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A Theory of Curricular Approaches to the Teaching of Socio-Scientific Issues

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Resumo. Usando o modelo de interface de Ziman entre ciência, tecnologia e sociedade, cinco modelos são derivados a partir da literatura sobre alfabetização científica para caracterizar o ensino de assuntos sócio-científicos para estudantes de ensino médio. Seis indicadores são desenvolvidos para ilustrar as características dos modelos: a natureza da hierarquia de relações entre cientistas, professores e estudantes; a fonte do conhecimento; epistemologia; distribuição do conhecimento entre participantes contenciosos; natureza da pedagogia e avaliação. Os modelos diferem substancialmente quanto as suas visões a respeito da autoridade do papel da ciência na sociedade, variando do déficit à práxis coletiva, mas é argumentado que cada modelo tem um propósito pedagógico dentro de um contexto social específico e que uma linha pedagógica perpassa os cinco modelos.

Abstract. Using Ziman's model of the interface between science, technology and society, five models are derived from the Scientific Literacy literature to characterize the teaching of socio-scientific issues to high school students. Six indicators are developed to illustrate the characteristics of the models: the nature of the hierarchy of relationships between scientists, teachers and students; the source of knowledge; epistemology; distribution of knowledge in contending participants; nature of pedagogy and assessment. The models differ substantively in their view of the authority of the role of science in society ranging from deficit to collective praxis but it is argued that each model has a pedagogic purpose within a specific social context and that an epistemological thread runs through the five models.

Palavras-chave: assuntos sócio-científicos, pedagogia, controvérsia, epistemologia.
Key words: socio-scientific issues; pedagogy; controversy; epistemology.

Introduction

The study of contemporary socio-scientific issues (SSI), such as genetically modified (GM) foods, the effectiveness of alternative therapies and the threat of global environmental damage, is now established in the science curricula of secondary (high), and some primary, schools in many industrialised countries. The introduction of such issues to the curriculum has varied progenitors as a development from scientific literacy (SOLOMON, 1993; 1994) and the increasing awareness of science as a public policy issue reflected by the growth in citizen responsiveness to scientific issues in the form of citizen juries (AMOUR, 1995; SMITH & WALES, 2000) and consensus conferences (JOSS & DURANT, 1995a; 1995b; BLOK, 2007). There has also been a burgeoning of the academic study of Public Understanding of Science (PUS) although the links between PUS and the growth of SSI in schools has been parallel rather than interconnected.

While curriculum statements about teaching SSI appear to be straightforward in being situated within the science curriculum, for example, 'Pupils should be taught . . . to consider how and why decisions about science and technology are made, including those that raise ethical issues, and about the social, economic and environmental effects of such decisions . .' (DES/QCA, 2004, p.37) reservations about, and objections towards, the teaching of such issues have been made on diverse epistemic and political grounds. In this article, therefore, I will attempt to draw out the very real problems in addressing SSI in school science before suggesting a typology for differentiated and contextualised approaches to support the teaching of SSI in schools.

Objections and reservations for teaching SSI in schools

The first reservation is that, although there are more and more media-based issues which draw on advances in science and technology such as nanotechnology, cloning, stem cell research, gene therapy and climate change, addressing these issues poses a problem because the science is complex. 'Frontier science' and associated emergent technologies are uncertain, often involve complex modelling (BAUER, 1997; THOMAS, 2000) and even experts are not agreed about the science (MILLAR, 1997). To expect young people to have the concepts to deal with such complexity might be unrealistic and in danger of presenting an over-simplified version of the issue.

Second and related to this, the science learned in schools and universities does not transfer easily into the kind of knowledge needed to make decisions on such matters as (GM) foods and cloning (CHAPMAN, 1991; DAWSON, 2000; RYDER, 2001). Nor is an understanding of basic science necessarily instrumental in supporting decision-making. As Dawson (2000) comments on his study of Ovine Johne's Disease in a farming community in South Australia, decisions were based on 'economic and political reasoning' (p.127) and the amount of scientific content knowledge needed by citizen-participants was minimal.

Third, where socio-scientific issues are enmeshed in political, social, ethical and cultural issues, this presupposes an interdisciplinary framework. Science has a high academic status on the curriculum: it has relatively impermeable boundaries allowing little diffusion or mix with other subjects (physics has the highest status whereas biology has a lower status and is relatively permeable, for example with health studies and even sociology)(BERNSTEIN, 1973).

Fourth is the problem of the nature of scientific discourse and its relationship to values. Linked to this is the positivist argument – and there is evidence to suggest that many science teachers take up a logico-positivist view in their teaching (VAN AALSVOORT, 2004) – that there is nothing meaningful to say about statements which are not factual (AYER, 1971), i.e. capable of being verified, such as statements concerning morality.

One expression of the epistemic incompatibility of science and morality or ethics is that:

'It is widely recognised that 'is' statements in science cannot be turned into the 'ought' statements of moral discourse. For example, science can fairly accurately judge the consequences of bringing together a number of sub-critical masses of U-235 above a densely populated geographical area. It can say absolutely nothing, however, about whether such an action would be right or wrong. The answer to the latter question lies outside the domain of science but within the remit of a moral discourse. The domains of scientific and moral discourse are fundamentally different; they have different core concepts . . ., different procedural ground rules and different tests for truth. . . To apply science's empirical test for truth within the moral domain would turn morality into pragmatism' (HALL, 1999, p.15).

The distinction made between fact and values is often derived from Hume's naturalistic fallacy in which Hume aims to demonstrate that an 'ought' statement cannot be derived from an 'is' statement - although *formally* this can be done[1](HUDSON, 1969; PUTNAM, 2002) - and that the way in which Hume used the term 'fact' has a very different meaning from the use of 'fact' in contemporary discourse (MACINTYRE, 1988). However, normative approaches towards science and ethics tend to draw is/ought distinctions between the two.

Donnelly's articulation of the key characteristics of natural science is that they are distinguished by their ontic categories (DONNELLY, 2002), the entities with which science deals such as electron charge clouds, thermodynamic equations and causation. Donnelly (2004) argues that unlike the humanities science is instrumental, it enables prediction and control, which go beyond any values we might attribute towards its procedures. The reviewing of scientific papers, the ethical constraints, the processes of the scientific community are contingent upon, but not intrinsic to, these ontic categories, that the 'potentialities of the material world are not to be altered by any number of social values, though of course such values may well influence which possibilities are realised' (DONNELLY, 2002, p.138). The implications for the science curriculum are that attempts to humanise science or place it in a social and ethical context result in the 'replacement of education in science with curricula in what might be loosely called the political sociology of science' (p.147). Kromhout and Good (1983) echo Donnelly's critique because social issues 'do not convey any real understanding of the structural integrity of science' (p.649).

The 'Science Wars' of the 1980s and 1990s (ROSE, 1997) reflected differences over the embeddedness of science practice in social and ethical values. The predominantly positivist critique of the problems of science being enmeshed in social practice has been challenged from many quarters

[1] For example, 'For you to assist that elderly person in crossing the road now is good, and for you to refrain from helping that elderly person cross that road is bad, therefore you ought to help that elderly person cross the road.' Based on Putnam (2002) (Putnam, 2002).

from feminist (HARDING, 1986), Marxist (ROSE, 1998) and sociological perspectives (COLLINS & PINCH, 1993).

Fifth, there is the problem of selection of knowledge. SSI have very specific contexts. Are we talking about stem cell research because we have a sick relative and need to know more about it or are we making decisions about whether to prioritise this research over something else? In an environmental issue, is the focus on the economic and agricultural consequences of growing monocultural biofuels or the kinds of personal considerations needed when moving from a petrol-powered engine to bio-diesel? Although the questions are inter-related the knowledge we need for one type of conversation is different from the other even though the broad topic is the same (LEVINSON, 2006).

Sixth, scientific knowledge is being reconfigured. Climate change is a global concern bringing together many different sciences and knowledge sources. This is also true of the biomedical sciences, and complex interactions are developing with the nature of citizenship manifested by the 'scientific citizen' or biological citizen' (ROSE & NOVAS, 2004; MICHAEL & BROWN, 2005). Ravetz (2005) argues that we are entering a post-normal era in which the old distinctions between science, technology and public policy are dissolving and new types of possibilities are opening up. This demands new conceptualisations of knowledge as being heterogeneous and distributed (NOWOTNY et al., 2001), of new relationships between knowledge communities (WENGER, 1998; GILBERT, 2005). But the conditions within schools which must be established for these knowledges to be constructed are seen as problematic (APPLE, 1979; ELLSWORTH, 1989) where schools act effectively as instruments of the State and where knowledge is seen as owned by individuals (FREIRE, 1996).

Re-configuring the curricular approaches to teaching socio-scientific issues

My own position towards the teaching of SSI is that science is a powerful, rational and authoritative means of understanding nature and that how young people come to learn the central theories of science is to accept the authority of that knowledge. School students are not makers of western science but have to learn its nature and content. While it is perfectly sensible for a teacher of literature to ask young people to critically evaluate Shakespeare's portrayal of the relationship between Polonius and Laertes it seems absurd to do the same with Newton's Laws of Motion. By this I certainly do not want to imply that the pedagogy is transmissive and authoritarian; on the contrary, science is best learned by a whole range of active teaching methods and immersion in ideas which stimulate interest and curiosity. But this does not invalidate the aim of teaching socio-scientific issues as a democratic process, it is to affirm that the teaching of substantive science calls upon a different type of pedagogy and purpose and that translating science into socio-scientific issues is not so straightforward as curriculum-designers often assume.

There is no monolithic approach to the teaching of SSI. How teachers approach these issues needs to be based upon fitness for purpose. In my reading of the literature on SSI pedagogies and curricular reforms in these areas I have identified a few (necessarily non-exhaustive) characterisations which span a representative range from positivistic, top-down deficit approaches through to communities seeking to find solutions to problems with a strong commitment to social justice from which diffuse and indeterminate conceptualisations of SSI emerge. In constructing this typology I am also addressing the concerns I referred to in teaching SSI by contextualising the teaching-learning approaches and describing the conditions – pedagogic and political – which enable these concerns to be met. Within each grouping I will construct a new description of what a controversial socio-scientific issue might look like (Table 1) in terms of:

a. social hierarchies of participants;
b. content;
c. epistemic view of science and society;
d. how participants stand in relation to the controversy of the issue;
e. pedagogy; and
f. assessment

These characterisations cannot be seen as discrete, the boundaries between them are fuzzy but the possibilities of teaching SSI are realised when contextualised within epistemological and social frameworks (see Table 1). My purpose in constructing this typology is that context and the meaning of controversial socio-scientific issues are related. Most secondary schools have a very particular relationship to society - predominantly cultural reproduction - which in itself presupposes certain relations between science and society. To understand the possibilities of a pedagogy there needs to be a perception of the context in which the teacher is working.

Table 1 Models of approaches for teaching SSI

Model	Hierarchy	Source of knowledge	View of knowledge	Controversy	Pedagogy	Assessment
Deficit	Scientist – teacher - student	Corpus of science	Science to be known is correct and certain. Nature is knowable. Where there are uncertainties and tentative knowledge this resides in the domain of experts. 'Hard' science diffuses out into applied science.	Students and lay people are unlikely to have the requisite knowledge and understanding to engage in controversial issues. Nonetheless, as well as science content they can be taught about the methods of science and controversies both within the scientific and socio-scientific domains.	Authority of knowledge resides within science and the teacher as science's representative. Knowledge needed for a controversy can be brought to the attention of students.	Test knowledge/facts of science relevant to a controversy
School and social issues	Scientist/teacher - student	Corpus of science and other disciplines	Science to be known is correct but the emphasis is on the methods and procedures of science rather than facts. Science diffuses out into social applications but there is some transparency about the scientific process.	Takes place within the classroom but might involve analysing science in newspapers distinguishing rhetoric from evidence.	Teacher controls content but might be a facilitator in discussion.	Tests argumentation abilities, use of warrants to support claims
Socio-pragmatic	Scientist/teacher/student as collaborators in school context	Science as needed	Teacher/experts delineate areas of controversy but science is seen as contestable and responsive to social needs.	Participative.	Teacher as facilitator. Knowledge shared between teacher and students	Could be knowledge and skills participant brings to sorting out a problem but difficult to ascertain.
Dialogic/negotiated	Scientist/User/ Student. Trust likely to exist between consumer and expert.	Various. Academic/decontextualised and local/contextualised. Interdisciplinary.	Limitations of academic science recognised but also its possibilities. Role for anecdotal evidence and lay decontextualised knowledge. The workings of science are transparent and contestable but there are still boundaries between science and society.	All parties engage in dialogue in trying to reach a resolution. Often action-oriented or action is an outcome.	Knowledge shared,distributed and negotiated between experts and users	Complex and problematic. Identifiers in a process such as the nature of dialogue.
Collective praxis	Led by needs of participants	Emerges from needs of participants and usually draws on local 'knowledges'. Scientific knowledge is subservient to the needs of the collective and frequently challenged	Shared and distributed. Facts and theories of 'academic' science are seen as irrelevant to the needs of the community. Science is heterogeneously distributed among groups and communities.	Might be around a particular issue but it is the view of science which is contentious. Drive is to address a social injustice. 'Scientific literacy is the contingently received outcome'. Action-oriented.	Knowledge shared and distributed between participants. Authority shaped by praxis.	Problematic.

Deficit model

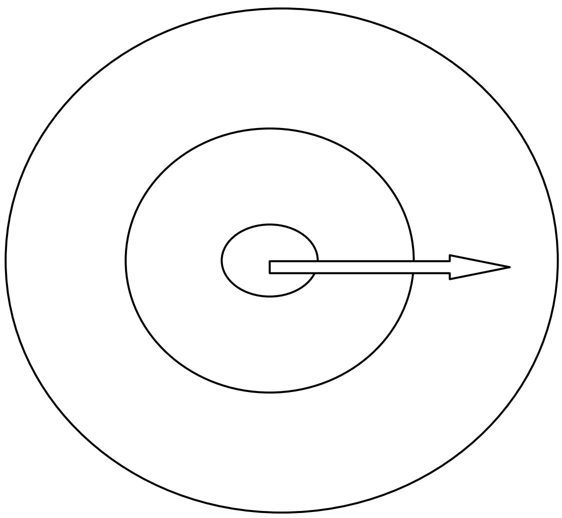
The *deficit* model specifies a difference, a gap of knowledge needing to be filled, between those who know and understand substantive science, i.e. the experts who are scientifically literate, and those who do not know, scientifically illiterate. Since the term ‘deficit’ can have perjorative and tendentious overtones I want to make a distinction between ‘deficit’ as it applies to teaching science content on the one hand and socio-scientific issues on the other. In terms of the former I conceive science broadly as rational and progressive but also authoritative. In school science established scientific knowledge is seen as uncontested and consensual (MILLAR, 1997). There are dissenters from this viewpoint which privileges western scientific knowledge, for example, indigenous people of the modern West ‘have culturally distinct belief patterns in which scientific rationality plays a central role. From an anthropological perspective, faith in scientific rationality is at least partly responsible for many Western beliefs that appear most irrational to non-Western people’ (HARDING, 1991, p.3). Teachers, therefore, face distinct pedagogic and cultural challenges in negotiating those border crossings into western science, (AIKENHEAD, 1996) indeed for some students the border crossings are relatively unproblematic, for others they are in the nature of a cultural upheaval.

Research carried out in the 1980s, which characterised this deficit model (MILLER, 1983; THOMAS & DURANT, 1987), measured the public’s knowledge of true or false responses to science questions such as ‘antibiotics kill viruses as well as bacteria’ and ‘the earth is nearer to the sun in winter than in summer’. Curriculum reforms (AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, 1990) and public programmes (BODMER, 1985; POSTGATE, 1995) attempted to address the problems of lack of knowledge. One conception of a scientifically literate person within the *deficit* model would not only be someone who knew some science but would know about science, its methods and procedures, the applications of science and its role in society. Hazen and Trefil (1991) for example, view scientific literacy as the knowledge needed ‘to understand public issues . . . a mix of facts, vocabulary, concepts, history, and philosophy’(HAZEN & TREFIL, 1991, p.xii).

This deficit view of scientific literacy is broadly one which implies that any individual’s scientific literacy can be measured by objective tests such as those carried out by Miller, and Thomas and Durant. Canonical science is perceived as something inaccessible to non-scientists and they need to be initiated into the basics, or given a sense of ‘how the world works’ (TREFIL, 1997). It is unlikely that these basics will give school students or lay people the expertise to grapple with the technicalities of a contemporary socio-scientific issue but will at least give them an awareness of what is at stake in such issues. Levitt and Gross (LAUGKSCH, 2000) doubt if a sufficiently high proportion of the populace could have the necessary expertise to make decisions on these issues. Shamos (1995) suggests that decision-making would involve experts working with lay people on complex decision-making processes, consistent with the *deficit* model. Teaching socio-scientific issues in schools could involve scientists and teachers working with students on an issue, directing students to appropriate questions to consider, but ultimately students would be given some insight into the complexities experts have to consider in making a decision at the interface of science and society. A resource for this approach could be the Science and Technology in Schools materials where students learn about a controversy in a socio-scientific issue having studied the related science, e.g. DNA fingerprinting (LOWRIE & WELLS, 1990) but any course materials which attempt to describe the background science as a pre-requisite for understanding the socio-scientific issue are subsumed in the *deficit* model.

In terms of the cognitive view of science in society from a *deficit* model perspective, scientific knowledge is very much at the core. 'The boundary between "science" and "society" is envisaged as a semi-permeable membrane, through which knowledge only flows outward . . ' (ZIMAN, 1984, p.4). The flow is in one direction where science is applied in the form of technology and used by society more generally. (Figure 1)

Figure 1: Model of interface between science, technology and society



In figure 1, derived from Ziman's figure, the small innermost circle represents established scientific knowledge, the '"hard" part of modern physical theories which have universal truth

(WEINBERG, 1998), the middle circle represents the technological sphere in which the substantive science is applied and the outermost circle represents society generally and the myriad of ways in which the technology is deployed. The arrow signifies the unidirectional flow of knowledge from the inner core to the outer domains; the epistemological core of science remains unchanged by the social changes around it. While the SSI in the outermost circle are subject to flux the decisions can be influenced by the application of science and the knowledge which resides in experts.

School science and social issues

A knowledge of science will help students as citizens-in-the making to ‘hold and express a view on issues which enter the arena of public debate and, perhaps, to become actively involved in some of these’ (MILLAR & OSBORNE, 1998, p.2007). The significance of the ‘perhaps’ here is to see this statement in contrast to *collective praxis* (see later) where controversy presupposes active involvement. The implications for a curriculum of this sort are for

‘individuals . . .to be able to understand the methods by which science derives the evidence for the claims made by scientists; to appreciate the strengths and limits of scientific evidence; to be able to make a sensible assessment of risk; and to recognise the ethical and moral implications of the choices that science offers for action’ (p.2004).

This sense of relevance to forthcoming active citizenship and a curriculum which puts more emphasis on an understanding of the methods and procedures of science is consistent with the reforms of major U.S. and U.K. curriculum bodies (YAGER, 1992; 1993; YAGER & LUTZ, 1995). Such a reformed science curriculum will address societal needs and problems but the control of the curriculum is in the hands of semi-governmental and governmental bodies and professional societies to decide what kind of knowledge has the most appropriate place in the curriculum. There is no suggestion that students will have control over what issues to study, what is learned or that they will have the skills to negotiate what they will learn. Knowledge is located in the individual and can be assessed, albeit through a framework which puts a greater emphasis on an understanding of the methods of science, and gives greater weight to ‘holistic understanding of the major scientific ideas and a critical understanding of science and scientific reasoning’ (MILLAR & OSBORNE, 1998, p.2025). This framework might test skills-in-action such as students making a presentation of their findings in discussing a socio-scientific dilemma in the classroom.

This category has scope for student discussion and debate on SSI. How teachers organise the discussion might vary but there will be certain expected outcomes such as a demonstration of how evidence was used in a controversy.

There is no effective change to the model of science and society described in figure 1. Around the inner core the shell is a little more transparent in that the inner workings of science are exposed to society. But the flow of knowledge is still from the inner core to the outer layers. Both the *deficit* model and this model are by and large representative of the science curricula in many industrialised countries.

Socio-pragmatic paradigm

In this category the approach to SSI is developed through engagement and participation in issues such as public health and the environment (LAW et al., 2000). The shift from *school science and social issues* is that the content derives from general public needs rather than curricular prescription, content which is likely to be fluid, uncertain and indeterminate, as well as a programme which presupposes some form of student participation (DAVIES, 2004). In this approach the problems are framed by experts such as urban planning officers and doctors and, in order to participate, students and lay people will need to grasp the underlying science and technology as well as contextual factors: scientific awareness (e.g. possible impacts of GM foods on different groups in society); scientific policy and legislation (such as food labelling procedures) and scientific values and commitment (such as consumer rights) (LAW et al., 2000). While the knowledge required is likely to be different from that of the academic school curriculum it is largely selected by experts and teachers.

Pedagogy around a discourse of collaborative planning among teachers from different disciplines would be essential (LANG et al., 2006). Students would not only discuss SSI but possibly be involved in participating in change. Since the scientific knowledge required is likely to lie outside traditional school curricula the teacher is a learner on an equal footing with the students. Assessment is therefore problematic and is likely to focus mainly on types of procedural conceptual knowledge such as the extent of participation and new knowledge produced.

The Making Informed Decisions about Sustainability (MIDAS) project is an example of a project which corresponds to the criteria of the *socio-pragmatic paradigm*. It involved a sequence of collaborative fieldwork activities between primary and secondary schools, university educators and community groups (RATCLIFFE & GRACE, 2003), which explored the sustainability on local ponds of fishing and feeding ducks. An important outcome of this project was to develop links with local community groups. Although the students participated in carrying out fieldwork and helped in the decision-making process, the authority of the science is not questioned and they were not responsible for initiating the project.

In terms of the science-society model the inner core and the layers remain but the boundaries between them are more permeable in terms of the flow of knowledge. The arrow still flows outward from science through technology to society but there is a smaller arrow going in the opposite direction and the contents of the inner core are less certain and academic.

Dialogic/negotiated

The new paradigm in the Public Understanding of Science in the 1990s was dialogue rather than deficit (LAYTON et al., 1993). Where trust and dialogue existed between expert and lay communities there was deemed to be more effective resolution of problems which related to the social contexts of people's lives. This was not so much the public understanding science but scientists beginning to understand diverse publics. The science of the problem often had to be transformed into a local context where experts and people affected could discuss the problem in local and specific terms of perceived need. What most concerned people was not a need to understand academic science or to estimate the risks but to feel that experts understood their concerns and that their voices had been listened to (IRWIN et al., 1996). Where there was a problem or dilemma to be addressed it was not the science facts which were the crucial factors but political understanding and trust, in fact knowledge of the science for most socio-scientific problems was seen to be marginal. 'Local' does not necessarily imply geographical constraints. People have concerns about global issues such as climate change, bird flu and the impact of GM farming methods. But engagement about such issues must involve more than canvassing or scientists listening to what people have to say; experts and non-experts are joint participants in negotiating change.

Science knowledge through the dialogic approach is also seen as distributed, that is knowledge does not reside in one person or group to be disseminated to those who do not have that knowledge. To try and resolve a problem or issue lay people and experts will have to draw on diverse knowledges: anecdotal evidence (TYTLER et al., 2001) can provide links between local knowledge and 'expert' science. The implications for teaching SSI are complex. If SSI are to be taught in schools then the students might not need any of the science normally associated with the school curriculum such as canonical biology, physics and chemistry or the science would be so transformed, disembedded and re-contextualised that it might not be recognisable as anything approximating to the science students have been used to. Skills in dialogue, and understanding the meaning of trust in the context of public policy, will be useful attributes. Trust here is not the same as fidelity; it implies lack of certainty in a future outcome which might be controlled by others. Nonetheless this is precisely why reasonable trust is needed because we do not need trust where the outcome is certain (SZTOMPKA, 1999). Dialogue around these issues presupposes tentativeness and uncertainty in the science. Since knowledge comes from a variety of sources an inter-disciplinary approach would seem suitable.

In this classroom context there is no one locus of authority in either scientists or teachers. Individuals engaged in finding a resolution to a dilemma will draw on multiple sources of knowledge. If, for example, a group of students were discussing whether to campaign against the use of foods in their school canteen they would take evidence from research, listen to the stories of others affected in different ways by GM foods (e.g. producers and campaigners), canvas the views of their peers and negotiate with the school authorities. No one source of knowledge and information would be privileged over any other. Assessment would, again, be problematic and would have to be negotiated by all involved parties.

The boundaries in figure 1 start to dissolve but they are still recognisable. Dialogue between scientists and lay people is represented by arrows of similar size flowing in both directions. Expert knowledge is responsive to and is modified by informal citizen knowledge.

Collective praxis

A more radical critique, very much connected with the teaching of SSI, has come from the United States and Canada in the form of reconstructing scientific literacy in schools as *collective praxis* (ROTH & CALABRESE BARTON, 2004). The assumptions driving this conceptualisation of teaching SSI are struggles for social justice and an understanding of power relations (HODSON, 1999). *Praxis*, as Habermas intends it, is a 'human engagement . . . embedded within a tradition of communally shared understandings and values, vitally connected to people's life-experiences' (DUNNE, 1993, p.176). Through the 'dialectic of interaction . . .the self emerges in a . . .process of working through conflict and struggle towards mutual recognition with others' (p.178). Central to this approach are a sense of identity and agency. As participants in community action, people are agents of change and their identities are formed and re-formed as a result of the changes in which they participate. Knowledge and understanding of SSI are not a property of individuals but emerges through action and are both indeterminate and under-determined. Perspectives are committed and come from members of interest groups and communities but also draw on marginal viewpoints, homeless children, women, ethnic minorities. Above all, it is citizens using science to address their own problems and, as a result of trying to find solutions, produce new knowledge.

This implies a very different use of science in SSI from that described in the *deficit* model, and of *school science & social issues*. Science becomes one tool amongst many – to use Roth's analogy one fibre among others making up a thread (ROTH, 2003) - which not only can be used to resolve an issue one way or the other but also becomes a means of critiquing and deconstructing the dominant, 'academic' decontextualised science. Science is a means of promoting a democracy where citizens act in socially responsible ways. Since science is so bound up with political, ethical, economic, social and communal aspects, locating and acting on SSI is intrinsically interdisciplinary. The location of the controversy is both on the issue – cleaning up rivers, choice over GM free foods in local outlets – but also in the tension between local science and dominant science, expert and non-expert, decontextualised science and generalised science. Schools as instruments of the state and cultural reproduction are therefore in problematic positions. As before, pedagogy is interdisciplinary but the boundaries between teachers and taught are disrupted.

The layers between academic science and society are completely broken down, the relationship between science, technology and society is heterogeneous and diffuse, science has no particular cognitive authority and science policy is played out in public spaces representing the *agora* in which science is contested and there are multiple and differentiated interactions between interested parties and scientists (NOWOTNY et al., 2001).

Implications for pedagogy

The five models in table 1 presuppose diverse roles for the teacher/expert. In the *deficit* model the teacher/expert controls the knowledge needed for a socio-scientific issue and scientific literacy can be a measure of the difference in science knowledge from before and after learning about the issue, where the emphasis is on the science rather than the controversy intrinsic to the issue. In *collective praxis* the teacher/expert is a participant whose knowledge is seen as problematic, and where expertise is not only distributed between the participants but is constantly changing. Knowledge in the *deficit* model is generalised scientific concepts which can be applied to an issue, in *collective praxis* knowledge emerges from local contexts. The science teacher in the *deficit* model will draw on the forms of knowledge they have been inducted into in higher education and with which they will feel confident. In *collective praxis* this new knowledge needed might be completely strange to the teacher.

Roth and Barton criticise the *school science & social issues* approach because the activities which might comprise part of this approach such as role play and consensus projects (KOLSTØ, 2000; SIMONNEAUX, 2001) reproduce 'existing separations between school and everyday society' (ROTH

& CALBRESE BARTON, 2004, p.176). They are based on assumptions that what is learned in school can be transferred to 'everyday knowing' (p.176). But if schools are the sites of cultural reproduction there are nonetheless instances when students become involved in transformative programmes when they discover, possibly with the help of an attentive teacher, the problems of the closed discourse of school science (DÉSAUTELS & LAROCHELLE, 2004). While there are both epistemological and social boundaries, both within subjects in schools and between schools and the world beyond, to accept school-based programmes as obstructions to democracy is to conceive of schools as asocial and to deny the possibility of student and teacher reflexivity. It is, in fact, to deny the transformative power of their own, i.e. Roth and Barton's, project.

Gramsci (1971) has argued that the values of the dominant class, in this case, those technocratic values that drive school policy, so deeply saturate the consciousness of society that it becomes part of society's commonsense. Thus we have a functionalist approach to school governance, an assessment-driven system and the discourse of 'delivery' and 'strategies'. But this hegemony is not static, it is in a constant state of challenge (WILLIAMS, 1973). To accept the non-possibility of any change emerging from schools is to accept a highly reductionistic and pessimistic account of praxis. From a pragmatic position that engagement with SSI within schools, however slight, is better than no engagement. Discussion around disagreements, even within a highly authoritarian system, enables the identification of contradictions and possibilities and the consideration of alternatives. Where schools do engage in action, for example in support of refugee children (CARRINGTON & TROYNA, 1988) or in countering environmental problems there is the awareness of change. The *deficit* model might be a very limiting account of studying SSI in schools, where the parameters of authority are closely defined. But certain attitudes or dispositions can be developed which, while not necessarily transferable, do raise awareness, for example, the importance of listening to points of view with which you disagree, the respect for rational procedures such as inference and the identification of fallacious argument (ZEIDLER, 1997).

Evidence from classrooms and interviews with teachers show that science teachers in particular do not feel confident about teaching SSI (LEVINSON, 2001; OSBORNE et al., 2002; BRYCE & GRAY, 2004) possibly as a result of their own apprenticeship in the institution of science (CROSS, 1997). To attain the *collective praxis* as demonstrated by Roth and Barton is a long way from the sights, practices and expectations of many teachers. In Table 1 I have tried to encompass both the problems and possibilities in teaching SSI. Its purpose is in representing those criteria which need to be met in developing consciousness of SSI in young people.

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