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Jonathan Osborne
King's College London

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Jonathan Osborne holds the Chair of Science Education at the Department for Educational and Professional Studies, King's College London where he has been since 1985. Prior to that he taught physics in high schools. Professor Osborne is currently the head of department and the President of the US National Association for Research in Science Teaching (NARST). He has conducted research in the area of primary children's understanding of science, attitudes to science, informal learning, argumentation and teaching the nature of science. He was a co-editor of the influential report Beyond 2000: Science Education for the Future, winner of the NARST award for best paper published in JRST in 2003 and 2004, and is a co-PI on the National Science Foundation funded Centre for Informal Learning and Schools. A particular agenda for his research is advancing the case for teaching science for citizenship. To this end, he has conducted a significant body of work exploring the teaching of ideas, evidence and argument in schools.

Abstract

This presentation offers a critical analysis of contemporary science education and the values on which it rests. Science education wrestles with two competing priorities: the need to educate the future citizen about science; and the need to provide the basic knowledge necessary for future scientists. It is argued that the evidence would suggest that it is the latter goal that predominates – a goal which exists at least, in part, in conflict with the needs of the majority who will not continue with science post compulsory education. The argument is advanced that there are four essential elements to any science education – the development of conceptual understanding; the improvement of cognitive reasoning; improving students' understanding of the epistemic nature of science; and affording an affective experience that is both positive and engaging. The decline in students' interest in school science is, in part, due to the emphasis on science for future scientists. This presentation will aim to show how a focus on ideas, evidence and argument can offer an education that is more appropriate to the needs of the future citizen and the values of contemporary youth.

Introduction

Curriculum innovations in science, such as those sponsored by the Nuffield Foundation in the UK and the National Science Foundation in the USA in the 1960s and 70s, have had little impact on the practices of science teachers (Cuban, 1990; Welch, 1979). Four decades after Schwab's (1962) argument that science should be taught as an 'enquiry into enquiry', and almost a century since John Dewey (1916) advocated that classroom learning be a student-centred process of enquiry, we still find ourselves struggling to achieve such practices in the science classroom. Witness the publication of the AAAS edited volume on inquiry (Minstrell & Van Zee, 2000), the release of *Inquiry and the National Science Education Standards* (National Research Council, 2000), and the inclusion of 'scientific enquiry' as a separate strand in the English and Welsh science national curriculum. The latter, in particular, has now been incorporated into a more embracing program which explores 'How Science Works' with an eponymous title (Qualifications and Curriculum Authority, 2005). These developments serve as signposts to an ideological commitment that teaching science needs to accomplish much more than simply detailing what we know. In addition, there is a growing recognition of the need to educate our students and citizens about *how* we know, and *why* we believe in the scientific world view. While acknowledging that the distinctive feature of science is its ontology, the argument will be presented that such a shift requires a new focus on the following: (1) how evidence is used in science for the construction of explanations; and (2), the development of an understanding of the criteria used in science to evaluate evidence. Central to this perspective is a recognition that language is not merely an adjunct to science but a core constitutive element (Norris & Phillips, 2003; J.F. Osborne, 2002)). In particular, that the construction of argument, and its critical evaluation, are discursive activities which are central to science and central to the learning of science.

The starting point for this argument is the recognition that science education exists on the 'horns of a dilemma'. On the one hand, it wishes to pursue the liberal notion of demonstrating and communicating the best that is worth knowing about this discipline. In so doing, it seeks to lay before the neophyte student the wondrous achievements of science, showing that it has freed us from the shackles of received wisdom, teaching a respect for empirical evidence as the basis of belief, and offering a vision of how new knowledge can be created.

Yet, science's dilemma (its second horn) is that it can only function effectively within a tradition where it is taught as received knowledge (Kuhn, 1970) – knowledge that is unequivocal, uncontested and unquestioned (Claxton, 1991). Presented to the young student in this manner, it is perceived as a body of authoritative knowledge which is to be accepted and believed. This second perspective is an inevitable product of a view that sees the function of science education as a propaedeutic training for the next generation of scientists. The fundamental flaw with this approach is that, while the unity and salience of such information is apparent to those who hold an overview of the domain, its significance is arcane for the young student. Only for those who finally enter the inner sanctum of the world of the practising scientist will any sense of coherence become apparent. As a consequence, only those that ever reach the end get to comprehend the wonder and beauty of the edifice that has been constructed.

More fundamentally, such an education does harm to the future citizen (Irwin, 1995; Layton, Jenkins, McGill, & Davey, 1993) and limits the development of the young person's understanding of the scientific enterprise. First, it oversimplifies and misrepresents the practices and processes of science, providing an education which fails to develop the skills and knowledge necessary to understand or interpret contemporary accounts of science, scientists and their findings. And second, its failure to develop any understanding of the nature of science beyond naïve empiricist notions (Driver, Leach, Millar, & Scott, 1996), leaves the majority poorly *educated about* science. Never is there any recognition that students have a right to what Arnold has called the 'best that is worth knowing'. Rather, the outcome leaves many students with an ambivalent or negative attitude to science (Gardner, 1975; Osborne, Simon, & Collins, 2003; Schibeci, 1984).

Yet, science education for all can only ever be justified if it offers something of *universal value to all* (Millar & Osborne, 2000). 'Science for all' requires a 'science curriculum for all' – one that recognises the cultural significance of science by offering insights to the knowledge, practices and processes of science. In essence, a science education that pursues *depth rather than breadth, coherence rather than fragmentation*, and *insight* rather than *mystification*. In such a curriculum, the study of the history of ideas and the evidence on which they are founded must lie at the core.

The goal of a science curriculum for all

What kind of science curriculum might then justify science's compulsory status? The starting point of the argument to be presented begins with the view that it is the developments of science and technology which are most likely to pose the political and moral dilemmas for the generations to come (Independent Editorial, 1999). The question of how we address climate change; whether we replace ageing nuclear reactors; invest more heavily in energy conservation; or how to minimise the effects of flu pandemics are just some of the examples that are currently confronting contemporary society. And, since answering such questions makes demands on the finite and precious resources available to a given society, the public have a right to part of the decision-making process. In short, the case that only science should decide what are the salient questions of interest is unacceptable.

Yet confronted with the need to engage a broader set of public(s) in the debate, society is confronted with a dilemma that the majority of people lack the knowledge to make an informed choice. What, then, does it mean to offer a science education that would contribute to enabling young people to make good decisions about issues associated with science and technology? This presentation will argue the view that science is one of the greatest cultural achievements of western society, if not the greatest. Any education in science must attempt to communicate, therefore, not only what is worth knowing, but also *how* such knowledge relates to other events, *why* it is important, and *how* this particular view of the world came to be. That in short, as well as teaching what we believe to be true in science, there is a need to address why we believe it to be true. It will be suggested that such an approach provides a better balance to the following goals of learning science.

The conceptual: There is a body of domain-specific knowledge which is essential to any understanding of science. At one level, this is simply a knowledge of the entities that populate the world – that is, what is meant by a cell, an atom or an electric current. Engaging with scientific concepts is not possible unless individuals are provided with the opportunities for these concepts to be introduced, and with time to learn their use and how to interpret their meaning in an appropriate context.

The epistemic and social practices of science: If the rationality of science is secured by a methodological commitment to evidence as the epistemic basis of belief, then surely the careful consideration of the practices that lead to secure and reliable knowledge should be a core feature of school science? An exploration of some of science's crowning achievements, even of such simple ideas as the explanation of day and night, would permit science teachers to show that scientific knowledge was hard won – the product of imaginative and creative endeavour, derived often in the face of fierce opposition. More importantly, it would permit the science teacher to show how science uses a range of methods; the features that demarcate science from non-science; the social practices and values that both sustain the scientific enterprise and lead to the production of reliable knowledge; the moral and ethical issues raised by the application of scientific knowledge; and to explore the relationship between science and technology.

The cognitive: from a liberal perspective, one of the goals of education is to develop the autonomous individual who is capable of making rational decisions. It is, for instance, almost a commonplace assumption of post-Enlightenment ethics and political theory that individual autonomy is a necessary condition of human fulfilment (Winch, 2006). In a society where science and technology permeates its foundational fabric, the ability to pursue what might constitute a worthwhile life is dependent on the ability to think critically about science and technology. Science education bears a responsibility for providing experiences which both maximise students' cognitive potential – the argument which underlies, for instance, the CASE program (Adey & Shayer, 1994) to accelerate cognition through science education – and to ensure that the experiences are offered that require the practice and application of critical thinking in science. Thus, science education must show how argument and its evaluation – in short, critical thinking – is a core feature of science.

Perhaps a more fundamental reason for the inclusion of this element is its value as a pedagogic heuristic. The case for the inclusion of argumentation as a form of pedagogy comes from the increasing evidence that learning to argue is learning to think (Billig, 1996), and from the increasing empirical evidence emerging from the work of social psychologists that the knowledge and understanding of school-age children can be facilitated by collaborative work between peers.

The affective and social: the education of young people in science should afford experiences that generate inspiration at the achievement of their scientific culture. Thus, while being challenging, it must offer 'feelings of understanding' and fascination at what it has to offer. Such elements are crucial to motivation and enduring engagement. In addition, science like any other subject must recognise the growing body of evidence (Daniels, 2001; Doise & Mugny, 1984; Rogoff, 1998) that suggests that learning is best facilitated through a process of social interactions and discourse where children are offered structured experiences that engage them in their zone of proximal development. Such experiences not only teach them how to reason, but also how to listen, how to evaluate the arguments of others, and how to construct counter-arguments – skills that are essential for life as an adult in general.

If an education for citizenship is to be the primary focus of formal science education – the central question is: what is the appropriate mix of these elements? The argument will be developed that the four pillars of such an education are a knowledge of scientific 'facts'; an understanding of the methods and process of science; an awareness of the context and interests of the various actors; and an ability to analyse the risk and benefits of developments in science and technology.

Drawing on a wide body of research, this paper will argue that a focus on examining ideas, evidence and argumentation has the potential to (a) improve students' conceptual understanding of science; (b) enhance their ability to reason and think critically; (c) develop a deeper understanding of the nature of belief in science; and (d) to make the quality of the learning environment and learning experience more enjoyable.

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