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FORUM

Scepticism and the science of global warming: a rejoinder

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> An adequate epistemology of science will not, as some Old Deferentialists expected [pre-Kuhnian thinkers who held that science progresses by the accumulation of well-confirmed truths], be exclusively logical, but will have a social dimension. Unlike the New Cynicism [of post-Kuhnian critics who write about science with factitious despair], however, it will not see the fact that science is a social enterprise as illegitimating its epistemic pretensions, but as an important factor contributing to its epistemic distinction; not as a reason for favoring the notion of acceptance and neglecting warrant, but as an important factor helping to keep warrant and acceptance appropriately correlated. *Puzzling out science*, Susan Haack (1995, p. 27).

This paper is a rejoinder to the three forum pieces stimulated by our original article in this journal: 'Scepticism and doubt in science and science education: the complexity of global warming as a socio-scientific issue' (Bryce and Day 2014). The articles by Colucci-Gray (2014), by Fensham (2014) and by dos Santos (2014), confirm the priority we attach to teaching about global warming at the present time and, in particular, the importance of developing rational scepticism in secondary school students while they learn about science. In providing additional thoughts as how best to achieve scientific literacy, the articles bring in further complications, adding to the debate and to the challenges for practitioners as they consider practicable classroom activities. As with scientists concerned about anthropogenic global warming (AGW), where there is a consensus of opinion but far from full agreement about what is happening and what should be done, educational researchers share some, but not all, of their thinking about how the complexities in the science can be most usefully handled by teachers. In the light of the comments, this rejoinder identifies areas where we seem to agree but focuses mainly upon those where there is dispute or difference in

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emphasis. In the case of the latter, we make suggestions as to how these differences might be resolved. Where we feel that there has been some misrepresentation of our original arguments, we respectfully offer clarification and correction.

Support for rational scepticism as an important goal in science education

Colucci-Gray's position

Colucci-Gray (2014) is supportive of our stress on developing scepticism and considers that its development in school science education should be further extended beyond micro-scepticism "to foster dialogical exchanges across different ideas of development and worldviews" (p. 644). Influenced by the writings of Jasanoff (2004, 2005, 2012), she strengthens her point by emphasising that the lives and actions of human beings are *inseparable* from the knowledge which scientists have accumulated about the world we live in (and live on). Thus, it is only right that matters of serious societal concern, such as global warming, be dealt with in schools. The truthfulness of evidence must then figure as part of any learning about what scientists report as their findings. She correctly points out that this requires an appropriate framing of what constitutes evidence. For Colucci-Gray, science teaching must contribute to 'transformative citizenship'; it must play its part in how we square privileged (scientific/technical) knowledge with public concerns about the outcomes and implications of scientific investigation. And so she reasons that the science that is presented in schools *must* meet the challenges posed by sustainability, biotechnology, genetic modification, and so forth, and reflect open-mindedness and shared honesty, as we argued in Bryce and Day (2014). Whereas our article tends to concentrate on the methodologies and the metrics of climate change, Colucci-Gray's paper tends to emphasise "the inherently complex nature of real-life contexts and which escape[s] the grasp of the scientific, analytical view" (p. 636). In her analysis, the inevitable reductionism in scientific approaches always risks the omission of factors important to humans and particular communities because of that complexity. The reductionism also means that any adopted scientific method sets boundaries upon what is *not* being considered at any one time. Humility and ethical reasoning are frequent casualties; cultural issues are neglected whereas biophysical concerns tend to dominate; that which is not quantifiable is obscured; she argues. If the distant future is about geo-engineering on a global scale, then political debate will become incredibly complex and life changing as we know it.

Thus school science needs to be reconsidered carefully and Colucci-Gray welcomes our recommendations concerning the merits of cooperative learning as a pedagogic approach. She emphasises, understandably, that teaching about global warming should not replace attention to other concerns about the surroundings in which we live; specific and localised environmental concerns must be addressed too. And she widens the whole debate about what education in school needs to consider, matters which, broadly speaking, could be described as being *socio-political* in character and which constitute the core of citizenship education. Citing Jasanoff (2005), Colucci-Gray pointedly states: "The challenge of making wise decisions in the face of uncertainty lies at the interface between ethics, politics and science" (p. 642). The papers by Fensham (2014) and dos Santos (2014) similarly stress this, particularly the latter, and so we need to look at it closely. First, however, we should consider Fensham's reaction to our paper.

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Fensham's position

Fensham also strongly supports our arguments for the teaching of global warming at the present time (and other issues where socio-scientific controversies arise—as do we). But for him: "It is only in relation to emerging and uncertain scientific contexts that students should be taught about scepticism". He presses for scepticism to be balanced with *trust* in science, that trust to be an "active intellectual dependence", meriting in his eyes an equal emphasis in teaching about science—indeed as an "antidote". Students should "learn when and why to trust science" (p. 649). He considers that (using the terms of Kurtz and Snowden's Cynefin framework) the scientific knowledge of simple and complicated contexts where established laws hold—including inter-disciplinary knowledge—should be free of scepticism during instruction; for him it is "inappropriate". For the science of complex contexts where there are varying degrees of uncertainty, scepticism "needs to be actively included". It is tempting to say that we agree here, and throughout the working day perceptive science teachers must nuance their instruction accordingly: sometimes taking the conventional line and conveying that 'this is how it is'; at other times emphasising scientific uncertainty, scientists' tentative thinking and the disagreements among experts. The difficulty is that, according to research findings which we discussed in Bryce and Day (2014) and in Bryce (2010), very many teachers are *not* so inclined to be flexible in how they go about teaching; the conventional line on what science is and is about (Roberts Vision I literacy at best) dominates and effectively pre-empts any alternatives (Roberts Vision II literacy). Only with a commitment to pedagogies appropriate to science 'where uncertainty holds', to cite Fensham's use of the Cynefin framework, will teaching be effective. There are plenty of examples to choose from as the literature indicates. Fensham adds to the ones we identified and highlights those where the deliberate promotion of doubt and an anti-science stance is deployed to confuse the public (and to which he says we only make oblique reference).

The precautionary principle

Fensham chides us for not making an explicit reference to *The Precautionary Principle* published by UNESCO in 2005, for he sees it as a re-wording of the importance of scientific scepticism and how it should be used by scientists. We certainly explained what the IPCC was charged to tackle in respect of global warming, all of its reports explicitly looking at AGW and therefore predicated on precaution. Perhaps more significantly, we would observe that the final sections of the UNESCO (2005) report concerned with 'Social and cultural implications' are strikingly scant about education and the schooling of future scientists and citizens. There were evidently no deliberations amongst the writers of that report about how future scientists might be taught—despite the 'E' in UNESCO and 'the ethics of scientific knowledge' being in the subtitle of the report!

Focusing more specifically on interpretations of the precautionary principle, it is interesting to note that it is by no means universally accepted within the scientific community where it has been criticized on grounds that it is conceptually ill defined (Sandin et al. 2002); theoretically incoherent (Peterson 2006); potentially absolutist in nature (Nollkaemper 1996); largely based around value judgments (Charnley 2000); potentially leads to increased risk-taking (Sandin et al. 2002); and is unscientific and could lead to the marginalizing of science (Gray and Bewers 1996). The precautionary principle has become something of a mantra of the environmentalist movement, which leaves it open to claims that it is a 'political' principle rather than one which is scientifically based.

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The problem with invoking the precautionary principle is neatly summed up by Henk van der Belt (2003) when he suggests that,

> … many environmentalists… believe that we possess a decision rule or principle for dealing with fundamental scientific uncertainty that is itself not the least uncertain. That rule is the PP [precautionary principle]. Thus, in almost any debate, it seems that the PP can be brought in as a *trump card to override* all other considerations and arguments. But what exactly is the PP? (p. 1123) [emphasis added].

While we certainly accept that the precautionary principle is, as its proponents assert, already "enshrined" in such international agreements as the Convention on Biological Diversity and the Cartagena Protocol on Biosafety, it could be argued that existing definitions are at best partial or incomplete, and at worst, fail to spell out the precise conditions that require to be fulfilled before it may be invoked or clearly specifies the nature of the preventative action that has to be taken (van der Belt 2003, p. 1123).

The general appeal of the principle makes it a natural candidate for political consensus among a public otherwise deeply divided about environmental policies. Furthermore, adherents to the precautionary principle tend to subscribe to the view that governments around the world should take precautions to protect public health and the environment, even in the absence of clear evidence of harm as a consequence, and notwithstanding the costs of such action. In the case of climate change it could be argued that the annual costs involved with the application of such a 'political' principle could inflict significant damage to the economies of the developed and developing nations since the proscribed solution would involve governments spending enormous sums of public money to mitigate the effects of climate change (in the case of developed nations) and could deprive developing countries of the means by which they might increase the rate of their economic development.

However, a worrying perspective on the precautionary principle has emerged recently, which advocates a shift in the burden of proof toward those who advocate a new science and technology or activity. Reversing the burden of proof amounts to substituting the maxim "guilty until proven innocent" for the age-old legal principle "innocent until proven guilty" (van der Belt 2003, p. 1125). Even more worrying is the call by Kevin Trenberth (a leading climate scientist and IPCC author) that in the case of climate science, "Given that global warming is "unequivocal", and is "very likely" due to human activities, to quote the 2007 IPCC report, the null hypothesis should now be reversed, thereby placing the burden of proof on showing that there is no human influence" (Trenberth 2011).

Trenberth's argument for reversing the burden of proof hinges on whether the IPCC's evidence and arguments meet an appropriate standard of proof, which in Bryce and Day (2014) we suggest is far from scientifically unproblematic (or, it could be argued, ethical). The commonly used levels of proof are the preponderance of evidence, clear and convincing evidence, and beyond reasonable doubt. If science is to carry on testing hypotheses (as it undoubtedly will), what of Trenberth's suggestion that we should assume human influence unless proved otherwise? It is doubtful that his argument would find much support within the wider scientific community. The key point missed by Trenberth is that while human influence may now be 'playing some role' in the rise of global temperatures, the incidence of intense storms is likely to decrease, not increase, by the late twenty-first century, according to the computer simulations carried out by Zahn and Storch (2010). North Atlantic polar lows should become less frequent, not more frequent, if and as global temperatures rise. Only when the signal of anthropogenic influence on extreme weather becomes overwhelming (which looks to be some way off at present) will it make sense to

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assume human influence has increased the odds of any weather event that occurs (Allen 2011).

What is particularly worrying about Trenberth's train of thought is that it highlights that some climate scientists (alarmists) consider that climate science is somehow different from the rest of science, believing that in the name of precaution, they can turn 400 years of scientific thought on its head.

Which brings us back to the question of how best to discuss the precautionary principle with students and how we teach our students to trust scientists? Are we really to accept the precautionary principle at face value? Should we present the precautionary principle to our students as if it is unproblematic? While we agree that teachers ought to discuss the precautionary principle as part of classroom discussions on climate change, we would suggest that, if introduced uncritically, it might possibly present more problems since it could be used to close down discussion rather than promote open debate. As for teaching our students to 'trust' scientists, the above example shows that the politically motivated views of some climate scientists make it difficult for science teachers to present the climate science (and several climate scientists) as trustworthy, hence our suggestion that science teachers need to carefully educate their students to critically scrutinize the science for confirmation bias as well as political motivation.

IPCC's fourth and fifth reports (AR4 and AR5)

Most interestingly, Fensham states that the very recent fifth report of the IPCC (which came out after our paper was published) "answers many of [our] concerns about climate change". Our article had looked closely at the fourth IPCC report (AR4) of 2007. This raises two observations immediately. First, it is indeed striking how different the reports are in style and presentation. The more recent report (2013) is much more upfront and explicit on the extent of the confidence which can be placed on predictions of climatic *change rates*. Caution and scepticism is the order of the day (with forecasts worsening on the whole). Second, summaries and reports for policy makers are also now very prominent—and fairly comprehensible; the sense of a wide readership is much greater than before. In that regard, the sceptics among the public and in scientific communities would seem to have been influential in the intervening 6 years: much more is now demanded of scientists regarding what and how they report. Sceptical scientists haven't gone away of course and it is interesting that when the Intergovernmental Panel on Climate Change (IPCC) consensus published that 5th report (AR5), there appeared a counter-consensus publication from the NIPCC (the Nongovernmental International Panel on Climate Change). [One is tempted to ask whether the rather similar title/acronym was used to confuse the careless journalist.] More seriously, the contents of the two reports are very different. The main difference between AR5 and the NIPCC report is that they come to opposing conclusions using largely similar evidence but, in the case of the NIPCC report, with less politically emotive, more scientifically nuanced language.

Looking specifically at the level of certainty expressed within the science portrayed within the AR5, Daniel Botkin who testified before the US house sub-committee on science, space, and technology on May 29, 2014 drew attention to the view that

> … both the reports [IPPC AR5 and the US National Climate Assessment] present a number of speculative, and sometimes incomplete, conclusions embedded in language that gives them more scientific heft than they deserve. The reports are "scientific-sounding" rather than based on clearly settled facts or admitting their lack.

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> Established facts about the global environment exist less often in science than laymen usually think… The rate of change we are experiencing is also not unprecedented, and the "mystery" of the warming "plateau" simply indicates the inherent complexity of our global biosphere. Change is normal, life on Earth is inherently risky; it always has been. The two reports, however, make it seem that environmental change is apocalyptic and irreversible. It is not (Botkin 2014).

Fensham's suggestion that the latest IPCC report answers our concerns seems not to be borne out by the evidence, since AR5 plays down recently published research which clearly shows that there has been a 'pause' in warming since the turn of the twenty-first century despite the unprecedented increase in atmospheric CO_2 concentrations. As we point out in our original article, this 'pause' has been discussed in the literature since 2011 (Kaufmann et al. 2011), and was recently highlighted in an article in *Nature* (Tollefson 2014), yet the summary for policy-makers for AR5 makes little mention of it. Why is this the case? Is it because the IPCC feels the needs to present the science as 'unequivocal' and in agreement with the consensus view held by the environmentalist message in order to persuade the world's politicians? Possibly, but it is more likely that the IPCC is still plagued by the *belief* that humans are the main cause of climate change, at the expense of objectively examining the peer-reviewed scientific literature from the perspective of the original hypothesis.

Mini-scientists and the education of future citizens

A point important to Fensham is his stress upon the educational goal of producing science-informed citizens, seeing this as *preferable* to the goal of producing mini-scientists. He sees the former as more realistic and the latter is what he seems to consider is our goal for secondary students. This juxtaposition needs some unpicking. We have no disagreement about science-informed citizenry; indeed our entire paper centres on what should be achieved for all students through the study of science with that as a main goal. However, reducing our emphasis upon investigative activities concerned with climate change to the placing of students in the role of mini-scientists, as that term has traditionally been understood, misses the point. The research we have personally conducted (see Day and Bryce 2011, 2012) has been with teachers implementing cooperative learning incorporating *both* practical lab work research and internet and textbook searches in order to combine the 'learning of science, the learning to do science, and the learning about science'. What these lessons achieve *unites* the introduction of young students to practical experimentation with their learning about what scientists in the field in question are reporting—corroborations, conflicts, and so forth. They generate real time discussion where the teacher can respond to student queries and debate. Following in-depth interviews with these teachers, we could readily detect that the emphasis of their discussions was to 'practice democratic citizenship' (of the five evident purposes across the sample questioned). This was in contrast to humanities teachers whose emphases for their classroom discussions were concerned with the development of reasoning skills and open-ended enquiry. For us, putting students in the role of mini-scientists means with a necessarily contemporary meaning of the word 'scientist', one whose commitments are to peers, the public and communities, as well as to the subject matter itself. Thus we do not see mini-scientists/science-informed citizens as 'alternative images' for school science, as does Fensham. These should be complementary images and we would argue enable a workable balance of 'collegial trust' and 'scientific scepticism' to be achieved in practice, targets

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which Fensham seems to regard as better achieved through the analysis of suitable dramas enacted for the purposes of educating science-informed citizens.

It is important to note that Scottish science education, which is the cultural environment from which we hail, is undergoing a series of curricular and structural reforms under the auspices of a 'Curriculum for Excellence'. As part of this reform, the purpose of science education has been re-oriented away from the traditional goal of science education for the production of future scientists (the 'pipeline' view) towards the development of students as scientifically literate citizens (Day and Bryce 2013). However, this re-orientation has not translated—so far—into the desired shift in science teachers' thinking about the purpose of science education, mostly due to the fact that the documents issued to them identifying the 'principles and practice' and 'experiences and outcomes' and used by them to focus the content and context of what they teach, *have continued* to focus on the learning *of* and the learning *to do* science, to the detriment of learning *about* science and its relationship with society.

While we wholeheartedly subscribe to the goal of developing students as scientifically literate citizens (particularly the vision II orientation towards scientific literacy), we also recognize that the prevailing culture of Scottish science teachers currently subscribes to the traditional 'pipeline 'view of the goal for science education. In Bryce and Day (2014), we present our analysis in a manner that would be accessible for science teachers regardless of their alignment with a vision I or vision II orientation towards scientific literacy. But we focus our analysis more on the development of critical awareness in the development of students' scientific literacy rather than placing students in the role of mini-scientists as Fensham suggests.

dos Santos's position

The article by dos Santos (2014) indicates strong support for the thrust of our paper. He welcomes the discussion of climate change in school science and illustrates answers to our three research questions by reference to recent investigations of his own in Brazil. He too found that students were not inclined to be sceptical in the course of their normal science studies and required to be taught "how to detect bias in scientific claims" (p. 667). In the research he describes, students were exposed to biased, alarmist newspaper reports and individual students' points of view regarding the political context of the climate change debate were made explicit. Thus he concludes that classroom discussion of the political issues surrounding global warming should take place in science. We object to one point which is repeated several times by the author: that is the assertion that we somehow confined our analysis to 'confirmation bias'. We most certainly discussed it in relation to research and thinking, and in some detail, both in general and in relation to what is evident amongst climate researchers. And we also discussed related issues like conflicting evidence and alternative perspectives on how data might be analysed. But we don't "propose confirmation bias" (as per his abstract), nor, in conveying the scientific view, do we "reduce the discussion of global warming issues to the confirmation bias and the conceptual understanding of the controversy" (p. 672). Perhaps something has been lost in the translation from Portuguese to English here and dos Santos only means to seek a widening of the debate to include political issues more thoroughly. If so, he could have made explicit concessions to our analysis of both the public and the political debates (including, for example, the climate-gate affairs). The serious challenge however is how science teachers might be persuaded to bring socio-political issues into their lessons, given all the rather

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negative research findings which have been published in the last ten years or so concerning what science teachers are disposed to do.

As a point of clarification, we suggest that as part of students' development towards becoming more critically aware (in our view a vital component of students' developing scientific literacy), science teachers need to support students' learning towards being able to identify and reason through potentially biased information, whether it is political, ideological or, in the case of some scientists, confirmation bias. We would suggest that this perspective aligns well with the development of students' socio-scientific reasoning as suggested by Sadler, Barab, and Scott (2007). In addition, the main thrust of our argument is for the maintenance of the discussion's complexity rather than its reduction to a trite sequence of activities designed to reduce the learning process to thinking skills required to identify confirmation bias.

Political literacy *and* scientific literacy?

Whilst we agree with dos Santos's suggestion that students ought to take into account different political perspectives during any discussion in the global warming debate, we would argue that the co-development of students' political literacy, in conjunction with scientific literacy, requires science teachers to be clear (conceptually) as to what constitutes political literacy. They need also to be able to recognise which elements of any such discussion relate specifically to its development. We would argue that the term political literacy is itself somewhat ill defined and concur with the view that it extends beyond merely acquiring knowledge and understanding of the political system (Eurydice 2012) and the party political dogma of the political class of the nation (whatever nation that might be).

Sir Bernard Crick has suggested that 'political literacy' was a term invented to mean that someone should have the knowledge, skills and values to be effective in public life (Crick 2007). The challenge is to help students to read issues and events from a political perspective. That involves students knowing where, when and how decisions are made in society—at the local, national and international level; recognising one's right to be personally involved with the issues under discussion; being familiar with a range of political ideas, language and forms of argument; developing a personal set of political values, while having the skills and confidence to apply them in practice; being able to engage effectively in dialogue with others on issues of shared political concern. In essence, we suggest that this view of political literacy aligns relatively well with Roberts' (2007) vision II orientation for scientific literacy in that:

> … Vision II derives its meaning from the character of situations with a scientific component, situations that students are likely to encounter as citizens. At the extreme, this vision can be called *literacy (again, read thorough knowledgeability) about science related situations* in which considerations other than science have an important place at the table (Sadler and Zeidler 2009, p. 730, emphases in the original).

Furthermore, we would also concur with Sadler and Zeidler when they suggest that "… vision II Scientific Literacy moves away from prioritizing decontextualized science concepts and focuses instead on understandings and use of science in situations removed from traditional boundaries of science… [and] emphasizes an approach that is broader in scope, involving personal decision-making about contextually embedded issues" (p. 910).

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The three responses to our original article underline the challenges which the classroom discussion of climate change raises for science teachers. While we have commented on them and 'science for citizenship' in places throughout this rejoinder, several points merit further examination. Of interest is a recent paper by Guerin, van der Ploeg and Sins (2013) which critically evaluates the mainstream conceptualisation of citizenship education, internationally and amongst the countries of Europe in particular, noting the stress that is placed on active forms of participation, that being both a goal and an effective teaching approach across the curriculum. It has been repeatedly found that teachers lack the knowledge to teach "political concepts such as equity, freedom, [to] sustainable development, human rights and all kinds of socially relevant issues" (p. 437); and that pupils find it difficult to learn the critical thinking skills involved. The discomfort that science teachers express in discussing socio-scientific issues has been pointed out by us in previous articles (see Day and Bryce 2011; Bryce and Gray 2004). Guerin et al. make a strong plea for improved, relevant teacher education and point out that schools can contribute to the development of students' political literacy in two ways. Firstly, through the development of an integrated curriculum since these themes are not limited to one knowledge domain but involve the use of different kinds of knowledge and the organisation of interdisciplinary learning activities. Secondly, teachers have to possess the knowledge and skills required to teach such issues and the ability to challenge students to take different perspectives on them. They suggest, and we would agree, that this last aspect requires (science) teachers to possess an elaborate epistemological knowledge, including insight into the limits of knowledge in various different disciplines such as ethics, economy and history (as well as an understanding of what amounts to sound evidence in each of these disciplines in order to teach students to understand the relevant knowledge relating to the issue). We would question whether it is reasonable to expect or assume that all science teachers have developed such a wide and sophisticated ontological/epistemological perspective.

Drawing on several empirical studies primarily focused on citizenship education, Guerin et al. (2013) show that teachers lack the necessary specific knowledge of the economy, politics and even of government or European issues in order to teach these broad themes; they also lack knowledge of instructional strategies on how to deal with these complexities; or are simply not at ease to discuss controversial issues (Keating et al. 2009). Using Oulton et al. (2004) as an example, they suggest that only 12 % of the teachers felt adequately prepared to teach controversial issues, due to a lack of training and guidelines. In a longitudinal study conducted by Keating et al. (2009), teachers mentioned the fact that active pedagogical techniques were time-consuming activities. Guerin et al. (2013) go further by suggesting that it is not only within citizenship education that the teaching of controversial issues is delicate; and they acknowledge what it means in science education. A large body of science educational research emphasises the fact that most science teachers are not at ease in teaching socio-scientific controversial issues due to, on the one hand, a lack of knowledge and on the other a lack of practicable educational approaches (Bryce and Gray 2004; Day and Bryce 2011).

In the Scottish context, as a consequence of the lack of an integrated curriculum in secondary education and the current general feeling among Scottish science teachers of being under-prepared to discuss complex issues such as climate change, when such discussions do take place they are dealt with on a superficial level. Potentially this gives rise to the adoption of naive beliefs about how to deal with and resolve such matters. When dealing with them, the pitfall of limiting teaching to the micro level, i.e. teaching students how to reduce their ecological footprint or adopting good ecological behaviours, should be minimised because solutions to many ecological problems, such as climate change, may

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only be found at the macro level: new regulations and new technologies are required. Helping students to discern what can be tackled at both the micro level and macro level is necessary, we would suggest. One of the goals for developing students' scientific literacy should be preparing them in a step-by-step manner to deal with the complexity and controversy of different kinds of issues in an open, balanced and unbiased manner. This would mean providing science teachers with professional support and the tools required to teach such controversial socio-scientific issues. Giving students a realistic view also involves teaching them that these issues require active engagement and effort on their part, over time, with the application of critical thinking skills.

Science teacher identity

While we have welcomed this opportunity to discuss some of the interesting perspectives thrown up by the forum pieces generated by our original article, it is incumbent upon us to discuss why most science teachers are resistant to the notion of teaching science from a more humanistic perspective. One of us has argued that such resistance is an endemic and persistent feature of university scientists as well as school science teachers (Bryce 2010). What lies at the heart of this resistance is the nature of science teacher identity.

Teacher identity is complex in that it is influenced by temporal and transient events in an individual's life. It can fluctuate over time under the influence of factors which are internal (emotions, mood or attitude) and external (job and life experiences) to the individual (Beauchamp and Thomas 2009). This complexity is further compounded by the makeup of teachers' collective conceptualisations of their specialized expertise. The interactions between teachers' professional and personal identities impact heavily upon the decisions made when teachers are planning lessons involving socio-scientific discussion and how they choose to organise the science classroom. These interactions are emergent from, and influenced by, immediate context; prior conceptualisations of self (teachers seeing themselves as scientists who teach rather than as educators of young people); social positioning; epistemological perspectives on the nature of science; and awareness of what is, or can be, personal proficiency. Each of these is a fluid and dynamic construct (Olsen 2008). From the socio-cultural perspective, teacher identity is both a *product*—a result of internal and external influences—and a *process*: an on-going series of interactions during the professional learning of the individual.

Focusing more specifically on why there is resistance to more humanistic forms of science education (as exemplified through the discussion of climate change and global warming), it is tempting to suggest that science teachers' *present* professional identity is at odds with the type of professional identity we would like to them to develop and adopt. Teachers' epistemological perspectives on science heavily influence their professional identity, as do their interactions with other science teachers: the enculturation into the sub-culture of science teachers is particularly powerful. Those who perceive socio-scientific discussion as part of a fact driven, epistemological hierarchy, where science knowledge is the dominant form of wisdom required to negotiate the way forward (and classroom discussion is simply "an add-on, should time permit"), are less likely to engage in relevant pedagogical debate—with each other and with their students.

In addition, other factors affecting their approach to socio-scientific discussion include their understanding of the role that science plays within modern society. This impacts strongly on their perceptions of the goals of science education (the development of scientifically literate citizens *or* the training of future generations of scientists) and how they

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view their own role towards fulfilling that goal. If most science teachers favour the view that the aim is to maintain the pipeline (which seems to be the case, at least in Scotland), then it is little wonder that most science teachers shy away from socio-scientific discussion (Gray and Bryce 2006). Such teaching requires a less authoritative, more open classroom discourse and a pedagogy which conflicts with their core professional identity. Our worry is that if, as dos Santos suggests, we are to throw the development of political literacy into the mix, we run the risk of adding a dimension that most science teachers will see as being in direct conflict with their chosen role. At best this might lead to superficial engagement with socio-scientific discussion and with political literacy specifically or, at worst, could lead to the complete alienation of socio-scientific discussion altogether. Colucci-Gray's (2014) analysis, in seeking deep engagement with socio-scientific ideas, focuses upon the imperative of both scientists *and* science teachers upholding the virtue of cooperation: "… a sceptical attitude and a form of education based on cooperation can go some way towards enabling students to critically appraise technological innovation" (p. 644). But it should (and must) extend student learning in practical ways—and thus the *actions* of key players in the global warming debate must be grappled with. For her, by implication, science teacher identity is rooted in their own personal scientific education (what science means for them) and their professional preparation to teach.

As we see it currently, a pervasive problem emerges from the undergraduate background of science teachers, this being that many lack the ability to critically examine research papers in their own fields with a proper degree of scepticism. They tend to uncritically accept scientific research findings as fact (and indeed the scientific view as incontrovertible) by paying undue deference to the scientific researcher's authority. If this overt 'trust' in scientists (c.f. Fensham's argument alluded to earlier in this paper) persists into teacher education and science teachers' practice then this can lead to a cursory engagement in socio-scientific discussion, one that is closed, uncritical and potentially biased; one which, as Susan Haack (1995) suggests, follows the 'Old Deferentialist' expectation that science is objective, logical and without regard for its social dimension. As we argued in Day and Bryce (2011), any hope for the encouragement of a socio-political dimension in the teaching of socio-scientific issues in a critical, unbiased and open manner requires a paradigm shift in science teachers' thinking.

The quotation from Haack (1995) which we cited at the start of this article emphasises the importance of keeping scientific *warrant* (the evidential basis for any scientific claim) and societal *acceptance* (the standing of any claim in the eyes of the wider community) "appropriately correlated" in our recognition of what constitutes science. In her discussion, Haack then describes her ideal of *scientists*:

> a scientific community of creative and careful enquirers, with adequate resources of equipment and time, all sincerely seeking the truth and unaffected by prejudice, and each making his work freely available to the scrutiny of others, who would thereby be enabled to build on what is solid and to correct what is not. For that would be a community in which creativity in hypothesis and care in seeking out and assessing the worth of evidence—the twin desiderata imposed by the dual goal of enquiry—were maximized (p. 27).

With appropriate guidance and support, science teachers have the potential to give young students an appreciation of the work of such people. And, should some of these students be inspired and capable, teachers should be able to direct their specialist studies to enable them to so participate in ensuing scientific careers.

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References

Allen, M. (2011). In defense of the traditional null hypothesis: remarks on the Trenberth and Curry WIREs opinion articles. *WIREs Climate Change, 2*, 931–934. doi:10.1002/wcc.145.

Beauchamp, C., & Thomas, L. (2009). Understanding teacher identity: An overview of issues in the literature for teacher education. *Cambridge Journal of Education, 39*, 175–189.

Botkin, D. B. (2014). Written testimony to the house subcommittee on science, space, and technology. May 29, 2014. http://science.house.gov/sites/republicans.science.house.gov/files/documents/HHRG-113-SY-WState-DBotkin-20140529.pdf. Last Accessed June 3, 2014.

Bryce, T. G. K. (2010). Sardonic science? The resistance to more humanistic forms of science education. *Cultural Studies of Science Education, 5*, 591–612. doi:10.1007/s11422-010-9266-6.

Bryce, T. G. K., & Day, S. P. (2014). Scepticism and doubt in science and science education: the complexity of global warming as a socio-scientific issue. *Cultural Studies of Science Education, 9*, 599–632. doi:10.1007/s11422-013-9500-0.

Bryce, T. G. K., & Gray, D. S. (2004). Tough acts to follow: The challenges to science teachers presented by biotechnological progress. *International Journal of Science Education, 26*, 717–733.

Charnley, G. (2000). 1999 Annual meeting: Past President's message—risk analysis under fire. *RISK Newsletter, 20*, 3.

Colucci-Gray, L. (2014). Beyond evidence: a critical appraisal of global warming as a socio-scientific issue and a reflection on the changing nature of scientific literacy in school. *Cultural Studies of Science Education, 9*, 633–647. doi:10.1007/s11422-013-9556-x.

Crick, B. (2007). Citizenship: The political and the democratic. *British Journal of Educational Studies, 55*, 235–248. doi:10.1111/j.1467-8527.2007.00377.x.

Day, S. P., & Bryce, T. G. K. (2011). Does the discussion of socio-scientific issues require a paradigm shift in science teachers' thinking? *International Journal of Science Education, 33*, 1675–1702. doi:10.1080/09500693.2010.519804.

Day, S. P., & Bryce, T. G. K. (2012). The benefits of cooperative learning to socio-scientific discussion in secondary school science. *International Journal of Science Education, 34*, 545–587. doi:10.1080/09500693.2011.642324.

Day, S. P., & Bryce, T. G. K. (2013). Curriculum for excellence science: Vision or confusion? *Scottish Educational Review, 45*, 53–66.

dos Santos, W. L. P. (2014). Debate on global warming as a socio-scientific issue: science teaching towards political literacy. *Cultural Studies of Science Education, 9*, 663–674. doi:10.1007/s11422-014-9596-x.

Eurydice. (2012). *Citizenship Education at School in Europe*. Brussels: Eurydice European Unit.

Fensham, P. J. (2014). Scepticism and trust: Two counterpoint essentials in science education for complex socio-scientific issues. *Cultural Studies of Science Education, 9*, 649–661. doi:10.1007/s11422-013-9560-1.

Gray, J. S., & Bewers, M. (1996). Towards a scientific definition of the precautionary principle. *Marine Pollution Bulletin, 32*, 768–771.

Gray, D. S., & Bryce, T. G. K. (2006). Socio-scientific issues in science education: implications for the professional development of teachers. *Cambridge Journal of Education, 36*(2), 171–192.

Guerin, L. J. F., van der Ploeg, P. A., & Sins, P. H. M. (2013). Citizenship education: The feasibility of a participative approach. *Educational Research, 55*(4), 427–440.

Haack, S. (1995). Puzzling out science. *Academic Questions, 8*(2), 20–31.

Jasanoff, S. (2004). *States of knowledge: The co-production of science and social order*. London: Routledge.

Jasanoff, S. (2005). *Designs on nature: Science and democracy in Europe and the United States*. Princeton: Princeton University Press.

Jasanoff, S. (2012). *Science and public reason*. Abingdon: Routledge.

Kaufmann, R. K., Kauppi, H., Mann, M. L., & Stock, J. H. (2011). Reconciling anthropogenic climate change with observed temperature 1998–2008. *Proceedings of the National Academy of Sciences USA, 108*, 11790–11793. doi:10.1073/pnas.1102467108.

Keating, A., Kerr, D., Lopes, J., Featherstone, G., & Benton, T. (2009). *Embedding citizenship education (CE) in secondary schools in England (2002–08): Citizenship education longitudinal study (CELS) seventh annual report*. London: DCS.

Nollkaemper, A. (1996). 'What you risk reveals what you value', and other dilemmas encountered in the legal assaults on risks. In D. Freestone & E. Hey (Eds.), *The precautionary principle and international law* (pp. 73–94). Dordrecht: Kluwer Law International.

Olsen, B. (2008). *Teaching what they learn, learning what they live*. Boulder, CO: Paradigm.

Oulton, C., Day, V., Dillon, J., & Grace, M. (2004). Controversial issues: teachers' attitudes and practices in the context of citizenship education. *Oxford Review of Education, 30*(4), 489–507.

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MS Code : CSSE-TGKB | ☑ CP | ☑ DISK

Peterson, M. (2006). The precautionary principle is incoherent. *Risk Analysis, (26)* 3, 595–601.
Sadler, T., Barab, S. A., & Scott, B. (2007). What do students gain by engaging in socio-scientific inquiry? *Research in Science Education, 37*, 371–391. doi:10.1007/s11165-006-9030-9.
Sadler, T., & Zeidler, D. L. (2009). Scientific literacy, PISA, and socioscientific discourse: Assessment for progressive aims of science education. *Journal of Research in Science Teaching, 46*(8), 909–921.
Sandin, P., Peterson, M., Hansson, S. O., Rudén, C., & Juthe, A. (2002). Five charges against the precautionary principle. *Journal of Risk Research, 5*(4), 287–299.
Tollefson, J. (2014). The case of the missing heat. *Nature, 505*, 276–279.
Trenberth, K. E. (2011). Attribution of climate variations and trends to human influences and natural variability. *WIREs Climate Change, 2*, 925–930. doi:10.1002/wcc.142.
van der Belt, H. (2003). Debating the precautionary principle: "Guilty until Proven Innocent" or "Innocent until Proven Guilty"? *Plant Physiology, 123*, 1122–1126.
Zahn M, von Storch, H. (2010). Decreased frequency of North Atlantic polar lows associated with future climate warming. *Nature*, *467*, 309–312.

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