Why Knowing What's Wrong Matters as Much as Knowing What's Right

Jonathan Osborne

Stanford University, USA

osbornej@stanford.edu

One of the defining characteristics of science (and scientists) is a critical spirit that is central to science as a practice. Critique is essential for the construction of claims to knowledge as ideas must be defended against alternative hypotheses. Only those which survive such onslaught are considered worthy of belief.

Typically arguments in science for an idea may either be deductions about the world from a set of a priori premises such as those used in the development of kinetic theory; inductive generalizations about what patterns may exist typified by laws such as the law of conservation of energy; or inferences to the best explanation such as those used by Darwin in developing his argument for evolutionary theory. The thesis of this presentation is that, as important as the use of reasoning for the construction of knowledge is, it is the role of argumentation for critical review and evaluation that matters as much in the construction of new ideas. Indeed, as Ford (2008) argues, it is 'critique which motivates authentic construction of scientific knowledge'. Claims must be defended against critical arguments that question either the validity or reliability of the data, the warrant that justifies the significance of the data to the claim, or the background theoretical assumptions. Only claims to knowledge that survive this process are considered to be reliable knowledge. The formal embodiment of this process is peer review and it is through this practice of discourse and argument that science maintains its objectivity (Longino, 1990).

During the past decade, there has been a growing body of work on argumentation in science education. Drawing on research conducted by those working in the sociology of scientific knowledge, science educators have recognized that the failure to explore the role of argumentation in formal science education contributes to its misrepresentation of science (Duschl, 1990). For without an exploration of how scientific ideas came to be, the arguments that were required to establish their validity, students have no sense of the intellectual achievement that science represents or why it matters. Rather, students are left with the impression that there exists a singular scientific method; that nature speaks directly from the data that the scientists collect; and that science is an activity conducted in solitary isolation (Driver, Leach, Millar, & Scott, 1996).

The argument for the significance of argument in science education claims that it enhances conceptual understanding, develops investigative competence, provides insights into the epistemology of science, reveals the social nature of scientific practice, and enables them to engage in debate about socio-scientific issues raised by the political and moral dilemmas posed by science (Driver, Newton, & Osborne, 2000). Such arguments have led to a growing body of research that has explored how argumentation can be introduced in science classrooms, the kinds of effects it has on students, and how teachers may be trained in its use (Osborne, Erduran, & Simon, 2004; Simon, Erduran, & Osborne, 2006; Zohar & Nemet, 2002). Much of this work has been based on Toulmin's conception of argument as a field-dependent *rational* activity – that is that arguments are ultimately resolved by either the weight of evidence or by critical pieces of evidence. Rather, drawing on a Bayesian account of scientific reasoning, this presentation will argue that coming to a rational acceptance of a scientific idea is essentially a probabilistic judgement made between competing ideas. Any scientific idea is rarely tested in isolation but rather by weighing the merits of alternate hypotheses. Therefore, it is not sufficient to know the reasons for belief, but rather, it is also necessary to know the reasons why alternative theoretical accounts or explanations are not credible. Rhetoricians instinctively recognize this as do scientists in their writings – a notable example being the original DNA paper of Watson and Crick (1953).

In a similar manner, the teacher's rhetorical project is to convince his or her students of the scientific worldview. Whilst teachers manipulate the material world to demonstrate the validity of the accounts they offer, they give insufficient recognition to the wide range of alternative conceptions that students commonly hold (Driver, Guesne, & Tiberghien, 1985). For students, just like scientists, new ideas must be evaluated for their plausibility, coherence and fruitfulness. And just like scientists, a stronger and more secure belief will be developed if students are encouraged to explore why alternative explanations are flawed or erroneous. In short, that knowing why the wrong answer is wrong matters as much for student learning as knowing why the right answer is right. Significant empirical evidence that this is so comes from the work of Alverman, Quin and Hynd (1995) and van der Broek (2010) who have both showed how such knowledge leads to a more secure belief in the scientific conception. A theoretical account for why this is so rooted in Bayesian reasoning will be offered.

Furthermore, exploring why the wrong answer is wrong brings to the fore the centrality of modelling in science. That the development of theories comes not from representing the world as it appears to be, but from imagining the world as it might be – and the testing this idea against the data. Thus engaging in argumentation and critique helps to convey the centrality of the construction of theories to science, that theories are the crowning glory of science, and that data is but the handmaiden to this process. Adopting this perspective offers science education an essential argument to free itself from perception and view that it should be about the transmission of a body of unequivocal and unquestioned knowledge, and rather, that it needs to let students see that science is a vibrant, intellectual activity which requires as much critical engagement as any other form of disciplinary practice.

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