International Journal of Science Education, 2015
Vol. 37, No. 9, 1504–1523, http://dx.doi.org/10.1080/09500693.2015.1042942

What Account of Science Shall We Give? A Case Study of Scientists Teaching First-year University Subjects

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This article presents a case study of four academic scientists. These academics teach in the first year of a Bachelor of Science degree at a large research-focused Australian university that has demanded and supported a greater focus on undergraduate learning. Taken as a whole, the accounts of science that the first-year academics in this case study gave, and which they are presenting to their students, challenge the images of science and scientists typically presented in school science curricula. Using Roberts' heuristic of Vision 1 and Vision 2 for the broad purposes of learning science, we consider various accounts given of science by these academic scientists and consider how science might appear to a student who takes all four of their subjects.

Keywords: *Practice of scientists; Visions 1 and 2 for science; Undergraduate science; Nature of science; First-year university; Curriculum*

Introduction

> … if someone were to say to me now, 'What matters about what we cover and what I think they get?' It's scepticism—it's belief that this matters. It's integrity, and I guess the sort of interdisciplinary shared nature of modern science. (Prescott's interview, 23 July 2013)

Anecdotal reports from science teacher educators suggest that university science graduates tend to describe science in terms such as empirical, logical and methodical

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and to give a simplistic account of the scientific method, as distinct from methods of science (Gunstone, 2015). This is also the account of science typically conveyed by school text books. Yet, the relationships between science and society have become more complicated over the past several decades in ways that have added complexity to the practice of science (Funtowicz & Ravetz, 1993, 2003; Ziman, 1998). In this altered social context, it is important that scientists and science teachers should be able to give more nuanced accounts of the nature of science, its methods and practices (for discussion of this claim see Smith, 2011; Smith & Gunstone, 2009).

Prescott, the scientist who made the above remarks, was discussing his teaching intentions for his first-year university subject. His intentions are significantly different from the focus on mastery of abstract canonical ideas in idealised or narrow contexts that is perceived to characterise much of school and university science, and which contributes to the simplistic reductivist view of science noted above (Miller, Pfund, Pribbenow, & Handelsman, 2008; Tytler, 2007). Prescott is one of four Australian academic scientists whose expressed teaching intentions we explore in this article.

The four scientists we discuss in this case study portray science as having aspects that are empirical, logical and methodical. They do this, however, in a variety of ways that provide students with insight into the complexity and messiness of the practice of science. They express values about science and their teaching priorities that convey a diversity of intentions. In this article, we discuss these expressed teaching intentions and consider the extent to which each might be associated with a view of science that is inward or outward looking, corresponding to Roberts' (2011) Vision 1 and Vision 2 for images of science in the school curriculum. Appropriating Roberts' heuristic we draw from our data contemporary accounts of both Vision 1 and Vision 2 for the science curriculum at an elite Australian university. These accounts have the potential to better prepare students for their future roles as scientists and citizens because they offer an account of science disciplinary knowledge that is richer than the reductivist accounts usually associated with this knowledge at first-year university and in schools.

The Background to this Study

One consequence of present structures of curriculum control and decision-making in Australia is that many university science academic staff have a greater degree of freedom than do most school science teachers. School teachers' images of the nature of science are developed in response to many influences, amongst which are the various accounts of science that they encounter in their own school and tertiary education (Roberts, 2011). Traditional images of science are perpetuated by the forms and content of school science curriculum, and school teachers who have a different story to tell may find it difficult to be heard (Blades, 1994; Fensham, 1998, 2013; Gaskell, 2002; Hart, 1995, 2001), whereas university teaching is less constrained. As Bryce (2010) points out, both school and university science teaching must change in order to give students a better appreciation of contemporary science. It is of some interest, then, to consider the accounts of science given by university academic staff, whose images of science are informed by an experience of research science that is more immediate than that of most school teachers.

The case study presented here is drawn from a larger study of scientists whose work brings them into contact with the community. The larger study investigates how contemporary science may be better represented in the school science curriculum. Research-active scientists who teach in first-year university were included as part of this study because of their potential to have an influence over the images of science formed by future scientists, school teachers and citizens.

The scientists in this case study teach in the first year of a Bachelor of Science degree at a large research-focused Australian university that has in recent years demanded and supported a greater focus on undergraduate learning. They are research active and in positions of continuing employment. Being research active means these scientists are aware of the current social context in which their own scientific research is embedded.

Undergraduate science degrees in Australian universities typically comprise three years of undergraduate study; students intending to specialise in a particular area of science will include science subjects from a wider variety of areas in the first and second years of their degree. Some students may go on to an additional year of honours study in a specialist area after completing the three undergraduate years. At most Australian universities, mainstream first-year subjects, such as the subjects these scientists teach, are shaped as preparation for the honours year. Students can take science subjects as part of other degrees, some students in each first-year subject will go on to specialise in a different area of science, and science degrees are promoted as appropriate for both the future scientist and for those who will work in non-scientific fields. These descriptions apply at the university where these data were generated.

Internationally, undergraduate degrees in science have been under scrutiny for some time. In 1999, the US National Research Council advocated transforming undergraduate education in the USA in science, technology, engineering and mathematics by the inclusion of subjects with a multidisciplinary or interdisciplinary focus (National Research Council, 1999), reasoning that society was increasingly being stratified into a technologically competent elite and a majority whose grasp of scientific and technological issues left them ill equipped to cope with the demands of participating in society. To some extent this scrutiny has been prompted by concern for diminishing numbers of students taking mathematics, science and engineering degrees at university (college) level and in part by concern that scientists should be better equipped to handle the altered relationships between science and society already mentioned above (see e.g. Marginson, Tytler, Freeman, & Roberts, 2013; National Academy of Sciences, National Academy of Engineering, & Institute of Medicine, 2010; Tytler, 2007).

One response has been to include a focus on science communication and/or science literacy skills for future scientists or for science graduates who will not eventually work in science (Bray, France, & Gilbert, 2011; Correia, do Valle, Dazzani, & Infante-Malachias, 2010; Edmondston, Dawson, & Schibeci, 2010; Rodrigues et al., 2007; Savage & Jude, 2014). Much of the activity in undergraduate science teaching has been concerned with content and pedagogy, as illustrated by the articles published in the August 2013 special issue of the *Journal of Research in Science Teaching* entitled 'Discipline centered postsecondary science education research'. By contrast, there has been little, if any, attention paid to the ways in which implicit or explicit accounts of science presented to undergraduate university students have or have not changed.

In this article we consider the accounts of science that might be conveyed to a student who takes the four first-year university science subjects separately taught by the academic scientists in this study. We initially do this by using Roberts'(2011) heuristic schema of Vision 1 and Vision 2 for the broad purposes of learning school science. Vision 1 can be broadly characterised as orienting school science inwards towards science as 'if its major purpose [was] to develop a potential scientist pool', whereas Vision 2 orients school science 'towards having students comprehend and cope with a variety of science-related situations' that they may encounter in their lives, in the present as students or in the future as adults (Roberts, 2011, pp.13–14). A key distinction that Roberts identifies between Vision 1 and Vision 2 is that Vision 1 privileges a scientific perspective on individual and social issues as a characteristic of a scientifically literate person, whereas Vision 2 would expect a scientifically literate person to be able to appreciate other perspectives as well. The two visions are not a pigeonholing device: rather, as Roberts (2011) puts it, 'we need to think of more like Vision [1] or more like Vision [2]'(p. 16).

Roberts' (2011) two visions were developed by examining the literature for school science education. His analysis has proved valuable and the heuristic of Vision 1 and Vision 2 is widely used and well known. The use of Roberts' heuristic in this case study allowed us a schema, readily understood in the context of school science, within which we could examine what these university lecturers expressed in an interview situation as desirable contemporary learning outcomes for their undergraduate science students. This is of interest because generally, in the school science education literature, the two visions are seen as competing or even contradictory. In particular, Vision 2 has been seen as unsuitable for the preparation of scientists. Employing Roberts' heuristic allows us to draw attention to instances where a Vision 2 approach is expressed as desirable by our participants, and consequently seen as legitimate in the science education of scientists.

When we applied the broad categories of Vision 1 and Vision 2 to expressed undergraduate teaching intentions we found that they were useful for considering the intentions of the four academic scientists in this study. We also found two expressed intentions that clearly were not in Roberts' (2011) account of Vision 1, even though they were concerned with students' potential futures as scientists, and arose from our scientists' personal experiences of research science. These expressed intentions were a keen concern that students should understand that science is multidisciplinary and that students should see science as a 'community exercise' that is done with other people rather than by an isolated single scientist.

Roberts (2011) summarises two key messages about science conveyed by Vision 1 as:

- The purpose for learning science is to understand science stories about the natural world.
- The most important way to approach and understand individual and social problems is the way a scientist would, using a theoretical reasoning pattern. (p. 22)

While these are typical drivers of an inward looking academic account of traditional science, we suggest that they do not completely represent an equally inward looking account of contemporary science. Below, we offer analysis in support of this view.

Research Design

The academic scientists who are the focus of this case study were participants in a larger research project as noted above. That project involved 36 Australian scientists who were invited to participate, either because their work brought them into contact with the public or because they were research active and taught a first-year university science subject. The four academic scientists in the present case study were chosen for analysis as reported here because they worked at the same university and taught four key mainstream first-year subjects.

The research questions that guided this case study then were:

- What messages about science are implicit or explicit in the teaching intentions that each lecturer expressed during her or his interview?
- What account of science might be conveyed to a student who takes four first-year science subjects separately taught by these academic scientists?

All of the 36 participating scientists participated in semi-structured one-on-one interviews that lasted from 90–120 minutes. Each author conducted at least two of these interviews. At the beginning of the interview, each interviewee was asked to complete an information sheet that provided basic demographic data about their education and work background as well as academic qualifications. The interview questions explored how the scientific work of each scientist involved interaction with community groups; the skills required to communicate with those different groups, and how they developed those skills; and how they saw the relationship between science and society. Some of these questions involved diagrammatic as well as oral responses. All scientists were asked about their own experiences in school science. The academics who taught first-year subjects were subsequently asked additional questions concerning their teaching intentions for that subject or subjects. Examples of the questions used in these semi-structured interviews appear in the appendix.

All interviews were fully transcribed. These transcriptions were checked by the relevant interviewer. Each interviewer also added clarifying notes as appropriate to the transcriptions and diagrammatic responses, including comment about any revealing tone of voice or emphasis.

As noted earlier, this case study focuses on four academic scientists who all teach a first-year subject at the same research-focused university. All have a Ph.D. in a scientific field, are currently research active and have taught undergraduates for at least six years. Three of them coordinate as well as teach their subject, while the fourth teaches only, thus, arguably, having less control over subject design and delivery and assessment than the others. Below, we refer to the four as 'lecturers', in order to aid the flow of the discussion.

The first-year subjects taught by the lecturers occur during Semester 1. Three of these subjects represent major disciplines common in university science courses—Chemistry, Biology and Physics—and provide entry points for students who wish to specialise in these areas in their degrees. The fourth subject is not discipline specific, but teaches about aspects of scientific practice. It involves application of quantitative modelling to real-world issues, and examines aspects of philosophical approaches to science and scientific thinking. This fourth subject is compulsory for some students who wish to specialise in certain areas but is considered relevant to all science disciplines.

All four subjects have undergone considerable development in recent years as part of an institutional review of the undergraduate science degree. For that reason, it is interesting to consider how science might appear to a student taking all four subjects in the first semester. We do that by examining the messages about science that were implicit or explicit in the teaching intentions that each lecturer expressed during her or his interview.

The process of analysis involved multiple readings by all four authors of each lecturer's transcript and diagrammatic responses. Two forms of analysis were developed after extensive discussions between the authors. Both forms were prepared by one author, checked by the others for consistency with the data and for accuracy of interpretation, and modified until consensus was reached. This involvement of multiple highly experienced researchers strengthened the trustworthiness of the research.

Consultation of course descriptions that are provided to students also enabled some validation of our analyses. The course descriptions included broad details of the assessment tasks used in each subject, and we were able to verify that none of the assessments was at odds with the intentions expressed in these interviews. It might be argued that a limitation of this study is that we did not observe any classes and were unable to judge the extent to which the teaching intentions were achieved. However, our interest is specifically in the account of science that each lecturer *intended* to convey.

The first form of analysis developed was a narrative summary designed to describe and explain the detail of each lecturer's expressed intentions for their subject, how those intentions developed, and how and if they linked with their views and experience of science. The second form of analysis involved generating a list of what appeared to be the intended learning for each of the four lecturer's first-year subject. As elaborated below, each element of intended learning was then categorised according to the account of science that appeared to underpin the relevant lecturer's purposes. This cross-case analysis (Eisenhardt, 2002) allowed us to identify the similarities and differences between the accounts of science that might be conveyed to a student taking all four subjects taught by these lecturers.

The findings are now provided. All names are pseudonyms and the titles of each of the subjects are also inventions. First, the narrative summaries that describe the expressed teaching intentions of each lecturer are presented. This is followed by the list comparing the intended learning in each lecturer's subject in terms of the accounts of science they might convey to a student. Then the findings are discussed. Finally, we discuss the conclusions we draw from the research.

Findings

The Teaching Intentions of the Lecturers

The case of Prescott. Prescott coordinates and teaches a first-year subject, Scientific Practice 1. The focus of the subject is mathematical modelling, which, as Prescott noted, is 'representing reality in ways that are precise'. However, a significant feature of the subject is that it balances precision with what Prescott called 'useability' in real-world situations, an approach consistent with that advocated by Feinstein (2011). Thus, in the subject students are exposed to real-world science-related problems that are currently in the media. The students consider the data that scientists have collected and the modelling they have used to depict the situation, and then critique the modelling. 'Conversation' and 'debate' are significant features of Prescott's classes. He noted, 'It's a big interaction, and I don't know what the students are going to say', and that this required a capacity to 'think on your feet' in order to 'take [the discussion] somewhere useful'.

For Prescott, it is important that the problems being considered are related to everyday matters. Prescott was critical of school programmes where students might, for example, model life on board the Space Station—such problems were 'neat' but lacked the messiness and relevance of everyday issues. By contrast in his subject, the problems are current, cross-disciplinary and have an 'authentic authenticity', such as, for example, the management of particular resources, or vaccination of the population against specific diseases, with considerable scope for discussion and debate. Such problems are highly relevant to his students' lives either now or in the future. Furthermore, he considered that

> when you find current topical things that very much match what you're doing, that changes how people think about science … It goes from the abstract—from this is [a] neat mathematical puzzle or a neat structure of chemical things to the real and the concrete.

Prescott is concerned about the ramifications of humans' impact on Earth, and with the poor image that science has in the public domain. He considers that the latter is partly due to scientists who make claims that are either directly or indirectly dishonest—for example, claiming that a particular procedure will produce a medical cure when considerably more research is needed for that end to be achieved. Hence, he emphasised the importance of scientists having integrity and honesty, and explaining their research to the public in terms the public understands so they 'can make informed decisions about what's likely to be the best way to go'.

A significant experience that influenced the development of his teaching of Scientific Practice 1 involved a conversation with an honours students who had not studied biology, yet had poor opinions of that subject:

> So these were educated, smart people coming through a good university: in my mind I'm hoping they'll graduate … to become informed, inquisitive, engaged, smartly sceptic members of society, [but they were] dismissing a whole area of science … without having any knowledge of that area … And very much militating against having an informed scientifically aware populace.

Since that experience, Prescott has developed his subject with the intent and belief that it 'teaches [students] some of the values … curiosity, creativity, questioning, healthy scepticism … honesty and integrity … ' and an appreciation of the range of disciplines in science as well as programming, mathematics and some science and philosophy of science. Indeed, the values that he hopes his students learn are what he considers matter the most:

> … if someone were to say to me now, 'What matters about what we cover and what I think they get?' It's scepticism—it's belief that this matters. It's integrity, and I guess the sort of interdisciplinary shared nature of modern science.

Prescott's belief in the importance of these values, and the relative weightings they have in his teaching goals, has evolved over time:

> … [some] years ago, if you would have asked me what mattered, I would have said [that] they can do maths and science—that they understand the quantitative models that underpin science. Now that's all still there. There's no less an accent than there was, but I value it less now than I value the other things.

By contrast, he reflected that his own experience of school science involved 'learning science for the sake of knowing science' rather than studying science 'because it matters'. The focus was on acquiring scientific canonical knowledge and skills with very little, if any, attention given to links between science and the broader world. From his remarks he clearly intends to provide a richer account of science in Scientific Practice 1.

As Prescott noted, his students learn very little new content, and this enables considerable time to be spent on 'bigger picture thinking' and thinking 'sceptically, creatively and curiously'—ways of thinking that he considers are not afforded to students in the other first-year subjects, which are content heavy. He clearly felt that first-year science courses should continue to include their traditional focus on teaching content knowledge specific to the various science disciplines, but that it was important they provide a balance by including subjects that explicitly teach students about the values inherent in the practice of science. As he declared: 'Now you wouldn't want four subjects like mine in [a student's study programme in] first semester first year … but you shouldn't have zero like mine.'

The case of Jen. Jen is one of a number of lecturers who teach Chemistry 1. She does not coordinate the subject. The course is content heavy, and intended to provide a foundation in chemistry that will be useful for students who specialise in other science disciplines, as well as catering to those few who will become chemists. As the students number over a thousand, they are divided into streams with different lecturers. To ensure each stream receives the same information during lectures, all lecturers are supposed to work from the same set of notes and PowerPoint Slides. As a lecturer Jen clearly has far less input into and control over the teaching of Chemistry 1 than the other academic scientists in this case study, who are all subject coordinators.

Jen sees science, and the development of scientific knowledge, as fundamentally involving experimentation. Her view is consistent with her own research, which is in an applied field and laboratory based. It is also consistent with her experience of learning senior science at school, where she noted that 'we did a lot of experimentation' and were taught 'a lot about asking the right questions and gathering quality data'. By contrast, she considers her students have usually done very little laboratory work before coming to university. Unsurprisingly then, she hopes that her students in first-year chemistry develop an appreciation for the role of experiments in science:

> … one of the messages they need to take home from the moment they get here is that science is an experimental discipline. It's not about sitting in a library reading textbooks. It's about doing stuff, and you can't discover new things unless you experiment. … [T]here are very few things in physics, chemistry that you don't need a laboratory for.

This view is underlined by the requirements for satisfactory completion of the subject, which include passing a specified number of laboratory tasks.

Another goal of the course pertains to the majority of students studying first-year chemistry who intend to major in other scientific disciplines. The course endeavours to help students understand the links between chemistry and other sciences:

> … we try to teach them that there are fundamentals in science that will underpin everything, and that you need a good understanding of a range of things to be able to do whatever it is you think you're going to specialise in.

Wherever possible, links are made between the content being taught, and relevant concepts and contexts in other sciences. These links arguably assist in promoting a multidisciplinary view of science. For Jen, appreciating that view is particularly important for those students who will work in applied science where the ability to function in multidisciplinary teams is important; Jen herself was grateful that her secondary school promoted her understanding of this, which assisted greatly in her own career development. Jen's research, as noted earlier, is in an applied field where scientists from a number of disciplines collaborate, and involves explicit ethical considerations: these two points will be returned to later in this article.

Chemistry at the university has the reputation of being hard, not only in first year but also in later years. The chemistry lecturers have received considerable feedback that the course contains too much content, but Jen found it difficult to think of ways of reducing this:

> … part of the trouble is, chemistry is a lot of content, and so I try to **tell** my students at the beginning that chemistry is very like learning a language. You need to go through all the boring vocabulary and all the boring grammar before you can write a novel. And first

> year is the boring vocabulary and the grammar and all the yucky stuff that nobody really likes, but we all need. They're all **tools** to do the exciting stuff. (Interviewee's emphases)

Jen is aware that much of the content is difficult and abstract and she uses analogies and examples to promote better student engagement and interest. However, despite the course being intended to provide a foundation for later studies that are not in the chemistry field, it seemed from the thrust of Jen's interview that the course design is constrained by the need to cater for the very few students who will continue to do chemistry beyond first year.

In addition to the content demand, Jen noted that another aspect of the chemistry course that students found difficult concerned the application of concepts to problem-solving:

> … [in] a lot of [other] subjects, they're given their content and told to just learn it off. We never do that in chemistry … You can't learn every single reaction that's ever been known … And so we give them concepts and then ask them to apply those concepts to a problem they've never seen before. That's what they can't do.

The chemistry lecturers have given considerable thought to how they might respond to this difficulty, and now recognise that problem-solving skills need to be taught. Jen noted that previously they had assumed either that students had learned problem-solving skills in secondary school or that such skills were innate; now, however, the lecturers have altered their lectures to include times where the students are shown how to tackle a chemistry problem.

Overall, the large number of students studying the subject restricts the pedagogical options available to the lecturers. For example, assessment tasks include examinations, online quizzes and laboratory work, which are all relatively easy to mark. Other forms of assessments, such as those that Jen herself experienced in secondary school, which require students linking between society and the chemistry they are learning, are regarded as impractical because the marking would be too time-consuming. Thus, the lecturers' choice of learning goals to be assessed is narrowed, and consequently it seems the focus of student learning is limited to the relevant content in the scientific canon.

The case of Leanne. Leanne coordinates and teaches Biology 1. Recently the subject has been reorganised so the canon of biological science taught is now approached through a consideration of a number of global issues that are relevant to students' current and future lives. That is, the lecturers introduce a particular issue, and use this as a vehicle for teaching some biology:

> we have divided the course up into probably about six issues, and we start each module, if you want to call it that, with an issue. So the biodiversity crisis is the first one. What is it? What does it mean? And then we go on to talk about some biology related to it. Another one would be environmental change. Why is environmental change a big issue in biology? And then we talk about how organisms need to be able to respond to environmental change. So we've really flipped that around, and we're hoping that it's much more relevant to the students.

Few of the students in the course will continue to study biology, and, according to Leanne, this has framed her thinking and that of her colleagues when formulating their teaching goals so that as well as the subject now being presented in terms of global issues, links to other disciplines that students might study, or be studying, are made:

> … we're all of the mindset of that this will be the last biology that two-thirds of the course, maybe more than that, ever do. So if this is the only biology that they do, these are the messages we want them to come away with, and we try to make connections with how that area of biology relates to aspects of engineering or economics or whatever it might be, and … I think it's reaching at least some of the students because I have had some emails throughout the semester from students saying, 'Oh you mentioned, you know, economics in the lecture. I'm interested in both biology and economics—can you tell me more about career paths?' So we've had … so I think it has made a difference. Yeah. So I think a lot of the students are coming out with those messages.

Leanne sees herself as having an atypical background for an academic, having worked in a variety of positions that were not all biology related, which brought her into contact with a range of different groups. Through those interactions, she learned the importance of trying to understand the priorities of whichever group she was dealing with, and making bridges between their priorities and her own. This is essentially what she and her colleagues have done for their own students in Biology 1. In addition, working with media academics focused Leanne's attention on problems related to science communication, and led to a more nuanced appreciation that controversies around, for example, climate change, are not just about questions of scientific truth (Hulme, 2009). This understanding also influenced the redesign of the course, with the focus on issues and multidisciplinary links acknowledging at least tacitly that the complexity of the problems under consideration is such that scientists alone cannot solve them and need to be able to interact with, and/or work with, a range of groups in the community. Significantly, the redesigned course has retained an assessment task that requires students design and video a short documentary. Arguably such a task provides them with opportunities to develop a broader range of science communication skills than is the norm for science undergraduate subjects.

Aside from the goal of making biology relevant to students through examining real-world issues, Leanne noted that another goal was to help students to appreciate the process of science.

> We try in the lab classes to teach them the process of science. So the fact that you have a question and then from that … or you identify a problem and you develop a question. You then develop a hypothesis and do some kind of experimental study to try and answer that hypothesis, and then you get some results, and there's different ways of looking at those results, and come up with an interpretation based on the literature. So we try to take them through that … we do take them through that process, and we try to make that explicit. And I think that works reasonably well, and we've sort of tweaked that over a number of years to try and get it right.

Leanne emerged from her secondary schooling with a view that science is about facts, a view that she came to reject as a research scientist. For her, science is 'a way of thinking and a way of practising, a way of doing, a way of problem-solving', and something that is 'done' to benefit society, and these views underpin some of her goals for her subject.

The case of Max. Max teaches and coordinates Physics 1. The subject teaches content that is typical of introductory physics courses. However, the approach taken is quite different. Students are expected to do a considerable amount of pre-reading and complete online quizzes related to the material they have read prior to attending lectures, where class sizes are around 200. The 'lectures' themselves do not take the form of traditional lectures, that is, information giving, but instead involve 'guided discussion' and problem-solving, with interactions between students and between students and lecturer. These classes are informed by the responses which students have given to the online quizzes: selected responses that highlight particular misconceptions are anonymously displayed during the lecture as generators of discussion to promote learning and understanding. Max derives considerable satisfaction from student feedback that the lecture classes are more 'fun' than others they attend, despite complaints they have to work harder.

When Max first started lecturing, he drew on his own experiences as a learner and 'just copied' his own lecturers, whom he described as 'just presenting information'. A faculty review led to Max and his colleagues being exposed to ideas for teaching physics that drew on the notion of 'active learning' (Mazur, 1997) and to devising ways of encouraging this in their classes by using collaborative learning approaches.

Max's own area of physics is one that involves considerable cooperation between physicists across Australia. It was interesting therefore that his first priority for his students' learning was they learn that science is something 'you can do in discussion with other people' and 'can be a community exercise'.

His second priority relates to his experience of trying to help students to learn to solve problems. As Max put it

> I … hope [my subject]'s teaching them that there's a process you can follow to make progress, as opposed to just memorising the answer.

Max has found that his students arrive at the university with a 'plug and chug' view of problem-solving—that is, a view that solving a problem is just a matter of identifying appropriate formulae and substituting the values of the relevant variables. This view applies even to the more capable students, who, while being able to successfully solve problems where these are of a type previously seen, are nevertheless unable to explain to their peers why the process works. This student view that problem-solving is a matter of 'plug and chug' undermines Max's purpose of encouraging student collaborative learning. It also has the consequence that students have no process for solving problems that are unfamiliar.

Clearly the focus of Physics 1 is on canonical physics. However, the teaching approach during lectures is one that encourages meaning-making by students in ways that are quite innovative for a first-year university subject. There is a strong commitment to processes that allow students to indicate their uncertainties and misunderstandings without identifying and embarrassing individuals, allowing misconceptions to be addressed and promoting deep understanding. Max became aware as a school student that the 'actual true answer about something might be quite different to your prejudice or your preconception' and he linked this with the notion that the process of science involves changing ideas, a view that is now reflected in the teaching of Physics 1.

Comparison of the lecturers' accounts of science

As noted earlier, Roberts (2007, 2011) developed the notion of Vision 1 and Vision 2 to describe purposes for learning school science. Vision 1 is associated with an inward looking view of science as a discipline. Vision 2 is an outward looking view that links specifically to situations involving both science and social issues that are relevant to students' lives. Traditionally Vision 1 has been at the heart of most university science courses and much of school science, and to a large extent it remains so (Bryce, 2010; Miller et al., 2008; Osborne, 2010). As already mentioned, the notion of Vision 1 and Vision 2 was intended to be a heuristic rather than a pigeonholing device. In that spirit we have appropriated Roberts' heuristic to compare the expressed teaching intentions of the lecturers in this study.

We use the heuristic to explore how the intended learning in each lecturer's subject links to Vision 1 or Vision 2 and so consider how science might appear to a student taking all four of their subjects. Table 1 summarises the expressed intended learning for each subject as articulated by the relevant lecturer, and classifies these in terms of Vision 1 or Vision 2. This classification is necessarily inferential, being based on what seemed to be the relevant lecturer's purpose for each intended learning outcome in their subject. Thus, the choice to locate a tick in one or more of columns for Vision 1 or Vision 2 depends on how the matter was framed by the relevant lecturer in the interview, and was guided by Roberts' (2011) advice that the '*watchword*' (p. 14, emphasis added) for Vision 2 is '*relevance* of science' (p. 14, emphasis in original).

According to Roberts (2011), Vision 1 concerns 'the products, processes, and characteristics of the scientific enterprise' (p. 12). However, the Vision 1 that Roberts identified within the existing science education literature is conceived in terms of the highly individualistic science historically practised by academics and taught in universities, whereas, contemporary scientists often work in large teams and funding bodies now require an increased sensitivity to ethical issues within science (Ziman, 1998). This is an apt description of Jen's work, and applies to some extent to Max, whose work necessitates collaboration with scientists in other institutions. Also prevalent today are recognition of the multidisciplinary nature of much scientific work and recommendations that university courses should reflect this (National Research Council, 1999; Tytler, 2007). We have drawn attention to the possible influence of these changing emphases and practices in universities, by including within Vision 1 two elements required to work in contemporary science on projects that are often multidisciplinary. These elements are asterisked in Table 1(below).

Table 1. Classification of intended learning in each subject

Subject	Intended learning	Vision 1	Vision 2
Scientific Practice 1	Science is cross-/interdisciplinary*	✓	✓
	Mathematical modelling skills	✓	
	Informed scepticism and integrity matter		✓
	How researchers model real-world problems		✓
	Big picture thinking		✓
	Skill in thinking sceptically, creatively and curiously		✓
	Debates around real-world issues relevant to students' lives (e.g. vaccination, resource management)		✓
Chemistry 1	Chemistry is multidisciplinary*	✓	
	Chemistry is the basis of everything	✓	
	Chemistry is an experimental science	✓	
	Laboratory skills	✓	
	Problem-solving skills	✓	
	Content knowledge that provides a foundation for all science majors	✓	
Biology 1	Multidisciplinary nature of science*	✓	✓
	Process/laboratory skills	✓	
	Science is a way of thinking		✓
	Content knowledge	✓	
	Real-world issues relevant to students		✓
	Science communication skills		✓
	Science provides a way of addressing real-world problems		✓
Physics 1	Using a process to develop an answer	✓	
	Understanding of content knowledge	✓	
	Science is something you do in discussion with other people/ Science is collaborative*	✓	

Discussion

Clearly each subject promotes goals that are consistent with Vision 1, and two of the four have broader goals that are suggestive of Vision 2. The emphasis on the multidisciplinary nature of science in three of the subjects is, as noted earlier, one that has been seen as important in undergraduate science courses for some time (National Research Council, 1999) and, as shown in Table 1, may be linked to either a contemporary Vision 1 (where the intent is to prepare future scientists who can work collaboratively and across other science disciplines) or Vision 2 (where the intent is to assist understandings of real-world socio-scientific issues), or both, depending on the relevant lecturer's intentions.

Vision 1

With the exception of Scientific Practice 1, each subject promotes learning of canonical science content, in keeping with the traditional practice of undergraduate science courses. Other elements of the scientific enterprise, such as mathematical modelling; process, laboratory and problem-solving skills; and the structure of science, also feature strongly in each subject. Where these aspects of science are the sole focus of the subject, as in the case of Chemistry 1 (and to some extent, Physics 1), a student might develop a view (or, more likely, have reinforced a view already presented in their high school science courses) of what has been called 'normal science', where science is 'understood as steadily advancing in the certainty of our knowledge and control of the natural world' and 'values are unspoken'(Funtowicz & Ravetz, 1993, pp. 739–740). This view is at the heart of Vision 1 and has conventionally been seen as appropriate in the preparation of future scientists.

A more contemporary account of Vision 1 may be seen in those aspects of lecturers' expressed intentions that, while located within a discipline, show science to be multidisciplinary or done collaboratively. Scientific Practice 1, Chemistry 1 and Biology 1 all emphasise the multidisciplinary nature of much scientific work. In the case of Physics 1, Max expressed the hope that his students learn about the collaborative nature of much scientific work; while implicit in the teaching approach used in the subject, the extent to which this intention is explicitly conveyed to students was unclear from Max's remarks. Nevertheless his intended account of scientific practice for his Physics 1 students differs from the image of the stereotypical lone scientist at the bench top that is arguably an outcome of the Vision 1 science teaching. The multidisciplinary accounts of science in the other subjects also provide some challenge to that stereotype.

We noted earlier that Jen, who teaches Chemistry 1, works in an area of science where research practices have been influenced by a contemporary framing of ethical considerations. It was interesting that the ethical dimensions of scientific research did not appear to be explicitly raised in any of the subjects.

Vision 2

Scientific Practice 1 and Biology 1 have a strong emphasis on real-world issues involving science. Explicitly considering these exposes students to situations where application of scientific ideas and processes is problematic and messy, and there are no easy answers; this is reinforced in Scientific Practice 1 where debates around the issues are explicitly encouraged and big picture thinking is fostered. Such an approach underscores the limitations as well as the strengths of science. Given most issues have a social aspect as well, the approach also underscores that science, albeit powerful, is but one way of knowing and doing.

That science is a socially enmeshed practice is taken up in Biology 1 and Scientific Practice 1. Both these subjects, in different ways and to different extents, highlight differences in language and understandings between scientists and non-scientists, and present accounts of science which are more complex than those represented by Vision 1. In Biology 1, the focus on students' acquisition of science communication skills attends to an aspect of their preparation as future scientists who will likely need training in public communication (Trench & Miller, 2012). Scientific Practice

1 adds a further dimension to understanding science as a social practice through promoting informed scepticism and integrity as desirable attributes when considering socio-scientific issues and thus making explicit scientific values that are often not well understood by the public or well explained by scientists (Kolsto, 2001). This approach contrasts with Osborne's (2010) observation that science education generally does little to foster 'the cultivation of scepticism, a feature that is one of the hallmarks of the scientist' (p. 463). Indeed the cultivation of scepticism is considered important for developing students' ability to reason about socio-scientific issues (Zeidler & Sadler, 2010), an ability that will stand them in good stead as citizens, regardless of their future as scientists. The encouragement of creativity and curiosity in Scientific Practice 1 during discussions about socio-scientific issues fosters additional critical thinking skills required to evaluate relevant information and understand different perspectives when addressing such challenges (Aslan, Pinsky, Ryan, Souther, & Terrell, 2014; Riehle, 2012).

Thus, the combination of aspects of science discussed above in Scientific Practice 1 and Biology 1 would likely help students to appreciate a view of science and scientists' work that is broader than, and may even be in tension with, that encompassed by Vision 1. Such a view tends towards Vision 2, and assists in laying a foundation for future scientific work that students might undertake where they interact with a range of scientists or other groups, 'systems uncertainties or stakes in decision-making are high', policy risk is not resolved by the normal processes of science alone but requires input from multiple perspectives, and 'values are not presupposed but made explicit' (Funtowicz & Ravetz, 1993, p. 740). Arguably it also provides appropriate (albeit not sufficient) insight into the practice of 'civic science', where practising professional scientists interact with the public (Edmondston et al., 2010).

Overall then, as discussed above, a range of elements in Scientific Practice 1 and Biology 1 support a view of science as a social practice and human endeavour where the goal is to benefit society and the environment, and the production of scientific knowledge is not the sole concern. That is, science is portrayed as relevant to students regardless of whether or not they work in scientific fields upon graduating. Indeed, developing an understanding of social and ethical aspects of issues in science, for example, is important preparation for both future scientists (Smith & Gunstone, 2009; Tytler, 2007) and for science graduates who work in non-scientific fields (Rodrigues et al., 2007) as well as assisting students' decision-making around socio-scientific issues in their present and future lives as citizens (Correia et al., 2010).

Conclusion

Internationally, some undergraduate courses have been developed that promote scientific literacy for future citizens (Correia et al., 2010; Savage & Jude, 2014) but these courses seem to be relatively rare. Rather, science courses at the undergraduate level generally tend to focus on the transmission of facts (Miller et al., 2008), and convey an image of science more consistent with a conventional version of Vision 1 than with Vision 2. This has significant consequences for the images of science developed by future scientists, and also by those who have a science degree but who will not work in research science. School teachers fall into the second category, and scientists teaching undergraduate courses that present science as an unproblematic and settled body of facts may serve as role models for those students who become science teachers and perpetuate this approach (Bonner, 2004; Tytler, 2007).

In this article we have reported the cases of four academic scientists, working largely independently of each other, but within the general priorities of their university, who have come up with different but complementary messages about science that they convey to their students. Their choices illustrate interesting and important shifts in what it is possible to conceive of doing in university science subjects. In addition to discipline knowledge and skills, a student taking all four of these subjects will learn about a range of characteristics and practices of science that include the following:

- to do science involves learning a good deal of content;
- it is important to be able to communicate science;
- science has immediate, contemporary and vibrant real-world relevance;
- scientific practice includes values such as scepticism and integrity;
- science is about working together;
- practice of science is messy;
- science is one way of thinking and doing, but not the only way; and
- there are different ways of thinking about and doing science.

These four academic scientists are not all giving their students the same messages about science, neither are they all reinforcing the same messages. As far as we know, they have all reached their positions independently. The extent to which they are able to effect change in their own practice and respond to the various pressures, insights and principles that guide their choices varies, yet they are all responding to what they see as their students' present and future needs in ways that have brought about different priorities in their teaching.

Scientists today need to be able to work in contemporary science. These types of scientific work entail developing productive relationships with a range of communities within science and also more broadly. An account of science that serves the needs of the undergraduates who will become the future research scientists of contemporary science is not dissimilar from the account that will serve the needs of science graduates who will not work directly in science. These four academics show that it is possible to give an account of science in a mainstream teaching programme at an elite research-focused university that caters for a number of different futures for students, while at the same time not diminishing the significance of discipline knowledge.

Disclosure Statement

No potential conflict of interest was reported by the authors.

Funding

This research was supported by the Australian Research Council (Project No. DP120102714).

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Appendix

Examples of Interview Questions

Following elicitation and clarification of different groups that scientist has worked with:

1. *B. Have you developed different ways of interacting with these different groups? What differences are there? Why?*
2. *A. What particular capacities/abilities have you needed to develop in order to engage with each group? What has helped you develop these changing capacities/abilities/competencies? Describe how you came to understand what was needed? How did you figure out how to do it?*
3. *A. Is there a need for scientists in your field to engage with the public about their work? How important do you think this is? Why?*
3. *C. What capacities do scientists require for productive engagement with the public? Have you any experience doing this yourself?*
3. *E. What capacities/abilities/competencies do members of the public require for productive engagement with scientists in your field?*
5. *D. What did school science teach you about the way science works?*
6. I'd like you to consider the first year students you work with in your teaching.

   A. What do you think your subject teaches them about science? Is this what you would like to teach them? Is there a difference? Why?

   Areas to explore in subsequent conversation:

   B. What purpose do you see your subject having in the students' future professional lives?

   C. What do you believe has greatest impact on students' engagement with your general area in (i) first year? (ii) subsequent undergraduate years?

   D. How do you think the detailed content and approach of the curriculum taught to your first year students impacts on their engagement? On students' achievement? On the development in your students of an understanding about science? If time runs out go straight to understanding about science.