iii) the lessons that can be drawn from the Murray-Darling controversy about how the science curriculum might better equip teachers and students to tackle such complex SSIs.

Keywords Socio-scientific issues · Science curriculum · Framing · Boundary work · Water management · Science controversy

Introduction

Ever since the official endorsement of ‘Science for All’ in the 1980s (Fensham, 1985), authorities responsible for science education have acknowledged that school science has a definitive role in equipping all students, as future adult citizens, with the knowledge, skills and attitudes needed to participate in the ways that science and technology (S&T) influence society.

As a first response to ‘Science for All’, there was a spate of interest in introducing real world S&T contexts into the science classroom. These innovations used technological applications of science to link science and society and collectively they became the Science–Technology–Society (STS) movement (Solomon & Aikenhead, 1994). Unfortunately, they made little impact on official science curricula because wider reforms of schooling were occurring, which included establishing Technology as a new subject area for a number of existing ‘make and design’ subjects. This sense of ‘Technology’ was very different from the ‘applications of science’ meaning it had in the STS movement. Nevertheless, ‘making decisions about S&T issues’ persisted as a goal of school science and became increasingly common among its list of intended outcomes (Aikenhead, 1992; Kortland, 1996; Ratcliffe, 1997)—although there is little evidence from international curriculum-based studies since 1994 to indicate that ‘making decisions’ has become a serious part of the mainstream school science curriculum (Thomson, Hillman, & Wernert, 2012).

How this learning outcome can be taught in school science has, nevertheless, been a major twenty-first century interest for science education research. Some of these studies have been concerned with the scientific processes that are components of decision-making. Others have gone further, engaging the teacher and students with an actual or précised account of a real world science and technology issue in order to make decisions about it. Because these issues have societal dimensions as well as scientific ones, they are referred to as socio-scientific issues (SSIs).

SSIs vary greatly in the science that is involved and in their societal impact. Some involve relatively simple knowledge of science and its application while others require both disciplinary and interdisciplinary scientific knowledge, as well as a substantial appreciation of the Nature of Science. In relation to the societal influence of SSIs, this can range from a localised group of citizens to large sections of a national society and beyond to the international community. At the latter end of these two spectra, where the science knowledge and the ramifications on society are both very broad and significant, the issues can be described as ‘complex’.

In this chapter we discuss the challenges and the opportunities that complex SSIs present to school science education. As an example, we use the case of the Murray-Darling River Basin in Australia to provide a set of scientific reference points against which Australia's new national science curriculum is judged for the opportunities it provides for teaching such a complex SSI. In doing so, we draw out in detail the science of this SSI and use insights from the sociology of science to examine how scientific evidence and expert authority are sometimes challenged by public scrutiny.

We conclude by reflecting on both the opportunities and challenges presented by the inclusion of complex SSIs in school science education. For example, SSIs challenge the traditional notions of students as intellectually independent learners in school science education, and suggest that a goal of *intellectual dependence* is also needed. Furthermore, we argue that some key common features of the science in SSIs will require a willingness among science teachers to embrace new pedagogies in their classrooms.

Complex Socio-scientific Issues

A number of more complex SSIs were identified in the beginning of the twenty-first century as Grand Challenges and Opportunities (AAAS, 2006; National Research Council, 2001). Decision-making about them falls into Rittel and Webber's (1973) category of 'wicked problems' because they are not single issues but are made up of a set of inter-related issues. Often these issues require high-stakes decisions to be made urgently, when the scientific and societal aspects are still uncertain and incomplete, and the related values are in dispute. Funtowicz and Ravetz (1993) invoked the term 'post- normal science' to describe the type of knowledge required for this decision-making. Once the SSI is presented in the public arena the diversity of stakeholders often expands, drawing into question the type of evidence that is considered relevant and who should be considered an expert.

Complex SSIs present a great challenge to school science education, because the science involved is invariably beyond what is included in the curriculum. Nevertheless, because they have significance for so many citizens and future generations they cannot be ignored. Some current ones are issues associated with climate change, food production, biodiversity, and the over exploitation of natural resources. Prominent among the last of these is the issue of access to water, which crosses territorial or national boundaries and is a matter of increasingly intense debate and diplomacy (Poff et al., 2003; Sullivan, 2014).

The Murray-Darling River Basin is an Australian example of an *access to water* issue. The Murray-Darling is Australia's largest river system, spanning over one million kilometres and passing through four of Australia's six states, each of which historically held the rights and responsibilities for the use of its water. Environmental concern and the intervention of the national government have recently led to the development of a management strategy for the river system. This intervention mobilised a diverse range of stakeholders. It also incited conflict over the social needs for water extraction and the environmental requirements for the rivers basin's functioning ecosystems.

The attempt to manage the Murray-Darling River Basin highlighted the scientific, economic, cultural and political considerations that are involved in all complex SSIs. In particular, it demonstrated how scientific evidence and authority is defined and challenged in public controversy.

The Renewal of Interest in S&T Issues for School Science

In the early 1990s, as the STS movement was petering out in relation to school science, a few science educators began to conduct case studies of small groups of citizens who had a 'need-to-know' about a local S&T issue affecting them (Irwin & Wynne, 1996; Layton, Jenkins, Macgill, & Davey, 1993). Even when the science involved was relatively simple, they found it needed more direct translation and its trustworthiness had to be explained. When decisions were made the science was still weighed against a range of other information. A review of 31 studies by Ryder (2003) confirmed the need for understandable scientific information but also for some appreciation of science's procedures for achieving knowledge, including how data are evaluated and used as evidence.

To an extent inspired by these studies in the public arena, there was a renewal of interest among science educators in 'making decisions' about S&T issues in school science. For example, Driver, Newton, and Osborne (2000) introduced into science classrooms scientific argumentation as it relates to decision making in both scientific contexts and in S&T issues. This extended the meaning of the 'Nature of Science' beyond the procedural sense of inquiry it had hitherto had in school science (Bell & Lederman, 2003). Others (e.g., Kolstø (2001) in Norway, and Zeidler, Sadler, Simmons, and Howes (2005) in the USA) took these studies a step further by introducing school students to a précised outline of an SSI issue and engaging them with its particular science, its scientific procedures, and its social implications. Of course, the content knowledge of science varies from issue to issue, but it can be taught in the classroom if it is relatively simple or it may have already been covered in science curriculum. However, what is common to SSIs, and to making decisions about them, is this more extended notion of the Nature of Science: an opportunity and a challenge for any science curriculum, as we discuss later in the chapter.

The studies of SSI science teaching have led to considerable debate among science educators about the extent to which the non-science aspects of an SSI should be included in science teaching. Levinson (2006, 2010) provided frameworks (See chapter "Pregnant Pauses: Science Museums, Schools and a Controversial Exhibition", this volume) for teaching both the scientific and social aspects of SSIs that call for a dialogic and democratic style of pedagogy that is very different from the transmissive and authoritative discourse that is so commonly used in science classrooms. Zeidler and Sadler (2008) have stressed the importance of making moral and ethical aspects explicit. Bencze and Carter (2011) argued for a more radical extension of Hodson's (2003) call for students to engage in socio-political action about the issues. On the other hand, Hodson, Bencze, Elshof, Pedretti, and Nyhof-Young (2002) and Levinson (2004) both provide cautionary evidence from science teachers and students against extending the boundaries of science education too far.

We do not contest the importance of the non-science components of SSIs. It will be evident that they were very important in deciding the final management plan for the Murray-Darling. However, as far as the mainstream science classroom is concerned, we assume that a lay acknowledgement and open discussion and debate about them is what ought to be expected of teachers and their students if SSI teaching is to be established in mainstream science teaching. Accordingly, in our analysis of this example of a complex SSI, our focus is on its science content and scientific procedures and how these were played out in the public debate and in the political resolution of the issue.

The findings of the analysis then become a set of reference points against which Australia's new national science curriculum is judged for the opportunities it provides for teaching this SSI's science content and procedural knowledge, and how it is challenged to better contribute to such decision-making.

Socio-scientific Issues and Public Deliberation

The deliberation of complex SSIs in public arenas can frequently erupt into controversies that provoke fervent and widespread disagreement. Over recent decades, sociologists of science have made extensive use of these controversies to produce important insights about the relationship between science and society (for a foundational example see Nelkin, 1979). In practice, these studies reveal that the closure of a controversy is often not found in the traditional domain of science, but is the result of negotiation across a range of social spheres.

One key determinant of how a controversy finds closure is through the way in which the problem is framed. Developed in early work by Goffman (1974) as mental structures that facilitate our basic interactions with the world, frames have more recently been applied to controversy studies as "underlying structures of belief, perception, and appreciation" that determine our policy positions (Rein & Schön, 1994, p. 23). Framing can be used to understand how different interpretations emerge of what a problem is, what evidence or expertise is relevant, and how a problem should be resolved. In particular, it has been shown that SSIs that are treated as purely 'scientific' or 'regulatory' often become unravelled as other publics seek to make sense of, and respond to them. Bonneuil, Joly, and Marris (2008), for example, examined how a scientific framing of research into genetically modified crops in France was rapidly challenged by publics more concerned with questions of who should benefit from the technological development. As such, identifying and adapting to emergent framing of SSIs becomes an important part of understanding and responding to them. As demonstrated by the case of the Murray-Darling, competing frames can limit productive dialogue in resolving SSIs.

The application of frame theory in science education is still in development but it has been used in recent studies of the transfer of learning in science (Engle, 2006; Patchen & Smithenry, 2013). It also has rich potential for the new emphasis on communication in science that science curricula are now including (see Gilbert & Stocklmayer, 2013; and chapter "Communicating Science" by Sue Stocklmayer).

In addition to exposing SSIs to competing frames, public deliberation can also throw into question the boundaries of science itself. As science is increasingly called upon to respond to pressing societal concerns, the traditional demarcation of science as distinct from other forms of knowledge making can become challenged (Jasanoff, 1987). The strategic efforts used to maintain, or modify, the demarcation between science and non-science is called 'boundary work' (Gieryn, 1983). The boundaries between science and other knowledge sources become particularly important in the resolution of SSIs. As outlined above, complex SSIs are often reliant on forms of post-normal science and, amongst the emergent groups of spokespersons, claims to scientific expertise can easily become contested. In these volatile spaces, the pre-negotiated boundaries of science and politics can break down, making choices about who to trust as an expert ever more difficult (Collins, 2009).

In science education, boundaries are drawn as to what knowledge is included in the science curriculum, in the choice by teachers of what contexts to bring into the science classroom, and how they choose to teach about them. School roles, for example of 'science teacher', 'biology teacher' or 'physics teacher', can also reinforce boundaries. In wider society, beyond the school, when complex SSIs are involved, delineations break down, and who represents science is much less clear. In the example of the Murray-Darling River Basin, which we now describe, the debate surrounding its management illustrates this blurring of boundaries.

The Murray-Darling River Basin

As with many large-scale river systems worldwide, the Murray-Darling River Basin is a central feature of the national agricultural economy and has played an important part in the lives of indigenous people for thousands of years. The large-scale production of wool, cotton, and food, accounting for 40% of the national agriculture income, underpins the economies of hundreds of communities. However, it has become increasingly recognised that these extraction industries are now leaving too little water to sustain a healthy river system and threatening its long-term ability to support extractive uses into the future.

For over 100 years, the four state and the single territory governments located within the Basin have determined water allocation from the river. However, ongoing conflict between them has led to the need for a nationally-coordinated water management plan that would achieve more equitable access to water resources, while balancing the ecological health of the river and its associated ecosystems. By the start of the twenty-first century, the management of the Basin had become a hugely divisive environmental issue, the resolution of which had become increasingly politically urgent.

An initial attempt to introduce a national management plan was made in 2003, but increasing conflicts over how best to proceed scuppered any progress (see Crase, Dollery, & Wallis, 2005). In 2007, the Australian Government passed the Commonwealth *Water Act 2007,* which was intended to facilitate the reduction of water extraction to environmentally sustainable levels, while optimising associated social and economic returns. The Act established a small independent and expert body, the Murray-Darling Basin Authority (MDBA), to develop an implementation plan. The Authority was responsible for setting out evidence and providing a set of recommended policy options to the newly enacted Murray-Darling River Basin Ministerial Council, comprised of the national Minister for Water and a minister from each of the four state governments involved.

In 2010 the Authority published an initial *Guide to the Proposed Murray-Darling Basin Plan*, which set out clear environmental targets and recommendations for an annual allocation of water to be returned to the river (in Gigalitres per year, GL/y) for environmental flows (MDBA, 2010).

These targets took into account a range of aspects, including:

(i) the legal rights of indigenous persons to hunt, gather and fish in these inland waters
(ii) the conservation of the biodiversity of the rivers' ecosystems—the natural habitats of many species of flora and fauna are now so degraded that 16 of its 80 mammals and 17 species of fish are endangered
(iii) the protection of the Ramsar-declared wetlands and the internationally listed water-dependent ecosystems used by migratory bird species
(iv) the connectivity of the rivers and the flood plains
(v) the prevention of salination of the river flood plains, which threatens food webs that sustain water dependent ecosystems
(vi) the periodical opening of the mouth of the Murray River with sufficient flows through the Coorong, the narrow estuary from the river mouth to the sea
(vii) the relation between ground water and the rivers that maintains the quality of the water to sustain the dependent ecosystems
(viii) the system's resilience to climate change and to drought
(ix) threats from anthropogenic-related impacts (e.g., introduced species)

Most of these key targets were underpinned by scientific data and findings that had been integrated into the hydrological and environmental models used by the Authority. These scientific data and findings had varying degrees of certainty and so were assigned three levels of confidence: high (uncontested, peer reviewed), medium (data available, but not yet peer reviewed), and low (limited or emerging, needing more study). A majority of the science information had medium-level confidence and came from government-initiated studies and reports that had not been peer reviewed. The *Guide* specified that an allocation of between 3000 and 7600 GL of water should be returned to the river each year, with the two figures representing the low-level and high-level certainty of whether the targets identified in the *Water Act 2007* would be met. This volume of water to be allocated to the river became centrally important to the public debate around the issue.

The public and state government responses to the water allocations in the *Guide* were so critical that the national government reconstituted the Authority under a new chairman and a new executive officer. This new body presented an updated *Draft Basin Plan* in 2011 with an amended allocation of 2750 GL per year (MDBA, 2011a, 2011b). In contrast to the *Guide*, the uncertainties in the science were not explicitly addressed in the *Draft Plan* and the recommended allocation was not directly argued for on scientific grounds. Instead, the MDBA asked the national scientific body, the CSIRO, to convene an international team of scientific experts to review the quality of the scientific knowledge and procedures used in its development. The CSIRO (2011) review confirmed that sufficient science knowledge was available for the Authority to decide on the environmentally sustainable level of water that could be taken from the Basin. They also found that the hydrological models being used were among the best available, and that the methods of analysis and interpretation were sufficient to begin a scientifically-based adaptive management process. The CSIRO review did, however, identify gaps in (i) the scientific knowledge included, (ii) the potential of other possible modelling, and (iii) the limited use of expert scientific opinion in developing the *Draft Plan*. The review concluded that the allocation of water now specified in the *Draft Plan* would only meet a minority of the targets set by the authority in its original *Guide*.

The *Draft Plan* was put to public consultation between the end of November 2011 and early 2012, resulting in nearly 12,000 comments. Interested publics tended to congregate under existing banners, such as the New South Wales Irrigators Council, or formed new ones, such as the Basin Communities Association, both of which engaged in the debate at public meetings and through news media. A final *Plan* was then drawn up (MDBA, 2012), and on 22 November 2012 it was approved by the national parliament. The Bill for the *Plan* accepted the amended recommendation for a reallocation of 2750 GL/y, but added two important clauses: the first delayed any action for 7 years, and the second allowed the volume of water for environmental flows to be revised upwards or downwards at an appropriate future time for adaptive management. This provided a political compromise that moved action on the issue forward, albeit slowly, and provided the potential for 'learning by doing'.

In 2008, very soon after Australia's new national Labor Government made the move to nationalise the management of the Murray-Darling River Basin, it also launched a project to develop, for the first time, a national curriculum for all Australia's schools (Minister for Education, 2008).

The Australian National Science Curriculum and the Murray-Darling River Basin

The National Curriculum, a first for Australia, was to replace the diverse curricula that had hitherto been the province and responsibility of the six individual states and two territories. Science was among the first four subjects to be developed and was to be mandatory for all students during their first ten compulsory years of schooling. In the final 2 years of school, students could then choose further science studies in any of Biology, Chemistry, Earth Science and Physics.

The details of the Australian National Curriculum for Science were endorsed in 2011 (ACARA, 2014a) and it is now currently being implemented by the different state and territory authorities. This very new science curriculum provides a pertinent opportunity to analyse its educational intentions and intended learnings, and to appraise the extent to which, in the compulsory years, it could contribute to students' understanding of the Murray-Darling River Basin issue—and hence other complex SSIs. The specialised science for Years 11 and 12 are not included in the analysis below, since they are all optional studies, and none of them are chosen by a majority of Australia's students.

The Science Curriculum begins with a *Rationale* for the place of Science in the totality of school learning, and this is followed by year-by-year *Content Descriptions* of the intended science learnings. From the beginning of developing the new science curriculum it was decided the intended learning in this new science curriculum would be in three strands, *Science Understanding, Science Inquiry Skills* and *Science as a Human Endeavour*. The second and third strands were influenced by recent research interest in the Nature of Science and the promotion by the OECD's PISA project of 'Knowledge about science' alongside the more familiar 'Knowledge of science' (OECD, 2007). Having two strands that relate to the 'Knowledge about science' was innovative, and signalled the inclusion of more aspects of the Nature of Science and its social bases than have hitherto usually been included.

Early in development of the curriculum, a challenging statement for the *Rationale* was unanimously adopted that affirms that the learning of Science should be challenging and oriented outwards to applications in the wider society: Science is about "interesting and important questions", and should be related to "local, national or global issues".

A very substantial debate then took place among the team of advisers and developers about how the content for learning in Science should be conceived and listed (Fensham, 2013). This debate reflected the alternative views of scientific literacy (SL) that Roberts (2007) described as Vision I (learning content drawn from the disciplinary sciences) and Vision II (learning content drawn from relevant real world science and technology contexts). It was, indeed, a rerun of debates that have occurred in many countries about the curriculum for school science since the 1990s. The final decision was to list the science content in the key *Science Understanding* strand from a Vision I perspective. This decision reflected Bernstein's (1971) more general conclusion about curricula that the power of a few (in this case, the bureaucrats) will win over others (in this case, the scientific and science teaching experts) in defining what is valued knowledge. Furthermore, it was decided that the *Inquiry Skills* and *Human Endeavour* strands would not be tightly linked to the content knowledge in the *Science Understanding* strand.

Each of these features of the Science curriculum is now examined against the science that underpins the reference targets listed above for the Murray-Darling Basin issue.

The Science Curriculum and the Murray-Darling River Basin Targets

The Rationale

The *Rationale* makes a clear statement concerning the role of science education in decision making and that the Science curriculum aims to prepare students to make informed judgements about real world issues:

> Science provides a way of answering interesting and important questions about the biological, physical and technological world. The knowledge it produces has proved to be a reliable basis for action in our personal, social and economic lives; Science is a dynamic, collaborative and creative human endeavour arising from our desire to make sense of our world; The curriculum supports students to develop the scientific knowledge, understanding and skills to make informed decisions about local, national and global issues. (ACARA, 2014a)

This statement requires the teaching of science to equip students to make decisions with respect to SSIs of all types, including complex ones such as the Murray-Darling River Basin issue.

The Science Understanding Strand

Despite the outward-looking *Rationale*, the science content for learning in the *Science Understanding* strand is oriented inwards to the science disciplines and not outwards towards real world issues involving science and technology. The strand is therefore traditional rather than innovative. For each grade level (1–10) the content descriptions are listed under the four familiar disciplinary sub-headings of *Biological sciences, Chemicals sciences, Earth and Space sciences* and *Physical sciences*. Over the 10 year levels, the strand lists 58 separate significant science knowledge topics. However, no “interesting and important questions” involving this science content knowledge are asked, and no “local, national or global issues” for making decisions are identified. Table 1 lists the science content knowledge in the *Science Understanding* strand, by year level, that has some direct or indirect relationship to the environmental targets for the Murray-Darling river system’s health.

Although at least one of these knowledge topics could be related to each of the nine environmental targets, they do not represent enough of the underpinning science to make these targets understandable. Furthermore, much of this science is intended to be learnt in the primary years, when such a complex national S&T issue is less relevant to the majority of Australian students.

Table 1 Science content knowledge (by year level) in the *Science Understanding* strand that has potential relevance to the environmental targets for the Murray-Darling River Basin

Year level	Content descriptions
Biological sciences	
1	Living things live in different places where their needs are met
4	Living things have life cycles
4	Living things, including plants and animals, depend on each other and the environment to survive
5	Living things have structural features that help them survive in their environment
6	The growth and survival of living things are affected by the physical conditions of the environment
7	Interactions between organisms can be described in terms of food chains and food webs and humans can affect these interactions
9	Ecosystems consist of communities of interdependent organisms and abiotic components of the environment; matter and energy flow through these systems
Earth sciences	
2	Earth's resources including water are used in a variety of ways
6	Sudden geological changes or extreme weather conditions can affect Earth's surface
7	Water is an important resource that cycles through the environment
10	Global systems, including the carbon cycle, rely on interactions involving the biosphere, lithosphere, hydrosphere, and the atmosphere
Physical sciences	
6	Energy from a variety of sources can be used to generate electricity

Comment

The Vision 1 framing of the *Science Understanding* strand in terms of separate science disciplines makes it likely that the majority of Australia's students would complete their school science without exposure to many key interdisciplinary scientific phenomena that underpin the Murray-Darling River Basin issue. Soil salinity, the cycling effects of drought and flood, the impact of hydroelectric generation on river floodplains and their forests, the evaporative loss from slow and fast moving rivers, and the movement of river materials, are some topics that are likely to fall through the gaps that result from this Vision I framing. In contrast, a Vision II framing would have been very likely to have Australia's river issues as a theme at some point in Years 7–10. This would have required science teachers to teach the related disciplinary and inter-disciplinary sciences that are integral to the health of Australia's river systems and to signal their socio-scientific consequences. Although the science of any of these systems can be as complex as the Murray-Darling River Basin, numerous sub-issues involving simpler amounts of science knowledge could be identified, which may be common across river systems.

In Bernstein's (1971) view of the curriculum as a public statement, the Vision I framing of the *Science Understanding* strand creates a science curriculum that is most useful to future disciplinary scientists. A Vision II framing of the science knowledge as practical knowledge for real world contexts (Layton, 1991) would have more directly addressed the needs of all students and been in line with the outward intention of the *Rationale*.

It is noteworthy that the new Geography Curriculum does have a Vision II framing. Its themes and topics cover both the physical and social environment (ACARA, 2014b). For Years 7–10, under the headings *Water in the world, Place and liveability, Biomes and food security* and *Environmental change and management,* there are 18 topics that could be directly related to the Murray-Darling River Basin. The *Rationale* for Geography also refers to the importance of links being made with Science, but this cross boundary linkage has not been reciprocated in the Science curriculum.

The Science Inquiry Strand

The *Science Inquiry* strand identifies its intended science skills under the headings of *Questioning and predicting*, *Planning and conducting*, *Processing and analysing data and information*, *Evaluating*, and *Communicating*. The framing of this set of learnings suggests an active practice of these skills in relation to authentic contexts. This is in line with Allchin's (2011) 'whole science' approach to the learning of these aspects of the *Nature of Science*, rather than the rule and rubric manner that has often been used to teach about science inquiry.

The extensive scientific data in the *Guide to the Proposed Murray-Darling Basin Plan* (MDBA, 2010) would provide students with opportunity to practise the skills listed under *Processing and analysing*. How the *Guide's* conclusions are drawn from these data would illustrate some skills under *Evaluating*.

The skills under *Communicating* are an innovation in this Science curriculum and the developmental intention for them is evident across the year levels:

- Years 5/6—Communicating ideas, explanations and processes in a variety of ways including multi-modal texts.
- Years 7/8—Communicating ideas, findings and solutions to problems using scientific language and representations using digital technologies as appropriate.
- Years 9/10—Communicating scientific ideas and information for a particular purpose including constructing evidence-based arguments and using appropriate scientific language, conventions and representations.

Teaching for each of these involves students practising to present their own ideas, but also analysing science communications from a variety of sources. The *Guide* (MDBA, 2010) and the *Draft Plan* (MDBA, 2011a, 2011b) provide both good and bad examples of science communicating. Students in Years 5/6 would appreciate the variety of ways a river system can be presented. By Years 9/10 students would benefit from comparing the evidence-based arguments for the science claims in the *Guide* with the apparent lack of explicitly scientific evidence in the *Draft Plan*.

In relation to "Communicating for a particular purpose", the different ways the *Guide's* recommendations are framed compared with the framing of the *Draft Plan*, again would provide a good example of the importance of framing a message to meet "a particular purpose", for example, a particular target audience. Ogawa's (2013) discussion of 'drivers' and 'targets' in communication of science in private and public domains is relevant to the practice of this skill.

Comment

The *Science Inquiry* strand of the new Australian curriculum, with its expanded sense of the Nature of Science does have considerable potential for the teaching and learning of a number of intended skills. These skills apply not only to the Murray-Darling River Basin issue, but also to many other complex SSIs. However, scientific modelling, a Nature of Science skill that is gaining prominence in the management of SSIs, is notably absent in this strand. Fortunately, the research literature does have suggestions as to how this omission might be remedied in subsequent revisions of the curriculum. For example, in a review of the use of models in school science, Gilbert, Boulter, and Rutherford (1998) found that the focus is almost always on 'model' as a noun, rather than as a predictive verb. It is in this predictive sense that 'modelling' occurs in the science of complex SSIs. Justi and Gilbert (2002), in a subsequent study, found that science teachers did recognise predictive modelling as a scientific skill, and it is on this ground that a strong case has since been made to include this skill in science education (Clement, 2008; Gilbert, 2004). Justi and Gilbert's two stage process for developing modelling in science education has been further developed (Fensham, 2014) to provide a fairly simple procedure for its teaching.

The Science As a Human Endeavour Strand

The content descriptions of science knowledge in the *Science as a Human Endeavour* strand are more developmentally described than those in *Science Understanding and are organised under two substrands—Nature and Development of Science and Use and Influence of Science.* Accordingly, only those for Years 7–10 that directly or indirectly relate to the environmental targets are listed in Table 2.

All ten of these intended learnings lend themselves to be practised through the context of a complex SSI, as they certainly do for the example of the Murray-Darling River Basin. The first three learnings under *Nature and development of science* are pertinent to the Basin's science, and integral to the allocation of water in the *Guide*. Their adequacy is also the subject of comment in the CSIRO review of the *Draft Plan*.

Table 2 Intended science learnings (by Year Level) in the *Science as Human Endeavour* (SHE) strand of direct relevance to the Murray-Darling issue

Year level	Content descriptions
Nature and development of science	
7 and 8	Scientific knowledge changes as new evidence becomes available, and some scientific discoveries have significantly changed people's understanding of the world
7 and 8	Science knowledge can develop through collaboration and connecting ideas across the disciplines of science
9 and 10	Scientific understanding, including models and theories, are contestable and are refined over time through a process of review by the scientific community
9 and 10	Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries
Use and influence of science	
7 and 8	Science and technology contribute to finding solutions to a range of contemporary issues; these solutions may impact on other areas of society and involve ethical considerations
7 and 8	Science understanding influences the development of practices in areas of human activity such as industry, agriculture and marine and terrestrial resource management
7 and 8	People use understanding and skills from across the disciplines of science in their occupations
9 and 10	People can use scientific knowledge to evaluate whether they should accept claims, explanations or predictions
9 and 10	Advances in science and emerging sciences and technologies can significantly affect people's lives, including generating new career opportunities
9 and 10	The values and needs of contemporary society can influence the focus of scientific research

These learnings also acknowledge that the relevant science for an SSI can often be uncertain or incomplete, a feature of science that Kirch (2012) made a strong case for including as a learning goal for science education. She pointed out that the National Research Council in the USA, more than a decade earlier, had referred to uncertainties in science in the *Standards for Science Education* (National Research Council, 1996), and set out a two-pronged model for their teaching and learning based on their empirical aspects and their more psychological origins. Incidentally, the *Standards* were published in the same year that the international scientific community issued the *Precautionary Principle* (COMEST, 2005) as an approach to dealing with uncertainty in science for decision-making.

The Murray-Darling River Basin also offers examples that could apply to *Use and influence of science.* For example, that “Science and technology contribute to finding solutions to a range of contemporary issues”; that “These solutions may impact on other areas of society and involve ethical considerations”; and an example of “Science influencing agricultural practices” and “People using science in their occupations”. “The use of science knowledge to evaluate claims” is clearly evident in the *Guide* but is underplayed in the *Draft Plan*. The creation of the Murray-Darling Basin Authority and its charter of responsibility illustrates the importance of “The influence that social values and needs have on the locus of scientific research”.

It is the complexity of the Murray-Darling River Basin as an SSI that makes it so applicable to these learnings. Furthermore, the rich potential in the *Science as a Human Endeavour* strand is not restricted to the Murray-Darling River Basin issue. All ten of its learnings would be relevant in most other complex SSIs.

Comment

As we examine below, the case of the Murray-Darling River Basin exemplifies the range of scientific knowledge in a complex SSI and how its issues can become framed in different ways. Twenty-five years ago, Hardwig (1991) pointed out that many contemporary questions in science require the work of a number of different scientists who contribute their bit to the overall endeavour. It is common that none of them will be fully conversant with what the others are doing, but they must develop mechanisms of 'trust' within the science community. This statement also applies to the science underpinning complex SSIs, which invariably involves contributions from scientists from different disciplines, whose findings may have different levels of trust in the scientific community. Nevertheless, as in the Murray-Darling River Basin case, despite the variability of certainty and trust in the underlying science, political decisions may still be necessary.

Norris (1995) extended Hardwig's idea of 'trust' among scientists to science education by suggesting that 'intellectual dependence' is now a more realistic goal for school science than the 'intellectual independence' towards which he claimed school science has traditionally aimed. His radical ideas received little attention at the time, but now these ideas need revisiting in relation to the teaching of SSIs in science education. They do, however, need further explication, as they can be easily misunderstood. The intellectual independence, which he claimed has pertained to school science, is related to the sense of students in schooling being regarded as individuals, each expected to learn the science knowledge on offer. The constructivist pedagogies for teaching and learning that were popularised among science educators in the 1980s also treated the student as an individual developing knowledge. The later notions of social constructivism acknowledged students as more of learning a community.

In another sense, traditional science education has made students dependent on 'Science' as the bounded and established knowledge someone else has decided to include in the curriculum. They have had no independence about what or how to learn in school science. In whichever of these senses we describe the learning of the introductory pieces of disciplinary science in a typical science curriculum, Norris is arguing that a new term is needed for students' relation to the very diverse and often uncertain science in real world S&T contexts (and SSIs). He suggests that a stance of active intellectual dependence is a realistic one for science teachers and their students to adopt. This stance is not at all a passive one, as the word 'dependence' may imply, but is very active because it requires science students to learn who can, and cannot, be trusted regarding scientific claims to knowledge, and to know how to make judgements about credibility. This expertise, Norris foreshadows, will involve (i) learning science content, (ii) learning about science (its philosophical basis, historical progression, and social processes), and (iii) learning to live with science as an important—but not the only—source of knowledge. Each of these loomed large in the case of the Murray-Darling management issue.

The decision of the Australian curriculum authorities to give separate status to the three curriculum strands is fortuitous since it does not tie the second and third strands to the familiar *Science Understanding* that, as shown above, is least relatable to SSI teaching. Australian science teachers are, thus, free to choose both intra-science and out-of-school S&T contexts (e.g., SSIs) for teaching the range of skills and learnings that these two more helpful strands (*Science Inquiry Skills* and *Science as a Human Endeavour*) intend.

The success of this set of largely new science learnings will, however, very much depend on the support Australian science teachers receive in professional development and from the assessment authorities. Since these rather novel skills have not been part of the usual programmes for professional development, there will be a particular need for authorities to harness the help of science education researchers who have become aware of exemplary pedagogies that have been found in research studies to develop these skills. Similarly, the authorities responsible for assessing learning will need to publicise and use authentic modes for assessing the learning of these Nature of Science skills in context. A range of alternative modes for these sorts of assessment are also now appearing in in the literature (Allchin, 2011; Fensham & Rennie, 2013; Sadler & Zeidler, 2009). Since 2000, the OECD's PISA Science project, despite being restricted to paper and pencil testing, has also used contextually–based items to measure the learning of inquiry-based and evidence-based scientific literacies (OECD, 2007).

We now turn to the analysis of how the *Draft Plan* for the management of the Murray-Darling River Basin was reported and debated in the public domain. The role and importance of framing in this communication provides an exemplary means of access for bringing the complexity of this and other SSIs into the classroom.

Public Deliberation and the Murray-Darling River Basin

In the public domain the purely biophysical basis of an SSI loses much of its science disciplinary boundaries. The range of interest groups that are mobilised around issues such as the management of the Murray-Darling River Basin have diverse perspectives on what counts as evidence (scientific and other) and which experts are considered relevant. In order to examine the breadth of some of these perspectives around the issue of water management in the Murray-Darling, we analysed both published official documents and national newspaper accounts. Although not comprehensive in coverage, these statements provide an indication of how different communities framed the issue and conducted boundary work around evidence and expertise in the process. Forty-three newspaper articles or letters were sourced from the online repository of one of Australia's largest circulation newspapers, the Sydney Morning Herald, between the release of the *Draft Plan* (28 November 2011) and its final approval by national parliament (22 November 2012).

The analysis involved the extraction of quotes for each position-statement in the documents, articles and letters and assigning them to a category. Other perspectives did, of course, exist and they were often expressed in other sources like talkback radio. Our approach was not comprehensive, nor does it provide a measure of the dominance or relative weight of each of the categories. More simply, it reveals something of the range of perspectives that were expressed in the debate. In a similar way, any complex SSI will generate diverse responses in the public arena.

Framing of the Water Allocation Figure Among Different Groups

Throughout the debate and public consultation on the *Draft Plan*, the water allocation figure of 2750 GL/y became a central focus of division. However, the disagreement about this figure was not a straightforward disagreement about its underlying scientific basis. Rather, it was evident that an apparently scientific value such as the amount of water needed for healthy environmental flow can be understood as both 'sound science' and as 'political compromise'—a dualism that has been found in other complex SSIs.

The initial framing of the Murray-Darling River Basin as a regulatory issue goes back to the earlier attempt in 2003 at management of the river system. Crase et al. (2005) and Crase, O'Keefe, and Dollery (2013), in their study of the public debate that occurred then, pointed out that its focus on a fixed allocation of water allowed critics to claim that other important attributes of the issue had not been taken into account. Rather than simply asking a regulatory question (i.e., What is sufficient environmental flow to comply with the Water Act?), different groups queried what allocation of water was politically feasible, economically sensible and culturally appropriate.

When the question is rephrased in this way, a regulatory framing of the issue is no longer sufficient and a much broader range of evidence is now needed. Nevertheless, in the public debate following the release of the *Guide* in 2010, the Basin Authority continued to frame the issue in regulatory terms by releasing just the scientific reasoning behind the *Guide's* proposed water allocations.

This regulatory framing of the issue drew positive responses from scientific groups and environmentalists, but very negative responses from farming communities and other stakeholders, who argued it overlooked their needs and interests (Wroe, 2011). In their updated 2011 *Draft Plan*, the re-constituted Authority still presented a water allocation figure, but this time not only justified it on scientific grounds, but also on social and economic modelling (MDBA, 2011a, 2011b). The recommended reduction in the amount of water to be reallocated to environmental flows was an explicit compromise, intended to be part of on-going adaptive management of the river. However, this multiple framing of the issue as both a regulatory necessity and a socioeconomic compromise drove a persistent rift between the different interest groups.

On one hand, many scientists and environmentalists who had originally supported the water allocation in the 2010 *Guide* and the science that underpinned it now attacked the revised water allocation. One of the major groups was the Wentworth Group of Concerned Scientists, a self-assembled group of scientists, economists and business people who had interest and expertise in the management of Australia's natural resources. Although not exclusively a scientific body, the Wentworth Group was founded on the basis that they would "connect science to public policy" (wentworthgroup.org). The prominence of its scientific members in other science bodies lent the Group clout as a worthy voice in the debate. In their response to the *Draft Plan*, the Wentworth Group argued that the *Plan* lacked sufficient scientific information, made unjustified assumptions about the sustainability of ground water, and neglected the impact of climate change. In short, the revised allocation of water lacked what they considered a credible scientific base of evidence:

> The science used to establish the evidence for the 2,750 GL reduction is not only absent from the documentation, but even more disgraceful is that the science for the 2,750 GL reduction is not accorded the scientific scrutiny of transparent independent review. It is impossible to assess the ecological outcomes from a reduction to extractions of 2,750 GL from the information in these tables… Without the information to assess this, it is impossible to determine whether the draft Basin Plan complies with the Water Act. (Cosier et al., 2012, p. 10)

This perspective maintained and reinforced the regulatory frame of the debate that had been dominant in the original *Guide.*

In contrast, local community groups and irrigators showed concern about the economic and social impacts of the *Draft Plan*. Rather than challenge the scientific basis for and the limited environmental impact of the 2750 GL/y figure, their socioeconomic frame suggested that there still had been insufficient cost-benefit analysis to justify this amount of reallocation. Rather than questioning the validity of the science on its biophysical basis, this group argued that other important attributes and impacts had still not been adequately included. For example:

> The concern we've got primarily is that [the MDBA] haven't looked at people, profit and the planet… What they've done is they've looked at a cost-benefit of the environment and ignored people and profit. (NSW Farmers' Association chief executive, quoted in SMH, 2011a)

Comment

According to these media reports, the fixed water allocation figure could be challenged in different ways under both a regulatory and socioeconomic frame. One focused on the biophysical bases of a healthy river, and the other focused on the socioeconomic impacts on communities and livelihoods. Despite a shared disapproval of the proposed volume of water, the two sides drew on different forms of evidence and expertise to support their case. Their arguments, therefore, became mutually incompatible.

The challenges associated with a lack of mutual understanding have been previously explored by Lock (2011), who suggests that scientists and other publics should clearly communicate the evidentiary bases of their positions. Only then can 'talking past each other' be avoided and productive dialogue be achieved. In the case of the *Draft Plan*, the Authority's maintenance of focus on the water return of 2750 GL, albeit now using a regulatory frame, meant this miss-communication was indeed the case.

Drawing Boundaries Around Scientific Evidence and Authority

The theoretical approach of 'boundary work', set out earlier, provides a tool for looking at the way in which lines are drawn around science and scientists in society, and why this distinction becomes important in making sense of SSIs.

In the public deliberations about an SSI, there is often a series of competing claims to scientific authority. Who, then, can be regarded as a scientific expert? For example, in its highly critical response to the Basin Authority's *Draft Plan*, the Wentworth Group challenged its scientific authority by arguing that the Authority "manipulates science" for a "pre-determined political outcome":

> The Murray-Darling Basin Authority ignores much of the good work and has instead produced a draft Plan that manipulates science in an attempt to engineer a pre-determined political outcome. The Commonwealth government should stop the process, instruct the Authority to withdraw the draft Plan, abandon the proposal for a 2015 review and instead take the time necessary to include the science and social science now. (Cosier et al., 2012, p. 1)

Using their claimed status as 'concerned scientists', the Wentworth Group challenged the scientific legitimacy of the Basin Authority, excluding them from the boundary of science and portraying them as politically motivated. However, this charge was soon counteracted by the Authority's chairman who employed his own boundary work to undermine the claimed scientific authority of the Wentworth Group:

> The views of the Wentworth Group are well known. As with other groups with diametrically opposed opinions on the Draft, all views will be considered as part of the consultation period. (Craig Knowles, MDBA chairman, quoted in Arup, 2012)

Interestingly, few other explicitly scientific voices were given coverage in the newspaper articles on the *Draft Plan*. This may be because individual scientists were reluctant to enter public debate, or because it was perceived that the Wentworth Group already represented a 'universal' scientific position. In other science-related controversies, the absence of scientific voices in the public arena has had the consequence that non-scientific voices are able to advocate on behalf of science (Gregory & Lock, 2008; White, 2011).

In the case of the Murray-Darling River Basin, the absence of scientific voices meant that judgement of the Authority's *Draft Plan* was left predominantly to non-scientists. One article reported that irrigators gave the Draft Plan "a 'fail' rating on six out of seven criteria such as transparency, detail and balance" (Wroe, 2011). Another reported on a politician from the Australian Greens Party who argued that the plan "will fail to save the river and the species that rely on it" (SMH, 2011b). As in the earlier Murray-Darling debates (Crase et al. 2005), the absence of government socioeconomic data sources enabled some lobby groups to produce and publicise their own figures without independent verification. The validation of evidence was no longer the province of the scientific community, but had moved to other social actors for judgement and debate.

Conclusion

The management of the Murray-Darling River Basin illustrates the complexity of many SSIs. These issues can become seen from multiple perspectives, and public deliberation can demand evidence that extends far beyond a purely scientific or technical basis. At the same time, SSIs mobilise a range of stakeholders each with their own claim to expert authority on adjudicating how a controversy might find closure.

In the science classroom attention should be drawn to the diverse aspects of SSIs, including those that emphasise the non-science aspects. In doing so, students could be encouraged to view the issue from the point of view of different stakeholders and, in a role playing sense, students could be assisted to present the issue from the different perspectives that emphasise its social, economic, environmental or moral aspects, including what evidence and expertise might be relevant in each case.

With respect to the scientific bases of complex SSIs, the new Australian National Science Curriculum offers considerable opportunity for science teachers to include complex SSIs among the contexts they explore in their science education. There are, however, some aspects of SSI science that stand out as challenges that are yet to gain authoritative approval in the science curriculum.

Opportunities and Challenges

Despite the clearly stated intention in the *Rationale* of the Australian Science Curriculum for engagement with SSI issues, no such issues are suggested as examples. Instead, the manner in which the detailed knowledge for learning is listed, at best, allows science teachers to choose one piece of this knowledge as a starting point to open their students to complex SSIs and, at worst, discourages them from doing so. The *Science Understanding* strand is especially deficient. Its disciplinary listing of science content—a Vision I framing—fails to recognise much relevant interdisciplinary science. A science curriculum that aims to equip students, as future adult citizens, to understand and make decisions about complex SSIs should point to exemplary SSIs and list some of their disciplinary and interdisciplinary science content. A more thematically designed curriculum—one with a Vision II framing—would encourage and require science teachers to use some of their classroom time engaging with these issues.

The *Science as Inquiry* and *Science as Human Endeavour* strands of the Australian Science Curriculum, by extending students' understanding of the Nature of Science, do offer considerable opportunity for teachers and students to practice scientific skills and intellectual procedures that are integral to complex SSIs. The strands do not, however, include two key scientific aspects of complex SSI, namely, the skill of modelling and issues concerning of the certainty/uncertainty of scientific knowledge and its warrants for trust.

A big challenge associated with the opportunity to teach these skills and processes of the Nature of Science is a pedagogical one. Their teaching and learning will require science teachers to use dialogical pedagogies in their classrooms, which are very different from the transmissive ones so often used when science content knowledge alone is the central focus. For example, the new emphasis on science communication as a skill will require students to practice alternative ways of framing the same science for different purposes and audiences. As highlighted by Gregory and Lock (2008), public engagement with science is not just about the public developing an understanding of the science, but it is also an opportunity for scientists to "listen and learn as well as speak and teach" (p. 1257, see also Pedretti & Navas-Iannini, chapter "Pregnant Pauses: Science Museums, Schools and a Controversial Exhibition" and Stocklmayer, chapter "Communicating Science", this volume). This dictum applies also to teachers in science classrooms.

Finally, if the authorities responsible for the school science curriculum are serious about the curriculum's stated intention to bring "decision making about SSIs" into the classroom, they will need to respond to three obvious challenges:

- to recast the curriculum so that this intention is given priority,
- to develop new means for the assessment of science learning to ensure this priority is reinforced, and
- to ensure that science teachers get the support in professional development support they will need for these new teaching tasks.

Each of these will involve a considerable amount of revisionary boundary work in relation to science education. Only then can science teachers be expected to likewise change their sense of the boundary of science and engage with their students in making decisions about these far-reaching socio-scientific issues.

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