

GLEN S. AIKENHEAD

University of Saskatchewan, College of Education

CHEMISTRY AND PHYSICS INSTRUCTION: INTEGRATION, IDEOLOGIES, AND CHOICES

Received 5 October 2002

ABSTRACT: Teachers choose whether or not to integrate Chemistry and Physics, and if so, to what extent. Choices rest on the ideology of a teacher, particularly the professional self-identity of a teacher. Choices become more rational the more a teacher understands the ideologies guiding those choices. The purpose of the article is to uncover some of these ideologies in three different contexts: scientific disciplines, the science curriculum, and relevance of subject matter. Four decades of research in science education suggest that choices can be made, but putting those choices into action is a political process, not a rational process entirely. One major challenge for teachers who want to innovate is the need to rethink and reformulate their professional identities. [*Chem. Educ. Res. Pract.*: 2003, 4, 115-130]

KEY WORDS: *chemistry and physics instruction; integration; ideologies; relevance; history*

INTRODUCTION

Over the past decades pupil interest and achievement in chemistry and physics have steadily declined (Osborne & Collins, 2000; Ziman, 1994). The reasons for this, while multifaceted and complex, generally relate to pupils' feelings that chemistry and physics are irrelevant and boring, mainly because their instruction is out of synchrony with the world outside of school (Layton, 1986; Oxford University Department of Educational Studies, 1989; Reis, 2000; Sáez & Carretero, 2002; Seymour, 1992; Young & Glanfield, 1998). Chemistry and physics instruction is, however, very much in synchrony with university administrative units known as departments of chemistry and physics.

The professional self-identity of many science teachers is often moulded during their university years when they experienced socialisation into a particular scientific discipline (Aikenhead, 1984; Helms, 1998). Some teachers embrace their professional self-identity as an unchangeable natural reality. Other teachers recognize it as being historically contingent and are open to moving beyond their university socialisation to other views of school science for the benefit of their pupils.

Science educators who wish to contemplate new directions for curriculum and instruction must rethink their allegiances to discipline-bounded university administrative units and consider the 'real' world outside school science, where science has meaning only when integrated to meet the contingencies at hand (Ryder, 2001). Science graduates employed by industry, business, government, or private foundations, learn science concepts as the need

arises (Duggan & Gott, 2002), and those concepts are not bounded by disciplinary jurisdictions. The public, when faced with the need to learn sufficient science content to communicate with experts and ask critical questions, do learn the relevant science content without having a strong science background (Davidson & Schibeci, 2000; Duggan & Gott, 2002; Fensham, 2000b; Layton et al., 1986; Rennie & Williams, 2000; Ryder, 2001). The 'real' world of science-related careers and public interest is a world of dynamic integration of science content. For example, teams of scientists and engineers integrate (draw eclectically upon) content found in many 20th century disciplines such as biotechnology, molecular biology, ceramics, and biophysics. Rarely mentioned in the context of cutting edge research are the older disciplines of biology, chemistry, and physics. When people use science in the everyday world, professional scientists and the public alike, they also integrate scientific knowledge with the societal demands of the problem at hand, in which 'pure' science content is altered to fit a non-science context (Jenkins, 1992; Layton, 1991). Bright creative pupils tend to find these difficult challenges interesting and worthwhile (Layton et al., 1993).

What are the rational choices we can make concerning future directions for chemistry and physics instruction? The purpose of this article is to help clarify the values that guide these choices, particularly the choice to integrate or not to integrate. The status quo of today's school science, as well as innovative directions for future science instruction, all embrace different ideologies. This article analyses historical perspectives on three key issues – scientific disciplines, the science curriculum, and relevant integration – to uncover some ideologies that impinge upon a teacher's choice. Being aware of these ideologies can enhance the rationality of a teacher's choice.

HISTORICAL PERSPECTIVES: SCIENTIFIC DISCIPLINES

The domain of knowledge we call 'science' today has evolved over the years and continues to evolve today. Our Euro-centric line of evolution began with the Greek origins of *philosophy* and then radically advanced during the 17th century with the establishment of *natural philosophy* as a social institution within Western Europe (e.g. the inauguration of the Royal Society in 1662). As natural philosophers learned more about the physical universe, and as they incorporated more axiomatic assumptions into their collective worldviews (e.g. Descartes' mind-matter dichotomy), their success at exercising power and dominion over nature, to use Francis Bacon's phrase, attracted the attention of entrepreneurs who adapted the methods of natural philosophy to gain power and dominion over human productivity, in the context of various industries emerging across 18th century Britain (Mendelsohn, 1976). This gave rise to the Industrial Revolution and provided a new social status for technologists. Industrialists at the time spoke of natural philosophy as 'the handmaiden of technology' (Fuller, 1997). However, the independent minded natural philosophers would have none of it. In the early 19th century, natural philosophers began to distance themselves from technologists, thereby precipitating the next radical transformation in the development of modern science.

Natural philosophers, led by William Whewell (among others), an Anglican priest and natural philosopher of mineralogy at Trinity College Cambridge, set about to revise the public image of natural philosophy by portraying technologists, for example James Watt of steam engine fame, as people whose success depended upon *applying* the abstract knowledge of natural philosophy (Fuller, 1997; Layton, 1991). Today's vernacular would describe Whewell as a 'spin doctor'. He and his colleagues succeeded in their revisionist project, and

today almost all science professors and science teachers uncritically believe in the simplistic notion that technology is merely applied science, thereby maintaining the ideology that holds 'pure science' superior to practice (Collingridge, 1989; Fleming, 1989; Gardner, 1994).

Reconstructing history was only one step in the 19th century's radical advance towards modern science. A new social institution was required and it needed a secure social niche in 19th century society. In short, natural philosophy needed to be *professionalised* (Layton, 1986; Mendelsohn, 1976), defined by Orange (1981) this way:

To professionalise an activity, whether it be music or sport or science, is to change it: to secure adequate rewards for those who practise it, but at the same time to promote, formalize and delimit its cultivation, to generate among those who are accepted as its exponents a self-awareness, a sense of corporate identity and specialness, an acceptance of a primary loyalty and accountability to the discipline and to each other. (p. 59)

Very purposefully and deliberately, the name 'science' was chosen to replace 'natural philosophy' during the birth of a new organization in 1831, the British Association for the Advancement of Science (BAAS), an organization very different from the aristocratic and largely ineffectual Royal Society (Orange, 1981; Yeo, 1981). 'In seeking to achieve wider public support for science, the British Association wanted to present its members as a group of men united by a common dedication to the investigation of nature' (Yeo, 1981, p. 69). With the advent of the BAAS in 1831, a new meaning for 'science' was added to the English lexicon, a meaning we primarily use today (Brock, 1981; Orange, 1981).

The BAAS attracted members whose interests spanned the vast systematic knowledge of natural philosophy that had accumulated at the time. To accommodate participants at yearly meetings, concurrent sessions were organized around certain themes. The organization of concurrent sessions was greatly influenced by the administrative structure of the new University of Berlin, founded by Wilhelm von Humboldt in 1810, which partitioned natural philosophy into the disciplines of physics, chemistry, geology, zoology, botany, etc. (Fuller, 1997). During the 1830s, the BAAS established the following internal organization (MacLeod & Collins, 1981, App. II): Section A, mathematical and physical science; Section B, chemical science and mineralogy; Section C, geology and physical geography; Section D, zoology, botany, physiology, and anatomy; Section E, statistics; Section F, mechanical science (engineering). This classification scheme would eventually determine the structure of the science curriculum in the 1860s.

Within a decade of its inception, the BAAS meetings attracted large audiences comprised of those insiders who conducted the empirical research for the new science (i.e. professional natural philosophers) and those outsiders who were motivated by other personal interests. In a speech to the 3rd annual meeting of the BAAS in 1834, Whewell coined the term 'scientist' to refer to the cultivators of the new science – those who attended annual meetings of the BAAS (MacLeod, 1981). "By coining the word 'scientist', he hoped to encourage a sense of common purpose amongst men of science which would enable them to be recognized as a definite group in society" (Yeo, 1981, p. 69). For the next 50 years, however, some of those cultivators contemptuously rejected the label 'scientist' and instead used 'men of science' (Brock, 1981). The meaning of 'scientist' eventually shifted in order to distinguish between professional practitioners of science (i.e. scientists), on the one hand, and amateurs such as cultured gentlemen, dilettanti, clerics, and retired naval officers, on the other (Brock, 1981). This new meaning gained widespread acceptance.

In addition to providing a professional identity for scientists, a professionalised science required the authority to decide who would become a scientist and who would be excluded. This ‘gate keeping’ role was quickly taken up by universities where new disciplinary departments were established, based on the BAAS category system of biology, chemistry, geology, and physics. With gate keeping in place, the professionalisation of natural philosophy was complete.

In summary, natural philosophy became professionalised mainly through distancing itself from industrial technology: by rewriting history and defining technology as applied science (i.e. subscribing to an ideology that celebrates idealized abstractions over everyday practice), by changing its name to ‘science’, by identifying its practitioners as ‘scientists’, by ensconcing itself within the cloisters of university academia where it could control access to the various disciplines, and by defining what those disciplines would entail.

Science continued to evolve during the 20th century. World War II likely reshaped science more than any single historical event (Mendelsohn, 1976). Abstract science was forced to cohabit with practical technology in order to defeat the Axis powers and preserve democracy. This unlikely marriage irrevocably bound most of science and technology into a new social institution called research and development (R&D). Aikenhead (1994b, p. 16) summarized the advent of modern science this way:

By the end of World War II, ‘small science’ had become ‘big science’ (Price, 1963). Big science had profound implications. It meant big budgets; large partnerships with government, industry, and the military; and a narrowed gap between ‘pure’ and ‘applied’ science. Big science meant the creation of national wealth and military superiority. As a result, scientific knowledge today has political currency on two levels: (1) internationally, where it is traded in the diplomatic halls of foreign policy (Dickson, 1984); and (2) nationally, where it sustains the dominant socioeconomic infrastructure of that society (McGinn, 1991). For instance, governments support R&D in order to maintain their country’s competitive edge in the world marketplace (Ziman, 1984).

Today the dominant patrons of R&D include industry, government, private foundations, and the military. Only a small minority of academic scientists, less than 5%, undertake solely curiosity-oriented research. Following the 20th century radical transformation of 19th century science into modern science (i.e. the *socialisation* of science), scientists still strive for power and dominion over nature, but in a new social context of R&D where technology, values, corporate profits, and social accountability play an increasingly important role (Layton, 1986; Solomon, 1994), and where new organizational units of multifaceted disciplines meet the challenges of new frontiers in science, for example, molecular biology and biophysics. The evolution of science continues in the 21st century.

HISTORICAL PERSPECTIVES: THE SCIENCE CURRICULUM

In some British schools in the 1850s, one would have found a rather disorganized array of natural history courses, mechanics courses, school readers (e.g. the popular *Natural Philosophy for Beginners*), and a pervasive and growing interest in the new field called ‘science’. However, the curriculum in most schools was overcrowded with religious studies, the classics, grammar and languages, mathematics, history, etc. (Layton; 1973). There was

little room for new subjects such as the sciences. It would take the prestige and influence of the BAAS to change that.

Through the work of different sequential committees beginning in 1855, and with the aid of some leading educationalists, the BAAS finally approved its 'Scientific Education in Schools' report in 1867 (Layton, 1981). The organization of BAAS's annual meetings defined the structure of the new science curricula in universities and schools (i.e. chemistry, biology, physical and mathematical sciences, and geology). The BAAS also promoted an ideology of 'pure science', serving a self-interest in gaining memberships in the Association and in obtaining research funds for those members. This resonated well with the 19th century progressive education movement's ideology that stressed mental training (Layton, 1981). "It seemed that chemistry and physics had been fashioned into effective instruments for both intellectual education and the production of embryonic scientists. A common thread had been devised to the twin ends of a liberal education and the advancement of science" (Layton, 1986, p. 115, emphasis in the original). As a result, education reformers produced a science curriculum that marginalized practical utility and eschewed issues and values related to everyday life, reflecting the BAAS's newly achieved divide between science and technology. The 'mental training' argument helped squeeze the new science disciplines into an already crowded school curriculum.

The BAAS official position on education, published in 1867 as *On the Best Means for Promoting Scientific Education in Schools*, distinguished between public understanding of science and pre-professional training for future members of the BAAS (Layton, 1981). The latter secured favour with the contemporary science ideology and augmented the progressive education movement by promising: 'the scientific habit of mind [as] the principal benefit resulting from scientific training' (p. 194).

Many features of today's 21st century science curricula, characterised by strict disciplinary boundaries and disconnected from the utility of everyday life, are easily understood when placed in the historical context of the 19th century origin of the science curriculum. Discipline-based instruction is now an end in itself, rather than providing high priority to pupils' needs and to conveying a 21st century image of science (Bingle & Gaskell, 1994; Gaskell, 1992; Solomon & Aikenhead, 1994; Venville et al., 2002). Today's discipline-based science instruction is essentially 19th century science.

Since the science curriculum's inauguration in 1867, science educators in the UK and North America have attempted to reform school science into a subject that connects with technology and everyday society, but these attempts have largely been unsuccessful (Hurd, 1986; Layton, 1991). Perhaps the 21st century will be different.

RELEVANT INTEGRATION

Integrating the scientific disciplines has its own recent history that should not be overlooked lest we doom ourselves to repeat its historical failures. In North America in the early 1970s, integrated science became a popular innovation. The National Science Foundation funded 'Unified Science' housed at Ohio State University (Showalter, 1973). Scientific conceptual themes were logically chosen to unify the traditional science disciplines, particularly chemistry and physics (Showalter, 1969). Looking back on this movement, Cox (1980) reported that the conceptual themes chosen to integrate the two disciplines tended to be very abstract compared to themes of the traditional science courses, and that research into their effectiveness found unified or integrated science no more

successful than the PSSC, ChemStudy, or BSCS biology curricula of the day. More importantly, it was discovered that the success of an integrated science project in one high school could not usually be duplicated at other high schools (Cox, 1980). The scientific conceptual themes used to integrate the sciences were often unique to the innovators at one school, and consequently the themes made little sense to teachers at other schools. This type of integrated science was not easily transferable. UNESCO joined the integrated science movement during the 1970s (Richmond, 1971-77), but their projects in the secondary schools were no more successful than the American projects (Haggis & Adey, 1978).

The lesson to learn from the 1970s is that integration for the sake of integration itself is a futile innovation. It tends to be artificial, arbitrary, idiosyncratic, highly abstract, and therefore, not relevant for most pupils. For integration to be worthwhile, it requires a broader perspective such as the integration of school science with other school subjects, or with events in pupils' everyday world.

In a recent review of integration of the science curriculum with other school subjects, Venville et al. (2002) bring us up to date on conceptions and challenges associated with a broader perspective on integration. Five key questions are answered: What is an integrated curriculum? Why integrate? Why is integration difficult? What is being learned in integrated settings? Can curriculum integration be reconciled with the disciplines? There is no one best way to integrate, and it is more easily achieved in the junior secondary grades (ages 12 to 16) where high priority is given to enhancing pupils' engagement with school. Based on their own experiences and on the literature they reviewed, Venville and colleagues make the case for a balanced science programme that draws upon both discipline-based and integrated approaches that include appropriate use of direct instruction, cooperative learning experiences, and self-directed, relevant, inquiry-based knowledge construction (e.g. 'problem-based' instruction; Jenkins, 1999, 2000). The majority of junior secondary pupils normally do not view the world of science along disciplinary lines; hence the distinction between discipline-based and discipline-integrated instruction is immaterial; what matters is the school subject's integration with pupils' needs, interests, and lives outside of school (Erlandson, 2000).

Educators have proposed similar policy suggestions and some have developed programmes that integrate scientific knowledge, skills, and values, with knowledge *about* science (its history, sociology, and philosophy), with technology, and with the social context of pupils' lives (locally, nationally, and globally). Worldwide this type of science education has been called: 'humanistic' (Holton, 1978; Layton, 1986), 'science-technology-society' (STS) (Eijkelhof & Kortland, 1988; Fensham, 1992; Solomon & Aikenhead, 1994; Yager, 1996), 'citizen science' (Cross et al., 2000; Irwin, 1995), 'science-technology-citizenship' (Sjøberg, 1997), 'science for public understanding' (Eijkelhof & Kapteijn, 2000; Millar, 1996, 2000), and 'functional scientific literacy' (Ryder, 2001). Innovative projects and state-wide programmes dedicated to integrating school science for an informed citizenry have been completed, for example, in the UK (Millar, 2000; Solomon, 1996), in Norway (Knain, 1999; Kolstø, 2000), in the Netherlands (Eijkelhof & Kapteijn, 2000), in Germany (Hansen & Olson, 1996), in Spain (Sáez & Carretero, 2002), in Canada (Aikenhead, 1994a, 2000c), in the US (Kumar & Chubin, 2000; Thier & Nagle, 1994), in Australia (Giddings, 1996), and in Japan (Nagasu & Kumano, 1996).

This broader type of integration is guided by an ideology that emphasises a practical, functional, and pupil-centred curriculum, instead of an abstract scientist-centred curriculum in which pupils are expected to think like scientists and adopt a scientific habit of mind.

Aikenhead (2000b) explained the different ideologies of these two approaches in terms of the enculturation of pupils into their *local and national communities* (communities increasingly affected by advances in science and technology) versus the enculturation of pupils into the *disciplines of science*, respectively. These two ideologies represent fundamentally different views of relevance.

‘Relevance’ is certainly an ambiguous term. Mayoh and Knutton (1997) characterised relevance as having two dimensions: (1) ‘*Relevant to whom?* Pupils, parents, employers, politicians, teachers?’ and (2) ‘*Relevant to what?* Everyday life, employment, further and higher education, being a citizen, leisure, children’s existing ideas, being a ‘scientist’?’ (p. 849, emphasis in the original). Their first question is invariably answered by ‘pupils’, but their second question helps describe variations in the meaning of relevance. Subtly, however, Mayoh and Knutton embrace the ideology ‘enculturation of pupils into scientific disciplines’, in which pupils’ everyday life experiences, for instance, are deemed relevant to the extent to which those experiences motivate pupils to think like a scientist and to assume a scientific habit of mind. The 1990s ‘relevance-in-science movement’ (Campbell & Lubben, 2000, p. 240), exemplified by *Salter’s Science* (Campbell et al., 1994) and supported by arguments for engaging pupils in the social construction of scientific knowledge and scientific ways of knowing (Driver et al., 1994; Millar & Osborne, 1998), masks the implicit objective to assimilate pupils into a scientific worldview for those pupils whose worldviews are at odds with their science teacher’s worldview (Aikenhead, 1996). This assimilation is cleverly avoided by most pupils by playing ‘Fatima’s rules’ to get through chemistry, for instance, without really understanding chemistry (Aikenhead, 2000b). The fundamental issue is not so much ‘Relevant to what?’ but rather ‘Relevant to which enculturation process?’ – enculturation into students’ local and national communities or enculturation into a scientific discipline?

From an STS perspective, relevance is associated with informed decision-making on problems and issues related to science and technology, and therefore, associated with being able to participate in society as opposed to feeling alienated from society (Kumar & Chubin, 2000; Solomon & Aikenhead, 1994; Yager, 1996). Depending on the authors of an STS project, however, relevance will be guided by either enculturation into scientific disciplines or enculturation into pupils’ everyday communities. A transition from the former towards the latter is exemplified by the textbook *AS Science for Public Understanding* (Hunt & Millar, 2000).

Fensham (2000a) clarified our understanding of relevance further when he delineated four types of relevance, each related pragmatically to who decides what is relevant:

- *wish they knew science*: the answer one hears from academic scientists and many science educators when asked what would make school science relevant. This content often prepares pupils for the next level of science instruction. This type of relevance usually leads to the conventional discipline-based science curriculum and the attempted enculturation of all pupils into the sciences.
- *need to know science*: the answer an interviewer hears from people who have faced a real-life decision related to science. What science content was helpful in making their decisions? This type of relevance is exemplified by the Science for Specific Social Purposes project (Layton et al., 1986; Layton et al., 1993), a study of: parents dealing with the birth of a child with Down’s syndrome, old people’s dealings with energy use, workers at a nuclear power plant dealing with scientific information on radiation effects, and town councillors dealing with the problem of methane generation at a landfill site.

- *enticed to know science*: science content encountered in the mass media and the internet, both positive and negative in its image of science. This content often entices a reader/viewer to pay closer attention. Fensham reports that the OECD's Performance Indicators of Student Achievement project is using enticed-to-know science 'to see how well their science curricula are equipping [15-year old] students to discern, understand and critique the reporting of science in newspapers and the Internet' (Fensham, 2000a, p. 75). By its very nature, enticed-to-know science excels at its motivational value. Millar (1996, p. 204) reported on how an analysis of the content of science-related articles in a national newspaper led to identifying 'the science knowledge that would be most useful in making sense of these articles and the stories they presented'. This analysis stimulated a revision of the AS-level STS syllabus and eventually culminated in Hunt and Millar's (2000) textbook *AS Science for Public Understanding*.
- *have cause to know science*: science content suggested by experts who interact with the general public on real-life matters pertaining to science and technology, and who know the problems the public encounters when dealing with these experts. In addition to identifying common problems, an expert would also consider economic, personal health, and environmental well being as criteria for including science content as relevant. The process is being tested in Hong Kong (Law et al., 2000), is reflected in the two American STS textbooks *Issues, Evidence and You* (SEPUP, 1996) and *Science and Sustainability* (SEPUP, 2000), and has generated much discussion in the first two issues of the 2002 volume of the *Canadian Journal of Science, Mathematics and Technology Education*.

A notable combination of Fensham's first and fourth categories, perhaps a new category in itself ('functional science'), emerged from the work of Duggan and Gott (2002) when they investigated the science content that was relevant for science graduates who had careers in science-based industries. In addition, Duggan and Gott's study addressed Fensham's second category of relevance by including members of the public who interacted with science-related issues in an advocacy manner. Surprisingly:

the findings suggest that procedural understanding was essential in the higher levels of industry and in interacting effectively with everyday issues, while conceptual understanding was so specific that it was acquired in a need-to-know way. The implications for science education hinge on a substantial reduction in the conceptual content and [on an] explicit teaching of the nature of evidence (procedural understanding). (p.661)

Specifically recommended as 'procedural understanding' are concepts such as the validity and reliability of evidence, and how to apply these and other concepts of evidence (e.g. risk) in order to critically evaluate scientific evidence.

What conceptual scientific content (discipline-based or integrated) was relevant to the science employees and to the attentive public in Duggan and Gott's (2002) study? None, specifically. However, it was essential that pupils gained experience working with scientific content at the same time they learned to deal with scientific evidence. Duggan and Gott agree with Fensham (2000a) and Ryder (2001) when they conclude, 'Science curricula cannot expect to keep up to date with all aspects of science but can only aspire to teach pupils how to access and critically evaluate such knowledge' (p. 675).

Ryder's (2001) exhaustive analysis of case studies of need-to-know science (Fensham's second category of relevance) reinforced a similar analysis completed 17 years ago (Aikenhead, 1985) when Ryder concluded, 'Much of the science knowledge relevant to individuals in the case studies was *knowledge about science*, i.e. knowledge about the

development and use of scientific knowledge rather than scientific knowledge itself' (p. 35, emphasis in the original). This research result helps to explain the general failure of pupils when they try to use scientific concepts and processes in their everyday world (Layton et al., 1993), a goal central to the relevance-in-science movement (Campbell & Lubben, 2000). These findings, disquieting as they may be for discipline-based science teachers, suggest that the historical context of 19th century Britain, a context that originally spawned the disciplines of chemistry, physics, biology, and geology in the first place, was characterised by ideologies seriously at odds with current ideologies that give priority to functional learning and its relevance for 21st century realities; realities that include science-related careers in industry, business, government, private foundations, and the military, and include science-related decisions taken by an attentive public.

A more holistic yet practical concept of relevance in school science is advanced by Weinstein (1998) concerning the enculturation of pupils into everyday society. He identifies a network of communities in pupils' everyday lives: health systems, political systems, the media, environmental groups, and industry, to name a few. Each community interacts with communities of professional scientists. A network of communities in pupils' everyday lives will reflect and/or distort science into content that Weinstein calls 'science-as-culture'. He describes it as follows:

The meaning making that we call science happens in a way that is distributed over the society spatially and temporally. It happens through science fiction, it happens through laboratory work, ... it happens in hospitals, it happens in advertising, and it happens in schools. To emphasize this, I explicitly refer to *science-as-culture* rather than to just science. I do this as a reminder to the reader that I am concerned with science in all parts of the network and not just the laboratory, field station, and research institute. (p. 492, emphasis in the original)

Part of pupils' functional knowledge of their everyday world is science-as-culture, which is more than just pop culture (Solomon, 1998). The cultural contributions to society by science are partly embedded in science-as-culture, as well. Dealing with science-as-culture in the classroom can lead to relevant content for integrated school science, particularly for the enculturation of pupils into their local and national society.

A greater challenge confronts us when we try to make science instruction relevant to pupils who have grown up in a different culture from our own. Relevance for these pupils takes on an even broader meaning because relevance will be assessed by the degree to which the pupils' self-identities are respected and engaged during school science (Aikenhead, 2000b). In these circumstances, integration succeeds in an explicit cross-cultural context where science teachers serve as culture brokers, helping pupils negotiate the psychological risk-filled transition between their everyday culture and the culture of school science (Aikenhead, 1996, 2000a; Aikenhead & Jegede, 1999). For example, Aboriginal peoples worldwide have mastered their own ways of knowing nature related to their ancestry lands (Cajete, 2000; Peat, 1994). The fact that this knowledge (Aboriginal science) has sustained Aboriginal peoples for 20 to 60 thousand years testifies to its content validity. Their knowledge of nature is not organized by disciplines, but by concepts related to community responsibilities, family relationships, and individual talents or gifts. Some Aboriginal nations of North America use a concept called 'keepers' to organize, explain, and predict natural events (Caduto & Bruchac, 1989). Aboriginal peoples do not subscribe to Descartes'

mind/matter dichotomy, but instead think of everything as interrelated. Their science is much different than ours, though the two do share common features such as rationality and empiricism (Knutson & Suzuki, 1992; Peat, 1994). From an Aboriginal perspective, Aboriginal science is thoroughly integrated with all aspects of life. Imagine the difficulty Aboriginal pupils have trying to understand our 19th century discipline-based way of organizing the science curriculum.

Their difficulty is shared to varying degrees by pupils in Western countries whose worldviews are out of harmony with the worldview endemic to Western science, a worldview generally expressed by their science teacher (Aikenhead, 1996; Cobern, 2000; Cobern & Aikenhead, 1998). These pupils represent a large majority of pupils in most science classrooms (Costa, 1995) and they may require a cross-cultural science type of relevance (Aikenhead, 1996; Aikenhead & Jegede, 1999; Jegede & Aikenhead; Ogawa, 1995).

The divide between everyday commonsense ways of knowing and the scientific way of knowing (institutionalised, professionalised, and socialised in Western nations) has been an on-going puzzle to science educators over the years (Aikenhead, 1996; Campbell & Lubben, 2000; Hawkins & Pea, 1987; Lijnse, 1990; Millar, 1996; O'Loughlin, 1992; Reif & Larkin, 1991; Ryle, 1954). Crossing the divide intellectually, socially, or culturally continues to be explored by science educators to gain insights into the nature of relevance. Crossing the divide, however, becomes muddled and spurious to pupils when their science teacher's idea of relevance embraces conflicting ideologies.

To summarize, relevant integration of the scientific disciplines and relevant integration of school science with everyday life, both lead to innovative thoughts for future directions in school science. The following types of relevance were identified: (1) have-cause-to-know science for all pupils; (2) functional science for employment in science-related industries and businesses, and for the public actively engaged in science-related issues; (3) need-to-know science for a public coping with rapid advances in science and technology; (4) enticed-to-know science for purely motivational purposes; (5) science-as-culture for all pupils; (6) cross-cultural science for pupils who wish to be enculturated into their everyday communities; and (7) wish-they-knew science for future scientists and engineers who desire to be enculturated into 21st century scientific disciplines. Each type of relevance for school science is guided by different ideologies of education, of science, and of society. Choices must be made.

CONCLUSION

European ways of making meaning of nature have evolved over the years. Three radical transformations have occurred during this evolution: the 17th century institutionalisation of natural philosophy, the 19th century professionalisation of science, and the 20th century socialisation of modern science and technology. Each radical transformation, with its unique complex of historical contexts, resolved competing ideologies and gave rise to a reformed enterprise. Radical growth has strengthened the scientific enterprise at each turn.

Compared to science, however, the evolution of school science has been meagre. Perhaps school science is subjected to many more social and political pressures exerted by a greater diversity of stakeholders who have their own interests to protect (Fensham, 1992): (1) government and business interest in the national economy; (2) university science departments' self-interest in maintaining their disciplines; (3) parents' and pupils' social, economic, and political interests in using science course credentials (not science

comprehension) to get ahead in society; (4) the school's interest in gate keeping and maintaining its social position in its community; and (5) science teachers' loyalty to, and professional identity with, ideologies of discipline-based science. Venville and colleagues (2002) discuss challenges that confronted some teachers who integrated science with other school subjects, particularly the challenge of overcoming a school culture that celebrates the status quo: 'including teacher recruitment and identity, subject histories, assessment structures, department politics, subject status, pupil futures, and an overcrowded and content-laden curriculum' (pp. 53-54). 'These well entrenched and well-supported features of schooling are difficult to erode' (p. 58). Change in science education is challenging to accomplish. But without change, there is little growth, and without growth, pupil interest and achievement will continue to drop (Fensham, 2000b).

One consistent finding from research on science curricula points to the pivotal position played by classroom science teachers in effecting change (Welch, 1969). This suggests that choices can be made by teachers. The process of putting those choices into action is a political process, not a rational process entirely (Fensham, 1998). Collective strategies for action need to be negotiated by science educators (Aikenhead, 2000b, 2002). These negotiations will likely go more smoothly the more we are aware of the ideologies implicit in different types of science instruction, each dedicated to particular types of relevance. Equally important is the need for teachers to embrace consistent ideologies. This article has uncovered several ideologies reflected in the following divergent ideas (a partial list): (1) idealized, decontextualized abstract knowledge, versus functional, practical, personal knowledge; (2) training the mind versus preparing for life; (3) enculturation into a scientific discipline versus enculturation into local and national communities; (4) reductionist views of nature versus holistic views of nature; and (5) an uncritical adulation of science (scientism) versus a healthy scepticism open to critically evaluating modern science and technology.

One lesson to learn from the evolution of natural philosophy into modern science is that the professional self-identity of the practitioner is central to this evolution ('a sense of corporate identity and specialness, an acceptance of a primary loyalty and accountability to the discipline and to each other'; Orange, 1981, p. 59). One major challenge for chemistry and physics teachers is to rethink and reformulate their professional identities away from being loyal and accountable to their discipline towards another identity that celebrates views of relevance other than the 'wish-they-knew science'. There is ample empirical data that speak to how most school graduates use their science instruction for science-related careers in industry and government, for resolving everyday science-related issues, and for feeling conversant with one's own culture. Choices can be made.

CORRESPONDENCE: *Glen S. Aikenhead, Professor of Science Education, College of Education, University of Saskatchewan, 28 Campus Drive, Saskatoon, SK, S7N 0X1, Canada; fax: 1-(306)-966-7658; e-mail: glen.aikenhead@usask.ca*

Glen AIKENHEAD is a Professor at the *University of Saskatchewan*, Canada. He has always embraced a humanistic perspective on science, even as a young research chemist in Canada and as a science teacher at international schools in Germany and Switzerland. This humanistic perspective was enhanced during his graduate studies at *Harvard University* in the 1960's and has since then (at the University of Saskatchewan) guided his research into curriculum policy, student assessment, classroom materials, classroom instruction, and cross-cultural science education. This research and development has resulted in such publications as: *Science in social issues: Implications for teaching*

(1980); Views on science technology and society (VOSTS, 1989); Logical reasoning in science & technology (LoRST, 1991); STS education: International perspectives on reform (co-edited, 1994); "Toward a first nations cross-cultural science and technology education" (Sci. Ed. 1997); Cross-cultural science & technology units (2000); and "Integrating western and aboriginal sciences: Cross-cultural science teaching" (RISE, 2001).

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