Review of Research on Humanistic Perspectives in Science Curricula

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By convention, school science has traditionally aimed to prepare students for the next level of science courses, ultimately funnelling students into careers associated with science and engineering, that is, “the pipeline” phenomenon (Frederick, 1991; Millar & Osborne, 1998). For students who embrace other career goals (the vast majority of students; Atkins & Helm, 1993; Lyons, 2003; Reiss, 2000), the same school science is often rationalized as serving two main purposes: the need to understand science well enough to appreciate its national importance, and the need to be literate enough to receive scientific messages expressed by experts or the mass media (AAAS, 1989). The traditional science curriculum with its canonical science content assumes that “science” in “school science” has the same meaning as it has in, for example, “the American Association for the Advancement of Science.” A different assumption for school science is considered here.

Over the past century, alternative perspectives to the traditional science curriculum have been developed and researched. Probably the most pervasive alternative has been the perspective that views science as a human endeavour, embedded within a social milieu of society and conducted by various social communities of scientists. The purpose of this paper is to synthesize the research about these humanistic perspectives in the school science curriculum, perspectives that would significantly alter the tenor of school science.

Any perspective on the science curriculum, be it humanistic or solely scientific, expresses an ideological point of view explicitly or implicitly (Cross, 1997; Cross, Zatsepin & Gavrilenko, 2000; Fensham, 2000b; Fourez, 1988, 1989; Kain, 2001). This paper’s ideology gives priority to a student-centred point of view aimed at citizens as consumers of science and technology in their everyday lives, as opposed to a scientist-centred view aimed at scientific or science-related careers. In the political arena defined by Spencer’s (1859, p. 5) question, “What knowledge is [should be] of most worth?” the research literature expresses essentially two contrary positions, often in combination (Lijnse, Kortland, Eijkelhof, van Gerrderen & Hoymeyer, 1990; Solomon, 1999b): educationally driven propositions about what is best for students and society, and politically driven realities supported by de facto arguments of the status quo. Although empirical evidence overwhelmingly speaks to the educational failure of traditional school science (described below), the continuous survival and high status of traditional school science attest to its political success. The research reviewed in this paper reflects the tension between educational soundness and political reality. We must not forget that curriculum decisions are first and foremost political decisions (Brickhouse & Bodner, 1992; Carr, 1993; Eijkelhof & Kapteijn, 2000; Fensham, 1992; Roberts, 1988; Rudolph, 2003; Young, 1971). Research can inform curriculum decision making, but the rational, evidence-based, findings of research tend to wilt in the presence of ideologies, as curriculum choices are made within specific school jurisdictions, most often favouring the status quo (Aikenhead, 2002b; Bell,
Humanistic perspectives in the science curriculum have been described in various ways, including: values, the nature of science, the social aspects of science, and the human character of science revealed through its sociology, history, and philosophy. Since the 1970s, humanistic perspectives in school science content are perspectives typically found in science-technology-society (STS) curricula, but are not restricted to STS curricula. Table 1 describes dichotomies of goals and ideologies found in various research studies. Each row singularly represents what is included and excluded in the phrase “humanistic perspectives” used in this paper. The various rows indicate different definitions found from study to study. The first column in Table 1 does not necessarily describe humanistic science courses per se, but rather some possible components of those courses. Most humanistic science courses combine some of column one with some of column two, in order to meet the needs of students. (This integration of a humanistic perspective with a canonical science perspective varies with different research studies [Aikenhead, 1994d] and can be problematic [Hughes, 2000].)

Table 1. Possible Characteristics of “Humanistic Perspectives” in a Science Curriculum

<table>
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<td>Induction, socialization, or enculturation into students’ local, national, and global communities that are increasingly shaped by science and technology.</td>
<td>Induction, socialization, enculturation, or indoctrination into a scientific discipline.</td>
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<tr>
<td>Citizenship preparation for the everyday world</td>
<td>Preprofessional training for the scientific world.</td>
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<tr>
<td>Savvy citizens cognizant of the human and social dimensions of scientific practice and its consequences.</td>
<td>Canonical abstract ideas most often decontextualized from everyday life.</td>
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<tr>
<td>Emphasis on science-in-the-making.</td>
<td>Emphasis on ready-made science</td>
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<tr>
<td>Knowledge about science and scientists.</td>
<td>Knowledge of canonical science.</td>
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<tr>
<td>Moral reasoning integrated with values, human concerns, and scientific reasoning.</td>
<td>Solely scientific reasoning and scientific “habits of mind.”</td>
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<td>Seeing the world through the eyes of students and significant adults.</td>
<td>Seeing the world through the eyes of scientists alone.</td>
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<tr>
<td>Playing in the subculture of science as an outsider.</td>
<td>Identifying with the subculture of science as an insider.</td>
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Humanistic perspectives in the science curriculum have a long history, dating back to the early 19th century when natural philosophy was sporadically taught in some schools. This history, particularly events following World War II, provides a context for appreciating both the educationally and politically driven agendas that motivate the research found in the science education literature, and for understanding the literature’s conceptualization of humanistic perspectives in the curriculum.

This paper also encompasses the three forms of any curriculum: the intended, taught, and learned curriculum. An intended humanistic curriculum relates to curriculum policy that determines which humanistic perspectives are sanctioned. The taught humanistic curriculum comprises the classroom materials that support humanistic science teaching, and the teachers’ orientations that determine the implementation of a humanistic perspective into school science. The learned curriculum, of course, is the humanistic content students actually learn. Accordingly, pertinent research studies will be reviewed and synthesized in the following sequence: history of humanistic perspectives in science education, curriculum policy, classroom materials, teacher orientation, student learning, discussion of the research, and implications for future research studies. This synthesis gives emphasis to how different research methods shape different types of outcomes, and it draws conclusions concerning strengths, weaknesses, and fruitful directions for further research.

A humanistic perspective is not the only radical innovation to challenge the status quo of school science. Other innovations, such as project-based learning, technology-design courses, social constructivism, and science for practical action, are not considered here directly, but may surface as features of a particular humanistic oriented science curriculum.

In-depth studies into students’ abilities to deal with philosophical and social aspects of science suggest that overt humanistic content is more suitable for students aged 11 and older (Pedretti, 1999; Solomon, Duveen, Scot & McCarthy), and aged 16 or older for controversial issues (Driver, Leach, Millar & Scott, 1996). Accordingly, this paper restricts itself to school science that serves that age group. This review also excludes non-research literature that simply advocates a position or offers a rationale for a humanistic perspective.

A Short History of Humanistic Perspectives in the Science Curriculum

School subjects are grounded implicitly in the historical process through which they arose (Sáez & Carretero, 2002). The ideology of the traditional science curriculum is easily understood when placed in the historical context of its 19th century origin, an origin that emerged within the on-going evolution of science itself. Research into the history of the school curriculum is summarized here to provide a
framework for the conceptualizations of humanistic perspectives in the science curriculum. This summary is contextualized within the development of science itself.

Science

The domain of knowledge we call “science” today has evolved over the years and continues to evolve in the 21st century. This history has a direct bearing on school science content, traditional and humanistic. Our Euro-centric line in the evolution of science began with the Greek origins of philosophy (pure abstract ideas) and then radically advanced during the 17th century with the establishment of natural philosophy as a social institution within Western Europe, a transformation called “the scientific revolution” today. As natural philosophers, such as Newton or Boyle, learned more about the physical universe, their success at exercising power and dominion over nature 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 evolution of modern science.

Natural philosophers, led by Whewell, 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). He and his colleagues succeeded in their revisionist project, and today there is widespread belief in the erroneous notion that technology is solely applied science, thereby maintaining the ideology that holds “pure science” superior to practice (Collingridge, 1989).

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; Orange, 1981). 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). “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 (Orange, 1981). 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).

To accommodate participants at yearly BAAS meetings, themes of concurrent sessions were organized around the administrative structure of the new University of Berlin, founded in 1810, which partitioned natural philosophy into the disciplines of physics, chemistry, geology, zoology, botany, etc. (Fuller, 1997). This classification scheme would eventually determine the structure of the science curriculum in the 1860s.

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 being established. 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, the professionalisation of natural philosophy was essentially complete in England by 1850.

The BAAS served as a model for the American Society of Geologists and Naturalists when in 1848 the Society established the American Association for the Advancement of Science (AAAS, 2002). Similar to the BAAS, the prime functions of AAAS were to promote the cultivation of science across the US, give systematic direction to scientific research, and to procure resources for its members.

Nineteenth century 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). Today the dominant patrons of R&D include business, industry, the military, government, and private foundations. Only a small minority of academic scientists, less than 5%, undertake purely curiosity-oriented research (Council of Science and Technology, 1993). Following the 20th century radical transformation of 19th century science into modern science (i.e. the collectivization of science; Ziman, 1984), 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 (Hurd, 1994; Solomon, 1994a,b). The evolution of science continues today.

The Science Curriculum

The history of a formal, school science curriculum dates back to the 19th century (Bybee, 1993; DeBoer, 1991; Del Giorno, 1969; Gaskell, 2003; Hurd, 1991; Jenkins, 1985; Keeves & Aikenhead, 1995;
Layton, 1973, 1981; Montgomery, 1994; Osborne, 2003). In the 1850s, the British school curriculum was overcrowded with religious studies, the classics, grammar and languages, mathematics, and history. There was little room for new subjects such as the sciences. It would take the prestige and influence of the BAAS to change that.

The BAAS approved its “Scientific Education in Schools” report in 1867 (Layton, 1981). The BAAS promoted an ideology of “pure science,” serving a self-interest in gaining members in the Association and in obtaining research funds for those members. This also 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, UK education reformers in 1867 produced a science curriculum that marginalized practical utility and eschewed utilitarian issues and values related to everyday life, reflecting the BAAS’s newly achieved divide between science and technology, and at the same time, reinforcing social class ideologies that favoured the elite upper class (Seddon, 1991). The “mental training” argument certainly helped squeeze the new science disciplines into an already crowded school curriculum.

The BAAS official position on education in 1867 distinguished between public understanding of science for the general education of a citizen and pre-professional training for future members of the BAAS (Layton, 1981). Pre-professional training served the scientific community’s ideology and also augmented the progressive education movement by promising it the following outcome: “the scientific habit of mind [is] the principal benefit resulting from scientific training” (p. 194). These ideologies quickly became the status quo and have not changed much in spite of the collectivization of science during the 20th century (Aikenhead, 1994c).

In the US, organized curriculum development for high school science began in earnest during the 1890s in the context of a debate between advocates for citizen science (e.g. “Science of Society;” Spencer, 1859, p. 90) and pre-professional training (encyclopaedic science; Noll, 1939). The latter position was encouraged by events in the UK and by the appearance in the 1860s of German schools that specialized in teaching scientific disciplines (Jenkins, 1985). The AAAS was absent from this forum because of its preoccupation with its own survival as an institution between 1861 and 1894. Prior to the 1980s, the science curriculum in the US consisted of assorted topics in astronomy, physiology, geology, natural philosophy, physics, chemistry, zoology, and botany (Del Giorno, 1969). In 1892, the National Education Association established the Committee of Ten, chaired by Charles Eliot, President of Harvard University (Hurd, 1991; Kliebard, 1979). Ideologically Eliot championed mental training, but opposed
screening high school students for college admission as a central function of schools. The Committee proposed four areas of high school study: classics, Latin-sciences, modern languages, and English; a menu of programs much broader than the college admission requirements at the time. Eliot harboured an unbridled optimism about the intellectual capability of all students (“science for all” in today’s vernacular). Eliot’s Committee of Ten was unanimously against streaming students, within their elective interests. These and other proposals by the Committee drew strong criticism (Kliebard, 1979). As often happens in the heat of debate, one’s opponents make false accusations that sometime stick like Velcro in the public eye. Eliot’s critics accused the Committee of imposing college entrance expectations on the high school curriculum, a criticism that college science faculty then embraced as a Committee recommendation (Hurd, 1991). Thus, in the aftermath of the debate over the report by the Committee of Ten, the US science curriculum stressed both pre-professional and mental training. By 1910, the American status quo for school science mirrored England’s.

By contemplating the historical origins of today’s traditional science curriculum, we recognize it is as essentially a 19th century curriculum in its educational intent. In addition, we can better appreciate the powerful ideologies that guide and sustain school science today and therefore socialize students into scientific disciplines (i.e. moving through “the pipeline”). This same socialization causes most science teachers to teach in very similar ways toward very similar goals (Aikenhead, 1984; Cross, 1997; Gallagher, 1998). The ideologies of pre-professional scientific training, mental training, and screening for college entrance challenge any move to reform school science into a subject that embraces a humanistic perspective (Fensham, 1992, 1998).

Before, and ever since the science curriculum’s inauguration in 1867 (UK) and 1893 (US), there have always been educators who promoted school science as a subject that connects with everyday society. Different eras have brought different social, economic, political, and educational forces to bear on reforming the science curriculum into a humanistic type of curriculum (DeBoer, 1991; Del Giorno, 1969). Hurd (1986, 1991) reviewed American attempts at this type of reform, mentioning, among others: the early 1900s applied science and technology courses, “viewed by scientists as an educational fad and were soon replaced by … simplified versions of … university science courses” (1991, p. 254); a 1920 US Bureau of Education report; a 1928 AAAS committee; a 1932 NSSE study; a 1945 Harvard report; and the 1983 Nation at Risk report. Hurd’s historical research concluded that every committee and report criticized the science curriculum as being too narrow in vision, in subject matter, and in organization to relate science and technology to human, social, and economic affairs. “What the critics are seeking is a new and more viable contract between schooling and society, one in which science and technology are more closely tied to human affairs and social progress” (Hurd, 1989, p 2). Other historical studies by
Hodson (1999), Layton (1991), and Solomon (1994a), as well as case study research by Fensham (1998), showed how innovative humanistic proposals in the UK and Australia contravened the social privilege and power that benefited an elite student enrolled in a traditional science curriculum.

This historical research on the science curriculum leads to one conclusion: throughout the 20th century, attempts at reforming the traditional school curriculum into a humanistic one have largely been unsuccessful (Bromley & Shutkin, 1988; National Commission on Excellence in Education, 1983; Hurd, 1986, 1991; Klopfer, 1992; Layton, 1991; Walberg, 1991). This research finding provides further evidence for the complex political power involved in reaching curriculum decisions, an issue revisited throughout this paper.

A Recent Humanistic Science Curriculum Movement

The empirical research reviewed in this paper is framed by several post World War II humanistic conceptions of school science often associated with the history and philosophy of science (Matthews, 1994; Fensham, 1992; Seroglou & Koumaras, 2001) and particularly with a movement called “science-technology-society,” STS (Ziman, 1980). Details of the history STS are found elsewhere (Aikenhead, 2003b; Bybee, 1993; Cheek, 1992; Cutcliffe, 1989; Fensham, 1992; Keeves & Aikenhead, 1992; Solomon, 2003b; Solomon & Aikenhead, 1994; Yager, 1996a) but can be summarized as follows.

Many proposals for a humanistic alternative to school science were inspired by university STS programs formally initiated in the late 1960s, in the US, UK, Australia, and The Netherlands. These university academic programs responded to perceived crises in responsibility related to, for instance, nuclear arms, nuclear energy, many types of environmental degradation, population explosion, and emerging biotechnologies. Thus, social responsibility for both scientist and citizen formed one of the major conceptions on a humanistic perspective in school science (Aikenhead, 1980; Bybee, 1993; Cross & Price, 1992, 2002; Kortland, 2001; Rye & Rubba, 2000; Waks & Prakash, 1985). At the University of Iowa, for instance, a societal issue-oriented science curriculum project evolved from the integration of social studies and science (Casteel & Yager, 1968; Cossman, 1969) and a decade later in Colorado (McConnell, 1982).

A second major conception to emerge from post World War II academia were the poststructuralist analyses of science itself, often associated with Kuhn’s (1962) *The Structure of Scientific Revolutions*. This analysis tended to challenge the positivism and realism inherent in traditional science courses (Abd-El-Khalick & Lederman, 2000; Kelly, Carlsen & Cunningham, 1993). Interest in humanistic content in the science curriculum enjoyed a renaissance at several university centres after World War II. At Harvard, for instance, President J.B. Conant (1947) encouraged his faculty to give serious attention to the history,
philosophy, and sociology of science, encouragement taken up at the time by young instructors such as I.B. Cohen, Thomas Kuhn, and Everett Mendelsohn, respectively; and enhanced by physicist Gerald Holton. They influenced Ph.D. student Leo Klopfer who produced the *History of Science Cases* (Klopfer, 1969; Klopfer & Watson, 1957) and who critically researched their impact in schools (Klopfer & Cooley, 1963). Similarly influenced was Jim Gallagher’s (1971) presciently articulated blueprint for an STS science curriculum (echoed in Hurd’s 1975 seminal publication) that rationalized teaching scientific concepts and processes embedded in the sociology/history/philosophy of science, relevant technology, and social issues (i.e. teaching content, process, and context). Probably the most influential science education project to emerge from Harvard was the *Project Physics Course* (Holton, Rutherford & Watson, 1970), a historical and philosophical perspective on physics aimed at increasing student enrolment in high school physics (Cheek, 2000; Walberg, 1991; Welch, 1973). It stimulated many other humanistic curriculum innovations worldwide (Aikenhead, 2003; Irwin, 2000; Thomsen, 1998).

The integration of two broad academic fields, (1) the interaction of science and scientists with social issues and institutions external to the scientific community, and (2) the social interactions of scientists and their communal, epistemic, and ontological values internal to the scientific community; produced a major conceptual framework for STS (Aikenhead, 1994d; Ziman, 1984). However, in practice some STS projects narrowly focused on just one of these domains, for instance, the role of science and technology in society (Bevilacqua & Giannetto, 1998), societal issues (Yager, 1983), or applied science (Hunt, 1988). Other important conceptual frameworks for humanistic school science have been articulated in the research literature:

1. The degree to which a humanistic perspective supports or challenges a traditional positivist and realist view of science (Bingle & Gaskell, 1994).
2. Whether a humanistic perspective advocates: being aware of an issue, or making a decision on the issue, or taking social action on the issue (e.g. Dahneke, 1996; Rubba, 1987; Solomon, 1988b), a framework particularly salient to environmental education (Rubba & Wiesenmayer, 1991, 1999) and to social responsibility (Cross & Price, 1992, 2002; Cross, Zatsepin & Gavrilenko, 2000; Rye & Rubba, 2000; Waks & Prakash, 1985).
3. The degree to which humanistic content is combined with canonical science content (Aikenhead, 1994d; Bartholomew, Osborn & Ratcliffe, 2002; Jeans, 1998; McClelland, 1988).
4. The degree to which the content and processes of technology are integrated into the humanistic perspective (Black, 1986; Cheek, 1992, 2000; Fensham, 1988a; Layton, 1994).
5. The degree to which school science is integrated – the integration of scientific disciplines, and the integration of school science with other school subjects (Venville, Wallace, Rennie & Malone, 2002).

6. The degree to which schooling is expected to reproduce the status quo or be an agent of social change and social justice (Apple, 1996; Barton, 2001a; Cross & Price, 1999; Hodson, 1994).

Slogans for a humanistic perspective in the science curriculum, such as STS, can change from country to country and over time. In every era, slogans have rallied support for fundamental changes to school science (Roberts, 1983). Today, there are a number of slogans for humanistic science curricula worldwide, for instance: “science-technology-citizenship” (Knain, 1999; Kolstø, 2000; Solomon & Thomas, 1999; Sjøberg, 1997), “nature-technology-society” (Andersson, 2000), “science for public understanding” (Eijkelhof & Kapteijn, 2000; Millar, 2000; Osborne, Duschl & Fairbrother, 2003), “citizen science” (Barker, 2001; Cross et al., 2000; Irwin, 1995; Jenkins, 1999), “functional scientific literacy” (Ryder, 2001), “Bildung” (Hansen & Olson, 1996), variations on “science-technology-society-environment” (Bencze, Hodson, Nyhof-Young & Pedretti, 2002; Dori & Tal, 2000; Hart, 1989; Zoller, 1991), and “cross-cultural school science” (Aikenhead, 2000a). These humanistic science programs are often seen as vehicles for achieving: science for all, girls’ participation in science, and scientific literacy.

Will history repeat itself by rejecting a humanistic perspective in the science curriculum, as predicted by Rutherford (1988, p. 126) when he surmised of STS, “just one more passing fancy in education”? Or will the events of the past 30 years indelibly change school science? Time will tell.

Conclusion

Four conclusions seem warranted from the historical research summarized here. First, the current humanistic perspectives in science curricula are deeply embedded in our culture and have been for the past 150 years (Hurd, 1991; Layton, 1973; Solomon, 1997a).

Secondly, just as science had to compete in the 1860s with the classics and religion to get a foothold in the school curriculum, today a humanistic perspective must compete with the pre-professional training of elite students (moving through “the pipeline”) to earn a place in the school science curriculum. This reflects a competition between ideologies: on the one hand, promoting practical utility, human values, and a connectedness with societal issues to achieve inclusiveness and a student-centred orientation; on the other hand, promoting professional science associations, the rigors of mental training, and academic screening to achieve exclusiveness and a scientist-centred orientation. Society in general did not reach a broad consensus on the latter position, but instead specific stakeholders politically achieved their goals within 18th century European and North American society, establishing an ideology
that would become the status quo. Thus, historical precedents and ensuing social privilege, not consensus, buttress the traditional science curriculum (Hodson, 1994; Seddon, 1991).

Thirdly, while 19th century professionalised science has been dramatically transformed into a 21st century R&D by the collectivization of science (Ziman, 1984), school science has not similarly undergone any lasting dramatic reform. This conclusion addresses education soundness, not political reality.

And fourthly, humanistic perspectives fit a variety of curricular conceptual frameworks (partly captured in Table 1), all of which are found in the research studies reviewed in this paper. To bring a modicum of structure to this diversity and to ensure all three forms of the science curriculum are addressed, the review is organized around the topics: curriculum policy, classroom materials, teacher orientation, and student learning.

Curriculum Policy

The motivation to promote a humanistic curriculum policy for school science arises from, on the one hand, persistent, humanistic ideologies about the purpose of school science deeply embedded in our culture, and on the other hand, periodic and specific episodes of disappointment with the traditional science curriculum (usually designated as “times of crisis;” Klopfer & Champagne, 1990). Four areas of research address an educationally sound curriculum policy for humanistic perspectives in the science curriculum: major failures of the traditional curriculum, successes of learning science in non-school contexts, the relevance of curriculum content, and the processes for formulating curriculum policy itself. Each area is discussed in turn.

Major Failures of the Traditional Science Curriculum

Deficiencies in the traditional science curriculum have been the cornerstone of arguments supportive of a humanistic perspective (Ziman, 1980). At least three major failures are documented in research studies.

The first failure concerns the chronic declines in student enrolment (Dekkers & Delaeter, 2001; Hurd, 1991; Osborne & Collins, 2000; Tobias, 1990; Welch & Walberg, 1967) due to students’ disenchantment with school science (Bondi, 1985; Hurd, 1989b; SCC, 1984; Ziman, 1980). This failure of school science threatens its primary goal: to produce knowledgeable people to go into careers in science, engineering, and related jobs; or at least support those who do. It is instructive to examine “the pipeline” data from a 15-year longitudinal study (beginning in 1977 with grade 10 students) conducted by the US Office of Technology Assessment (Frederick, 1991). Of the initial sample of four million grade 10 students, 18% expressed an interest to continue toward university science and engineering courses. Of
these interested students, 19% lost interest during high school (i.e. they moved out of “the pipeline”), and then during university undergraduate programs, 39% of first year science and engineering students lost interest; twice the proportion than in high school. These quantitative data support in-depth qualitative research that concluded: the problem of qualified students moving out of “the pipeline” resides much more with universities than with high schools, especially for young women (Astin & Astin, 1992; Seymour, 1995; Tobias, 1990). Another substantial reduction in “the pipeline” population occurred between high school graduation and first-year university, a transition that showed a 42% loss in the number of students interested in pursuing science and engineering courses (Frederick, 1991; Sadler & Tai, 2001). These data are partly explained by an in-depth UK study which discovered that highly capable A-level science students, particularly young women and minority students, switched out of science as soon as they received their school science credentials, because the curriculum discouraged them from studying science further (Oxford University Department of Educational Studies, 1989). Similar results were obtained from international studies (Gardner, 1985, 1998). Most research into students’ views of the science curriculum concluded that school science transmits content which is socially sterile, impersonal, frustrating, intellectually boring, and/or dismissive of students’ life-worlds (Bennett, 2001; Hurd, 1989b; Klein & Ortman, 1994; Lee & Roth, 2002; Osborne & Collins, 2001; Osborne, Driver & Simon, 1998; Reiss, 2000; SCC, 1984). This perception prevails even for science proficient students who enrol in senior science courses in high school (Lyons, 2003). One major reason for advocating humanistic content in school science has been to reverse this chronic loss of talented students (Eijkelhof & Lijnse, 1988; Ziman, 1980). Evidence suggests that humanistic perspectives in the science curriculum can improve the recruitment of students (Brush, 1979; Solomon, 1994a; Welch & Rothman, 1968).

A second, and related, major educational failure of the traditional science curriculum concerns the dishonest and mythical images about science and scientists that it conveys (Aikenhead, 1973; Gallagher, 1991; Gaskell, 1992; Kelly et al., 1993; Knain, 2001; Larochelle & Désautels, 1991; Milne & Taylor, 1998; Olson, 1997; Schibeci, 1986; Weaver, 1955). As a consequence: some strong science students lose interest in taking further science classes, some students become interested in science for the wrong reasons, and many students become citizens illiterate with respect to the nature and social aspects of the scientific enterprise. One major reason for offering humanistic content has been to correct these false ideas (Ziman, 1980). The section “Student Learning” below will review research into these outcomes.

A third documented major failure dates back to the 1970s research into student learning: most students tend not to learn science content meaningfully (Anderson & Helms, 2001; Gallagher, 1991; Hart, 2002; Osborne, Duschl & Fairbrother, 2003; Shamos, 1989; White & Tisher, 1986), an empirical conclusion usually explained in one way or another by the lack of relevance in school science (Fensham,
Many research programs in science education have attempted to solve this lack of meaningful learning in different ways (e.g. Millar, Leach & Osborne, 2000). But much of the research suggests that the goal of learning canonical science meaningfully is simply not achievable for the majority of students in the context of traditional school science (Aikenhead, 1996; Cobern & Aikenhead, 1998; Costa, 1995; Hennessy, 1993; Layton, Jenkins, Macgill & Davey, 1993; Osborne et al., 2003; Shamos, 1995). As a result, alternative science curriculum policies have been proposed to radically change the meaning of “science” in “school science,” a controversial idea to be sure (e.g. Aikenhead, 2000a; Barton, 2001b; Fensham, 2000b, 2002; Jenkins, 2000; Layton, 1994; Millar, 2000; Roth & Désautels, 2002).

An important consequence to this third educational failure of the traditional science curriculum is the reaction of most students and many teachers to the political reality that science credentials must be obtained in high school or a student is screened from post-secondary opportunities. Empirical evidence demonstrates how students and many teachers react to being placed in the political position of having to play school games to make it appear as if significant science learning has occurred (Bartholomew, Osborne & Ratcliffe, 2002; Costa, 1997; Loughran & Derry, 1997; Larson, 1995; Meyer, 1998; Roth, Boutonné, McRobbie & Lucas, 1999). The many rules to these school games are captured by the phrase “Fatima’s rules” (Larson, 1995). Playing Fatima’s rules, rather than achieving meaningful learning, constitutes a highly significant learned curriculum of students and a ubiquitous hidden curriculum of school science (Aikenhead, 2000a). A curriculum policy that inadvertently but predictably leads students and teachers to play Fatima’s rules is a policy difficult to defend educationally from a humanistic perspective, even though the policy flourishes for political reasons.

Learning and Using Science in Other Contexts

Although the goal of meaningful learning of canonical science is largely unattainable for many students in the context of the traditional science curriculum, it seems to be attained in other contexts in which people are personally involved in a science-related everyday issue (Davidson & Schibeci, 2000; Dori & Tal, 2000; Goshorn, 1996; Lambert & Rose, 1990; Macgill, 1987; Michael, 1992; Tytler, Duggan & Gott, 2001b; Wynne, 1991). Thirty-one different case studies of this type of research were reviewed by Ryder (2001) who firmly concluded: When people need to communicate with experts and/or take action, they usually learn the science content required.

Even though people seem to learn science content in their everyday world as required, this learning is not often the “pure science” (canonical content) transmitted from a traditional science curriculum. Research has produced one clear and consistent finding: most often, canonical science content is not directly useable in science-related everyday situations, for various reasons (Cajas, 1998; Furnham,
In other words, the empirical evidence contradicts scientists’ and science teachers’ hypothetical claims that science is directly applicable to a citizen’s everyday life. What scientists and science teachers probably mean is that scientific concepts can be used to abstract meaning from an everyday event. The fact that this type of intellectual abstraction is only relevant to those who enjoy explaining everyday experiences this way (i.e. those who have a worldview that harmonizes with a worldview endemic to science; Aikenhead, 1996; Cobern & Aikenhead, 1998), attests to the reason most students perceive science as having no personal or social relevance. But when investigating an everyday event for which canonical science content was directly relevant, Lawrenz and Gray (1995) found that science teachers with science degrees did not use science content to make meaning out of the event, but instead used other content knowledge such as values (i.e. humanistic content). This research result, along with the 31 cases reviewed by Ryder (2001), can be explained by the discovery that canonical science content must be transformed (i.e. deconstructed and then reconstructed according to the idiosyncratic demands of the context) into knowledge very different in character from the “pure science” knowledge of the science curriculum, as one moves from “pure science” content for explaining or describing, to “practical science” content for action (Jenkins, 1992, 2002; Layton, 1991). “This reworking of scientific knowledge is demanding, but necessary as socio-scientific issues are complex. It typically involves science from different sub-disciplines, knowledge from other social domains, and of course value judgements and social elements” (Kolstø, 2000, p. 659). When the science curriculum does not include this reworking or transformation process, “pure science” remains unusable outside of school for most students (Layton, et al., 1993). When students attempt to master unusable knowledge, most end up playing Fatima’s rules instead.

This empirical evidence supports the educational policy of adding another meaning of “science” in “school science;” this in addition to and directly associated with humanistic content in the science curriculum. Researchers Lawrence and Eisenhart (2002, p. 187) concluded, “science educators and science education researchers are misguided not to be interested in the kinds of science that ordinary people use to make meaning and take action in their lives.” A humanistic science course would embrace a judicial balance between this everyday action-oriented science content (citizen science; Irwin, 1995) and canonical science content. (This position contrasts with a traditional science policy that attempts to replace citizen science concepts – preconceptions – with canonical science concepts.) Concept proliferation of canonical concepts is suggested, rather than simple conceptual change (Aikenhead, 2000a; Driver, Asoko, Leach, Mortimer & Scott, 1994; Mortimer, 1995; Solomon, 1983).

Given these research conclusions that question the efficacy of teaching for meaningful learning in the context of the traditional science curriculum, there would seem to be little educational advantage for a
teacher “to cover” the entire science curriculum but instead, greater advantage to teaching fewer canonical science concepts chosen because of their relevance to a humanistic perspective (Eijkelhof, 1990; Kortland, 2001; Eylon & Linn, 1988; Häussler & Hoffmann, 2000; Walberg & Ahlgren, 1973). The latter approach is supported by a plethora of comparison studies, based on standardized achievement tests of canonical science, that showed no significant effect on students’ scores when instruction time for the canonical content was reduced to make room for the history of science, the nature of science, or the social aspects of science (Aikenhead [review], 1994b; Bybee, 1993; Eijkelhof & Lijnse, 1988; Irwin, 2000; Kelly, 1981; Klopfer & Cooley, 1963; Pedersen, 1992; Wiesemayer & Rubba, 1990; Welch, 1973); and on occasion, students in a humanistic science course appeared to fair significantly better on achievement tests of canonical science (Blunck & Yager [review], 1996; Häussler & Hoffmann, 2000; Mbajiorgu & Ali, 2003; Meyers, 1992; Poedjiadi, 1996; Rubba & Wiesemayer, 1991, 1999; Solomon et al., 1992; Sutman & Bruce, 1992; Wang & Schmidt, 2001; Winther & Volk, 1994; Yager & Tamir [review], 1983).

In summary, a recurring evidence-based criticism of the traditional science curriculum has been its lack of relevance for the everyday world (Gibbs & Fox, 1999; Millar & Osborne, 1998; Osborne & Collins, 2000; Reiss, 2000), a problem dating back at least 150 years (Hurd, 1991). The issue of relevance is at the heart of most humanistic science curricula.

Research on Relevance

Humanistic approaches to school science represent many different views on relevance (Bybee, 1993; Cheek, 1992; Irwin, 1995; Kortland, 2001; Kumar & Chubin, 2000; Layton, 1986; Matthews, 1994; Millar, 2000; Solomon & Aikenhead, 1994; Yager, 1996b). “Relevance” is certainly an ambiguous term. Mayoh and Knutton (1997) characterized 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). In the educational context of a humanistic science curriculum, the first question is invariably answered “relevant to pupils.” (In a political context, however, the answer is much different.) The second question (Relevant to what?) leads to various meanings of relevance for curriculum policy. In this paper, however, the multidimensional character of relevance is defined by a more political question (Häussler & Hoffmann, 2000; Roberts, 1988): Who decides? Research into humanistic curriculum policies is reviewed here according to seven types of relevance, a scheme developed in part from Fensham’s (2000b) views about who decides what is relevant. These seven heuristic categories overlap to varying degrees.
Wish-they-knew science. This type of relevance is typically embraced by academic scientists, education officials, and many science educators when asked: What would make school science relevant? (AAAS, 1989; Driver, Leach, Millar & Scott, 1996; Fensham, 1992, 1993, 2000b; Shumba & Glass, 1994; Walberg, 1991). The usual answer, canonical science content, moves students through “the pipeline” for success in university programs.

But how relevant is this wish-they-knew content for success by science-oriented students in first year university courses? Research evidence suggests it is not as relevant as one might assume, and on occasion, not relevant at all (Aikenhead, 1994b; Champagne & Klopfer, 1982; McCammon, Golden & Wuensch, 1988; Stuart, 1977; Tanaka & Taigen, 1986; Yager & Krajcik, 1989; Yager, Snider & Krajcik, 1988). First year university students who had not studied the prerequisite physical science course in high school achieved as well as their counterparts who had enrolled in the prerequisite. Sadler and Tai’s (2001, p. 111) more recent survey research claims, “taking a high school physics course has a modestly positive relationship with the grade earned in introductory college physics.” An endorsement of “modestly positive” would seem to be faint praise indeed. These research studies might rationally assuage science teachers’ fear that time spent on humanistic content and citizen-science content will diminish students’ chances of success at university. Although the educational arguments favouring wish-they-knew science are particularly weak, political realities favouring it are overwhelming (Fensham, 1993, 1998; Gaskell, 2003).

Need-to-know science. This type of relevance is defined by people who have faced a real-life decision related to science, exemplified by the Science for Specific Social Purposes project (Layton, 1991; Layton et al., 1993), a study of: parents dealing with the birth of a Down’s syndrome child, 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. Curriculum policy researchers ask: What science content was helpful to them in making their decisions? Ryder’s (2001) analysis of 31 case studies of need-to-know science came to the same conclusion as a more modest analysis completed 16 years earlier (Aikenhead, 1985), when Ryder wrote, “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). In other words, for the “science” in “school science” to be relevant, the curriculum perspective must expand to include need-to-know science content, that is, knowledge about science and scientists (defined earlier as humanistic content). One reason that people tend not to use canonical science content in their everyday world (in addition to it not being directly useable, as described
above; Jenkins, 1992; Lawrence & Eisenhart, 2002; Layton et al., 1993) is quite simple: canonical science content is the wrong type of content to use in most everyday action-oriented settings; instead need-to-know science (humanistic content) turns out to have greater practical value. (This issue is explored in greater detail below in the section “Student Learning.”)

Even though research that identifies need-to-know science as having potential for rationalizing the selection of specific humanistic and scientific content for the science curriculum, its potential has not yet been demonstrated. Fensham (2000a, p. 74) suggests a reason: “Its retrospective unpredictability, its variation of experience among citizens, and the time gap between school and the ‘need’, make it unattractive to curriculum designers of school science.”

**Functional science.** This is science content that is deemed relevant primarily by people with careers in science-based industries and professions. The category encompasses Chin et al.’s (in press) notion of “workplace science.” Coles (1998) surveyed UK employers and higher education specialists in science who were asked to identify scientific content thought to be essential to school science. Unexpectedly this content received very limited consensus across all domains. The most valued prerequisites for advanced science qualifications were generic thinking skills and mathematical capabilities. Moreover, large organizations such as the Chemical Industries Association, the Association for the British Pharmaceutical Industry, and the Ford Motor Company preferred their recruits to possess general capabilities rather than specific canonical science content (Coles, 1997). Desired capabilities included (from highest to lowest priority): commitment and interest; skills in communication, numeracy and information technology; personal effectiveness, relationships, and teamwork; self-reliance and resourcefulness; initiative and creativity; analysis skills; a good general knowledge, and professional integrity. Of lesser importance was the list of scientific capabilities sought by these employers (from highest to lowest priority): practical common sense; problem solving through experimentation (e.g. formulate hypotheses and design simple and reliable experiments); decision making by weighing evidence; scientific “habits of mind” (e.g. scepticism and logical thinking); and finally, understanding science ideas. Similar research findings emerged from broader studies into economic development within industrialized countries (e.g. Bishop, 1995; Cuban, 1994; David, 1995; Halsey, Lander, Brown & Wells, 1997; Rotberg, 1994), although Walberg (1991) contends otherwise, a position critiqued in turn by Solomon (1997b). Consistently the research indicates that economic development depends on factors other than a population literate in canonical science, and on factors beyond the influence of school science, for example: emerging technologies, industrial restructuring, poor management decisions, and
government policies that affect military development, monetary exchange rates, wages, and licensing agreements.

Ogawa (1999) shed light on the complexity of functional science by describing a hierarchy of interpreters (knowledge brokers) who can function as a liaison between the lay public at one extreme, and the community of scientific experts at the other extreme. For example, interpreters include science journalists (Stocklmayer, Gore & Bryant, 2001) or government and public-spirited science people who can be telephoned by a lay person (Fensham, 2000b). These knowledge brokers have an important role to play in a nation’s science and technology literacy with respect to functional science.

By conducting research *on the job* with science graduates, Duggan and Gott (2002) and Lottero-Perdue and Brickhouse (2002) discovered that the canonical science content used by science graduates was so context specific it had to be learned on the job, and that high school and university science content was rarely drawn upon. On the other hand, Duggan and Gott’s findings suggested that procedural understanding (ideas about how to do science) was essential across most science-related careers. More specifically they discovered one domain of concepts, “concepts of evidence,” that was generally and directly applied by workers in science-related occupations to critically evaluate scientific evidence, for instance, concepts related to the validity and reliability of data, and concepts of causation versus correlation. Similar findings arose in their research with an attentive public involved in a science-related societal issue. Duggan and Gott spoke for many researchers (e.g. Fensham, 2000a; Ryder, 2001) when they concluded, “Science curricula cannot expect to keep up to date with all aspects of science but can only aspire to teach students how to access and critically evaluate such knowledge” (p. 675). The humanistic perspective germane here concerns a correct understanding of concepts of evidence when dealing with social implications, for instance: Is the scientific evidence good enough to warrant the social action proposed (Wiesemayer & Rubba, 1999)? In this context, it is useful to understand the ways in which scientific evidence is technically and socially constructed (Bingle & Gaskell, 1994; Cunningham, 1998; Kelly et al., 1993; McGinn & Roth 1999), that is, humanistic content for the science curriculum. Although functional science often lies outside the sphere of canonical science content normally transmitted in traditional school science, functional science does not ignore canonical science content, but rather, subordinates it in favour of more important capabilities valued by employers and employees in science-based occupations (Chin et al., in press). The implication for curriculum policy might be to include scientific content in school science, but to recognize it as being secondary in importance compared to objectives more directly related to a humanistic perspective in the science curriculum. For example, learning to critically analyze scientific evidence requires scientific concepts to be sure, but it
matters little which canonical concepts are used as long as they are germane to the evidence at hand (Kolstø, 2001b; Ratcliffe, 1999).

In a project that placed high school students into science-rich workplaces (e.g. veterinary clinics and dental offices), Chin and colleagues (in press) investigated ethnographically (1) the relationship between school science and “workplace science” (functional science), and (2) the participants’ perception of that relationship. The fact that students saw little or not connection was explained by the researchers: school science (canonical content) in the workplace was not central to the purposes of the workplace, and therefore, it was not overtly apparent in the workplace, which in turn made it less accessible to the students. In short, knowing canonical science content was not relevant to one’s accountability in a science-rich workplace; a very similar conclusion to the research concerning need-to-know science (reviewed above). The researchers concluded that workplace science (functional science) met the purpose and accountability of the workplace, causing workplace science to differ qualitatively from school science (just as citizen science differs from canonical science). At the same time, the students experienced accountability of school science in terms of playing Fatima’s rules.

Surveys and ethnographic research methods are not the only ways to substantiate functional science content. The Delphi research technique used by Häussler and Hoffmann (2000) in Germany was shown to be an educationally rational, in-depth method for establishing a physics curriculum policy by consensus among diverse stakeholders over “What should physics education look like so it is suitable for someone living in our society as it is today and as it will be tomorrow” (p. 691). Their 73 stakeholders represented people associated with wish-they-knew science (e.g. physicists and physics teachers) and with functional science (e.g. personnel officers in physics-related industries and general educationalists). Häussler and Hoffmann did not initially group their stakeholders into these two categories, but instead used a hierarchical cluster analysis statistic to tease out like-minded stakeholders. This analysis produced two coherent groups: Group 1 favoured “scientific knowledge and methods as mental tools” and “passing on scientific knowledge to the next generation” significantly more than Group 2 who favoured “physics as a vehicle to promote practical competence” (p. 693). These statistical results lend credence to the two categories of relevance that distinguish between wish-they-knew and functional science. Interestingly, however, Häussler and Hoffmann found that both groups gave highest priority to topics related to “physics as a socio-economic enterprise” that show “physics more as a human enterprise and less as a body of knowledge and procedures” (p. 704). (This Delphi study was only the first phase of Häussler and Hoffmann’s extensive research project. Phases 2 and 3 – relevance from a student’s viewpoint and student achievement in a humanistic physics curriculum – are discussed separately later in this paper.)
Enticed-to-know science. By its very nature, enticed-to-know science excels at its motivational value. This is science content encountered in the mass media and the internet, both positive and negative in its images of science and both sensational and sometimes dishonest in its quest to entice a reader or viewer to pay closer attention. Fensham (2000a, p. 75) 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.” In the UK and in Greece, Millar (2000) and Dimopoulos and Koulaidis (2003) described how their longitudinal analyses of the content of science-related articles in their respective national newspapers identified the science and technology knowledge that would be most useful in making sense of these articles and the stories they presented. Millar’s analysis stimulated a revision of the AS-level syllabus in the UK and eventually culminated in Hunt and Millar’s (2000) high school textbook *AS Science for Public Understanding* that provides a humanistic perspective. For highly controversial issues, however, Thomas (2000) cautions policy makers over the extent to which “sound science” can be taught strictly from newspaper articles.

Moral issues and public risk are often associated with enticed-to-know science because the media normally attends to those aspects of events (Conway, 2000; Cross & Price, 1992, 2002; Eijkelhof, 1990; Levinson et al., 2000; Nelkin, 1995; Osborne, Duschl & Fairbrother, 2003; Stocklmayer et al., 2001). Moreover, the more important everyday events in which citizens encounter science involve risk and environmental threats (Hart, in press; Irwin, 1995).

Have-cause-to-know science. This is 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, in terms of what people have cause to know. This empirical approach to developing curriculum policy is being tested in China where the societal experts were drawn from the following domains: home and workplace safety; medical, health, and hygiene problems; nutrition and dietary habits; consumer wise-ness; and leisure and entertainment (Law, Fensham, Li & Wei, 2000). The approach assumes that societal experts are better situated than academic scientists to decide what knowledge is worth knowing in today’s changing scientific and technological world. Fensham (2002) envisions a have-cause-to-know science curriculum policy unfolding in three phases: (1) selected societal experts systematically determine features of society endemic to an informed citizenry;
(2) academic scientists specify science content associated with the features of society identified in phase 1; and (3) based on the first two phases, science educators develop a school science curriculum.

Have-cause-to-know science is a feature of the Science Education for Public Understanding Project, SEPUP, in the US (Thier & Nagle, 1994, 1996). Societal experts in industry, the sciences, and education provided the curriculum developers with elements of a relevant issues-based curriculum that led to STS chemistry modules and three STS textbooks (SEPUP, 2003): Science and Life Issues; Issues, Evidence and You; and Science and Sustainability.

In the Netherlands, Eijkelhof (1990, 1994) used the Delphi research technique to gain a consensus among societal experts to establish the humanistic and canonical science content for an STS physics module, “Ionizing Radiation.” The 35 Delphi participants in Eijkelhof’s study were carefully selected to represent a variety of fields and opinions on the risks of ionizing radiation (a group purposefully more homogeneous than the stakeholders in Häussler and Hoffmann’s [2000] study discussed above). After the normal three rounds in the Delphi procedure, Eijkelhof’s radiation experts pointed to suitable societal contexts of application and concomitant scientific content that the public had cause to know (Eijkelhof, Klaassen, Lijnse & Scholte, 1990). Eijkelhof (1990) warned, however, that policy research by itself should not prescribe the final curriculum. A curriculum development team must also consider educational issues, for example, learning difficulties of students, available instruction time, and pedagogical factors. He attended to those issues by drawing upon a decade or more of research (Eijkelhof & Lijnse, 1988; Ratcliffe et al., 2003).

In contrast, an Australian chemistry curriculum committee could not reach a consensus on a balance between societal contexts of application and scientific content, and as a result the committee’s writers tended to promote the status quo (wish-they-knew science) rather than the intended have-cause-to-know science (Fensham & Corrigan, 1994).

The National Curriculum in the UK calls for humanistic content to be taught but does not specify the content in any detail. In a study focused entirely on humanistic content, Osborne and colleagues (2001) employed the Delphi technique to establish a consensus in the UK on what “ideas about science” should be taught in school science. During three rounds of the Delphi procedure, 23 “experts” (professional and academic people notable for their contributions to the clarification of science for the public) produced 18 ideas of which nine showed sufficient stability and support (“scientific methods and critical testing,” “creativity,” and “historical development of scientific knowledge;” to name the top three) to inform the development of teaching materials that explicitly taught these nine ideas about science (Bartholomew, Osborne & Ratcliffe, 2002). The resulting materials were embedded within a large-scale research project, “Evidence-Based Practice in Science Education” (IPSE). The have-cause-to-know ideas
about science, elucidated by the IPSE project, addressed only humanistic content; the canonical science content had been established by the National Curriculum’s wish-they-knew science.

Curriculum policy research has also included surveys of experts to determine which social issues (and therefore, which have-cause-to-know science) they valued most in a humanistic science curriculum. The experts included scientists and engineers (Bybee, 1984a), citizens (Bybee, 1984b), science teachers (Bybee & Bonnstetter, 1986), and science educators in the US (Bybee, 1987) and internationally (Bybee & Mau, 1986). The relevant contexts for have-cause-to-know science were identified, but their actual influence on curriculum policy has not been noticeable (Cheek, 2000). This survey research was perhaps more successful at raising awareness of STS than developing specific curriculum policies.

_Personal-curiosity science._ When students themselves decide on the topics of interest for school science, relevance takes on a personal, though perhaps idiosyncratic meaning when students’ hearts and minds are captured (Gardner, 1985, 1988; Osborne & Collins, 2000; Reiss, 2000). Based on a humanistic curriculum policy principle that one builds on the interests and experiences of the student, Sjøberg (2000) surveyed over nine thousand 13-year-old students in 21 countries to discover (among other things): their past experiences related to science, their curiosity toward certain science topics, their attitude to science, their perception of scientists at work, and their self-identity as a future scientist. Based on the same curriculum policy principle, Häussler and Hoffmann (2000) surveyed over six thousand German students, aged 11 to 16 years, to determine, among other things: (1) their interest in various physics topics (i.e. the everyday context for the topic and its relevant content), (2) their interest in physics as currently taught in their school, and (3) personal background factors. Data from Häussler and Hoffmann (2000) and from Sjøberg (2000) offered insights into students’ differential interests, for instance, “music” was much more interesting than “acoustics and sounds,” and “the rainbow and sunsets” much more than “light and optics.” In short, concrete themes embedded in student experiences were much more relevant than science discipline topics, a finding supported by three decades of research by the Dutch PLON project (Kortland, 2001). In Sjøberg’s study, students in non-Western countries had a significantly more positive image of scientists (i.e. heroic figures helping the poor and underprivileged) than their counterparts in Western countries, a finding that points to the importance of culture in a student’s everyday world. (This type of relevance is addressed in the next sub-section.) In the Häussler and Hoffmann (2000) study, two outcomes are pertinent here. First, compared to the two groups of stakeholders in their Delphi research (i.e. experts in wish-they-knew science and in functional science), students’ personal interests generally fell between the priorities of each Delphi group. Secondly, students’ personal interests were seriously at odds with the traditional physics courses offered at their school. In short, students’ views were congruent with
stakeholders who advocated a humanistic perspective in the physics curriculum but discordant with the status quo. Häussler and Hoffmann pointed out that a curriculum policy founded on the Delphi results would look very similar to a curriculum policy founded on student interests alone (i.e. personal-curiosity science). (As described in the section “Student Learning,” teaching a humanistic physics course structured by student interest did result in significantly greater achievement on canonical science content than teaching a traditional physics course.)

Sjøberg (2002, 2003) initiated an international in-depth study of personal-curiosity science, the Relevance of Science Education (ROSE) project, whose results will soon be forthcoming.

Surveys of student interest have typically accompanied the evaluation of a humanistic science pilot course. This research produced fairly consistent results: the personal-curiosity science in which students expressed most interest is related to sex and drugs (e.g. Aikenhead, 1992; Stoker & Thompson, 1969). These preferences, however, shift to problems of population and pollution when other questions of relevance are posed, for example: What topics are of most value to you now? or What topics will be most valuable to you in the long run? (Stoker & Thompson, 1969).

Science-as-culture. A more holistic yet abstract concept of relevance for school science was advanced by Weinstein’s (1998) research concerning the enculturation of students into everyday society, an approach to science education that stands in stark contrast to the enculturation of students into scientific disciplines (discussed below in “Cultural Relevance”). Culture decides, de facto, what is relevant for science-as-culture. For instance, in school culture, “Students constantly are being measured, sorted, and turned into objects of scrutiny. They learn science up close and personal but not as scientists; rather, they learn it as objects of science” (p. 493). Weinstein identified a network of communities in students’ everyday lives: health systems, political systems, the media, environmental groups, and industry, to name a few. Each community interacts with communities of science professionals, resulting in a cultural commonsense notion of science described by Weinstein 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)

Science-as-culture is more than just pop culture (Solomon, 1998). As a category of relevance, science-as-culture serves in part as a super ordinate category to the need-to-know, functional, enticed-to-know, have-
cause-to-know, and personal-curiosity science categories. Its relevance resides in the student’s community’s culture (a commonsense notion of science) and in the student’s home and peer cultures (Costa, 1995; Kyle, 1995; McKinley, in press; Solomon, 1994c; 1999a, 2003a). Science’s role in society is also embedded in science-as-culture, as evidenced by roles such as: setting standards, regulating commerce, providing legal evidence, announcing medical breakthroughs, creating novel ethical dilemmas, and requiring financial support for research and development (Dhingra, 2003; Jenkins, 2000; Stocklmayer et al., 2001).

Future research into students’ science-as-culture may reveal useful ideas for a humanistic science policy, particularly for the enculturation of students into their local, national, and global communities. Prelle and Solomon (1996), for instance, provide a rich account of the differences between students’ orientation to an environmental issue and their scientific knowledge on the subject. The researchers explored students’ science-as-culture by investigating those differences in three settings: the science classroom, students’ homes, and on holidays. McSharry and Jones (2002) discovered that television commercials continually expose viewers to a large amount of science (65% of all commercials), but apparently few viewers realized it. The researchers concluded, “Advertisements could prove to be extremely useful in increasing the relevance of science education to children” (p. 496). A new curriculum policy research question arises: What knowledge is of critical value to consumers of television commercials? Nelkin’s (1995) and Stocklmayer and colleague’s (2001) seminal research into science and the media raises an even broader policy question: What understandings of science and journalism are of critical value to consumers of the mass media?

Science-as-culture can also be captured by project-based learning in which local science-related real-life problems are addressed by students in an interdisciplinary way (e.g. Barton & Yang, 2000; Bouillion & Gomez, 2001; Dori & Tal, 2000; Hart, in press; Jenkins, 2002; Lee & Roth, 2002). This approach draws upon community resources and local culture to stimulate need-to-know, functional, and have-cause-to-know science, as well as science-as-culture; in short, citizen science. The presence of a humanistic perspective in a project-based curriculum depends, however, on the degree to which its humanistic content is made explicit in the instruction and assessment of students (Aikenhead, 1973; Kortland, 2001; Lederman, in press; Ratcliffe, 1997b).

**Conclusion.** These seven heuristic categories of relevance, based on who decides what is relevant, can help describe the content and contexts found in a humanistic perspective of a particular science curriculum. More often than not, a curriculum will embrace several categories simultaneously, for example, by combining some wish-they-knew science found in a government curriculum document (the
intended curriculum) with, for example, functional science, enticed-to-know science, have-cause-to-know science, and personal-curiosity science (e.g. Aikenhead, 1994a; Eijkelhof & Kapteijn, 2000; Eijkelhof & Kortland, 1988). From an STS perspective, relevance has generally been 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 (Bybee, 1993; Eijkelhof et al., 1990; Kumar & Chubin, 2000; Solomon & Aikenhead, 1994; Yager, 1996b; Ziman, 1980). This STS view embraces several categories of relevance described above.

Cultural Relevance

Ideologies inherent in any science curriculum can be categorized in terms of two mutually exclusive presuppositions of school science (Aikenhead, 2000a; Pillay, 1996; Rudolph, 2003; Weinstein, 1998): (1) the enculturation of students into their local, national, and global communities, communities increasingly influenced by advances in science and technology, and (2) the enculturation of students into the disciplines of science. These presuppositions represent two fundamentally different axiomatic views of relevance. From a student’s point of view, relevance concerns the degree to which curriculum content and classroom experiences speak to the student’s cultural self-identity (Aikenhead, 2000a; Brickhouse, 2001; Brickhouse, Lowery & Schultz, 2000; Brickhouse & Potter, 2001; Gee, 2001; Häussler & Hoffmann, 2000; Solomon & Thomas, 1999; Stairs, 1993/94). For instance, in an unusually rich, in-depth, longitudinal research study, Reiss (2000) examined 563 science lessons over five years as 22 targeted students worked their way through secondary school science in the UK. Not surprisingly, doing science was seen as getting marks on the examination. “Beating the examiner” was one of their Fatima’s rules. By interviewing students and their parents together at home (225 times in total), Reiss illuminated the cultural relevance that school science held for these students. Two unavoidable conclusions surfaced: science education played a meagre to insignificant role in most of the students’ personal lives; and school science will only engage students in meaningful learning to the extent to which the science curriculum has personal value and worth for students, that is, when it contributes to students’ cultural capital (Bourdieu & Passeron, 1977) and enriches or strengthens their cultural self-identities (Brickhouse, 2003; Brickhouse & Potter, 2001; Eijkelhof, 1990; Pillay, 1996; Stairs, 1993/94).

Drawing upon culture-based research into the worldviews of a class of grade 9 students, Cobern and Aikenhead (1998) identified a student (Howard) who felt comfortable with the traditional school science curriculum because it harmonized with his worldview of nature. Students like Howard have been called “Potential Scientists” or “I Want to Know” Students (Aikenhead, 2001) and they have future career paths enhanced by canonical science content (Lyons, 2003). Cobern and Aikenhead (1998) also identified
many more students’ whose worldviews of nature were at odds with the traditional science curriculum, and whose cultural self-identities were not enhanced by a traditional science curriculum because science seemed like a foreign culture to them. Research into this cultural issue is beyond the scope of this review.

In Mayoh and Knutton’s (1997) research into using everyday experiences in science lessons, the researchers implicitly embraced the presupposition “enculturation of students into scientific disciplines,” in which students’ everyday experiences were deemed relevant to the extent to which those experiences motivated students to think like a scientist and to assume a scientific “habit of mind.” The 1990s “relevance-in-science movement” (Campbell & Lubben, 2000, p. 240) similarly advanced the implicit goal to enculturate all students into a scientific worldview, even for those students whose worldviews are incongruent with the science curriculum (Aikenhead, 1996). From the viewpoint of these students, the curriculum’s goal was not enculturation but rather, cultural assimilation. As mentioned earlier, most students avoid this assimilation by playing Fatima’s rules (Aikenhead, 2000a; Costa, 1997; Larson, 1995). The most fundamental question of relevance is not so much “Relevant to who?” “Relevant to what?” or “Who decides?” but rather: “Relevant to which enculturation process?” – enculturation into a scientific discipline (the status quo), or enculturation into students’ local, national, and global communities (one possible facet of a humanistic perspective). In short, relevance precipitates a policy dilemma. Depending on the humanistic science curriculum, relevance will be fundamentally framed by a primary allegiance to scientific disciplines or to students’ communities. In an attempt to resolve the dilemma by integrating the two mutually exclusive positions into the same curriculum, educators risk confusing and alienating students (Egan, 1996).

The research reviewed in this paper suggests that any science curriculum, humanistic or purely scientific, dedicated to the enculturation of all students into scientific ways of thinking will constantly be challenged and undermined by Fatima’s rules.

Processes for Formulating Curriculum Policy

Throughout this paper’s review of research, educationally driven research findings conflicted with political realities. Politics intensify when we examine research into the processes by which people have formulated curriculum policy, for example, when answering the research question: Who has the socio-political power to decide, and how do they assert and maintain that power? The paucity of research in this domain (Kortland, 2001; Roberts, 1988) may speak to the unease felt by research participants when political events come under public scrutiny, exposing the natural tension between maintaining the status quo of pre-professional training in “the pipeline,” and innovating a humanistic perspective for equity and
social reconstruction (Apple, 1996; Barton, 2001a; Barton & Yang, 2000; Fensham, 1998; Lee, 1997; Roth & McGinn, 1998).

Curriculum policy is established in a number of different ways, from the “top-down” central control by government bureaucrats to the “grass-roots” populist control by stakeholders (Hart & Robottom, 1990; Lijsne, 1995; Solomon, 1999a). The ultimate expression of a top-down policy formulation happened when a national political leader publicly denounced, and therefore crushed, a humanistic perspective in the science curriculum (Solomon, 2002). Most curriculum policies develop by way of collaboration that lies between these two extremes.

Historical events, summarized earlier in the paper, revealed the political context in which the first science curriculum policy emerged; a context characterized by the cultural values, conventions, expectations, and ideologies that determined at that time what school science would be. Because context is paramount for policy inquiry, researchers have often employed qualitative methods such as case studies or vignettes to interpret and understand processes that formulated a humanistic science curriculum policy. This was certainly the case for research into power conflicts over curriculum policy reported by Aikenhead (2002b), Blades (1997), Fensham (1993, 1998), Gaskell (1989, 2003), Hart (2002), Roberts (1988, 1995), and Solomon (2003b). Each study revealed the power dynamics adopted by various groups of stakeholders. When deciding what knowledge is of most worth, people usually negotiate by using both rational criteria and political power in an attempt to ameliorate influences by various stakeholders. Each educational jurisdiction has its own story to tell about how curriculum policy is formulated. Two research studies are mentioned here to illustrate this type of research. In his book *Procedures of Power & Curriculum Change* (a research study into the temporary defeat of a humanistic science curriculum policy in Alberta, Canada), Blades (1997) allegorically described the intense clashes between newly aligned interest groups, who organized a network of relationships (actor-networks; Carlone, 2003; Foucault, 1980; Gaskell & Hepburn, 1998) to serve their own self interests, and who enacted “rigor” as a power ploy in their discourse. Blades discovered that one very powerful stakeholder-group altered its alliances along different lines, thereby reversing its policy position. Treachery thy name is government bureaucrat! A second study by Gaskell (1989) in British Columbia, Canada, showed how science teachers’ allegiances to different professional organizations and to their own professional self-identities undermined an emerging humanistic science curriculum policy (Rowell & Gaskell, 1987). Both of these research studies provide answers to the question (posed above): Who has the power to decide, and how do they assert and maintain that power?

Although each case study and vignette found in the literature was unique, all reached the same conclusion (with a few unique exceptions): local university science professors have a self-interest in
maintaining their discipline (empire building, perhaps) and will boldly crush humanistic initiatives in school science policy (Aikenhead, 2002b; Blades, 1997; Fensham, 1992, 1993, 1998; Fensham & Corrigan, 1994; Gaskell, 1989; Hart, 2002; Pandwar & Hoddinott, 1995; Roberts, 1988; Shymansky & Kyle, 1988); resulting in what Gaskell (2003, p. 140) called “the tyranny of the few.” If local science professors become marginalized and lose their power to control policy decisions, they tend to realign their actor-networks into international alliances to defeat a local humanistic curriculum policy (Rafea, 1999), or sometimes they resort to blackmail (Aikenhead, 2002b).

Science curriculum policy is normally formulated more smoothly through consultation with different stakeholders (Orpwood, 1985), for instance: government officials, the scientific community, science teachers, university science educators, students, parents, business, labour groups, industry, plus other groups and institutions. Government ministries of education generally rely on the advice of curriculum committees variously comprised of some of these stakeholders. Because government committee meetings are almost always held “in camera,” out of the view of an inquisitive researcher, their confidentiality has prevented research into the early stages of formulating government policy (De Vos & Reiding, 1999; Roberts, 1988).

Less confidential, and hence more amiable to systematic investigation, is the collaborative dialogue between parents and curriculum developers, a dialogue investigated by Cross and Yager (1998) in a pilot research study with 17 parents in Iowa. The researchers discovered parents’ concerns about the impact of science and technology on their lives, the role of scientific experts who advise the public, and the parents’ vision of science education (a vision that was most supportive of a humanistic science curriculum). This consultative type of research could inform and influence curriculum committees that do not have parent representation.

Consultative research has also taken the form of research and development (R&D) studies that produced STS classroom materials (e.g. textbooks and modules) as a means to influence or articulate a humanistic curriculum policy. Researchers collaborated with ministries of education, selected teachers, students, and experts who furnished “functional” and “have-cause-to-know” science (among other types of relevance) for the science curriculum (Aikenhead, 1994a; Eijkelhof & Lijnse, 1988; Eijkelhof & Kapteijn, 2000; Kortland, 2001; Solomon, 1981).

More rigorously systematic policy studies have used the Delphi research method to inform humanistic curriculum policy, for instance (as described above), the research by Eijkelhof (1990), Häussler and Hoffmann (2000), and Osborne and colleagues (2001). Their experts were able to reach a consensus on the relevant contexts and associated knowledge for an educationally sound, humanistic science curriculum policy.
The most elaborate, theory-based, consultative methodology is deliberative inquiry. Inspired by Schwab’s (1974) “deliberative enquiry,” it combines top-down and grass-roots approaches. Deliberative inquiry is a structured and informed dialogic conversation among stakeholders who, face to face, help government officials reach a decision on curriculum policy by discussing and re-examining their own priorities (i.e. values) along with their reading of relevant research (Orpwood, 1985). Because science teachers will be central to implementing a humanistic science curriculum (Roberts, 1988) and because curriculum evaluation research consistently shows that the teacher has more influence on student outcomes than the government’s choice of curriculum taught (Welch, 1979, 1995), the science teacher is a key stakeholder and usually holds a central role during deliberative inquiry meetings. The process of deliberation encompasses both educational and political dimensions to formulating curriculum policy.

The Science Council of Canada (SCC) used deliberative inquiry to produce a national science curriculum policy that embraced a humanistic perspective (Aikenhead, 2000b; Orpwood, 1985; SCC, 1984). The SCC study ensured that significant problems in science education were identified, that appropriate evidence was collected, and that the problems and evidence were considered by diverse stakeholders attending one of the 11, two-day deliberative conferences held across Canada. Stakeholders included high school students (science proficient and science shy students); teachers (elementary and secondary); parents; elected school officials; the scientific community; university science educators; and representatives for the business, industry, and labour communities. The students’ contributions were pivotal to recommendations related to student assessment. As Schwab (1978), predicted, “Deliberation is complex and arduous. …[It] must choose, not the right alternative, for there is no such thing, but the best one” (pp. 318-319, emphasis in the original). The “best” science curriculum policy for Canada was published as *Science for Every Citizen* (SCC, 1984). Inspired by the success of this deliberative inquiry, two other Canadian provinces conducted similar research but on a smaller scale. Drawing upon the SCC’s national study, Alberta resolved the problems identified by Blades (1997) (described above) by holding a series of deliberative conferences that gave science teachers a political voice (Roberts, 1995). Saskatchewan almost replicated the SCC study during the renewal of its science curriculum and yielded a strong teacher consensus on a humanistic perspective (Hart, 1989).

A very different method of policy formulation, illustrated by the AAAS’s (1989) *Project 2061* and the National Research Council’s (NRC, 1996) *Standards* in the US, utilizes consultation with stakeholders on a grand yet narrow scale. After conducting a complex series of inclusive national surveys and committee meetings, a “consensus panel of leading scientists” (Walberg, 1991, p. 57) determined the content of *Project 2061* (content critiqued as conveying a positivist non-contemporary view of science, by Bingle & Gaskell [1994] and Fourez [1989], and as ignoring student relevancy, by Settlage and Meadows...
Thus, the final say in the curriculum lay with people who narrowly espouse the conventional wish-they-knew science. This exclusivity, plus the lack of published research on the consultation process itself, suggests that the national agencies may have prioritized political opportunism over educational soundness and repeated their predecessors’ 1867 policy decisions. A humanistic perspective loses significance in the wish-they-knew science of *Project 2061* and *Standards*.

Considering all the research studies into policy formulation reviewed here, the process of deliberative inquiry holds greatest potential for devising an educational rationale for a humanistic perspective in the science curriculum, while at the same time providing a political forum for negotiations among various stakeholders. “This requires bringing to the surface the tacit social aims and assumptions that are constantly in play in the development of the school science curriculum as well as carefully considering the social consequences, intended or not, of the curriculum produced” (Rudolph, 2003, p. 76).

Although these considerations will likely enhance the quality of the resultant science curriculum policy, other important areas of research are pertinent to successful deliberative inquiry, areas such as classroom materials, teacher orientations, and student learning; topics to which we now turn.

**Classroom Materials**

Classroom teaching materials, particularly textbooks and modules, seem to dictate the taught curriculum for many teachers (Chiang-Soong & Yager, 1993; Chiappetta, Sethna & Fillman, 1991; Lijsne, 1995; Osborne et al., 2003; Weiss, 1987; Weiss, Pasley, Smith, Banilower & Hect, 2003). Textbooks and modules can operationally define a humanistic perspective for science teaching and therefore can provide needed support and guidance to an innovating teacher. In the absence of such support, teachers feel unsupported in their attempts to implement a humanistic perspective in their classroom (Bartholomew et al., 2002), discussed below in “Teacher Orientations.”

Roberts’ (1982) analyzed a number of North American science policy statements woven into textbooks during the 20th century to determine the implicit and subtle messages they conveyed about goals for studying science. His research inductively developed seven different messages he called “emphases.” (Fensham [2000b] added three more emphases to this list.) Although the most popular emphasis for secondary schools was “solid foundations” (the pre-professional training “pipeline”), Roberts also detected the highly humanistic emphasis “science, technology, and decisions.” Thus, over the years textbooks generally did not ignore a humanistic perspective, but they gave it wavering and meagre attention. (Roberts’ research results paralleled other historical analyses reviewed above; e.g. Hurd, 1991).

As the STS school science movement evolved in the 1980s, researchers investigated the degree to which STS content appeared in popular contemporary textbooks (e.g. Chiang-Soong & Yager, 1993).
This content, however, was defined differently from study to study (Aikenhead, 1994d). Bybee (1993) reviewed this literature and concluded that little STS content was found, reflecting the low value placed on it by school personnel, textbook authors, and commercial publishers. His review also noted that even when STS textbooks and modules were available across the US by 1990, they were not implemented by teachers to any extent; as was the case in the UK (Monk & Osborne, 1997). Thus, the availability of humanistic science materials is a necessary but insufficient condition for a humanistic perspective to be found in the taught curriculum (Cross & Price, 1996; Eijkelhof & Kortland, 1988).

Researchers have also systematically analyzed traditional science textbooks to investigate what images they convey about science and scientists (Anderson & Kilbourn, 1983; Cross & Price, 1999; Gaskell, 1992; Knain, 2001; Kelly et al., 1993; Milne, 1998; Olson, 1997). An idealized heroic rationalism paints a picture of individual scientists discovering (revealing) truth by applying the scientific method; a picture that equates scientific knowledge of nature with nature itself. Most textbooks convey an ideology of indoctrination into positivistic realism endemic to the traditional science curriculum. As mentioned earlier, replacing this ideology with a more humanistic one became a cornerstone for the STS movement.

Even though humanistic science textbooks can potentially play a critical role in classrooms, systematic investigations into their development have been rare, likely because the financial resources of most humanistic innovative projects are drained by the production of the materials themselves and the professional development of prospective teachers. Even Harvard Project Physics (Holton, Rutherford & Watson, 1970) did not systematically research the development of its textbook, and as a consequence the writers did not revise it sufficiently to meet the needs of many teachers and students (Cheek, 2000; Welch, 1979, 1995).

Research into the development of humanistic science materials exemplifies formative and summative assessment (Black, 1998; Scriven, 1967). Broadly speaking, formative assessment produces feedback to the writers from teachers and students by identifying problems to be resolved to improve the materials. Summative assessment usually produces data on student learning and teacher satisfaction to evaluate the overall effectiveness of the materials, for the benefit of other teachers (potential users) or policy makers who can offer political support for the innovation, for example, by influencing examination content. This section reviews studies in formative assessment, leaving summative assessment to a later section, “Student Learning.”

Various degrees of collaboration have been achieved between, on the one hand, writers or developers of classroom materials who have a vision of the intended humanistic science curriculum, and
Research and Development

In the natural sciences, R&D combines scientific inquiry and engineering design in a context bounded by everyday exigencies (Ziman, 1984). In the social science domain of education, R&D collects data to be fed directly into improving the product of the study or the practice related to using it. This type of research differs from the typical science education research reported in the literature where data are collected to inform a theoretical model, for instance, or to be interpreted to convey a participant’s lived experience.

Because R&D results are an improved product or the improved use of a product, R&D studies are rarely published in the research literature. Cheek (1992) conducted a formative assessment study for the New York Science Technology and Society project, a set of STS modules for lower secondary science that gave more attention to technology than was normal; and Sáez, Niño, Villamañan, and Padilla (1990) completed a formative assessment study of biotechnology units being developed in Spain for high school students.

The most substantial R&D study to publish its formative assessment of teaching materials took place in The Netherlands from 1972 to 1986. The PLON project developed many humanistic physics modules for lower and upper secondary school (Eijkelhof, 1990; Eijkelhof & Kortland, 1988; Eijkelhof & Lijnse, 1988). The modules attempted to motivate students into learning canonical physics content by placing that content in relevant contexts (e.g. the physics of sound is taught in a module called “Music”). The modules also aimed to improve students’ capacity to interpret media messages, to make consumer choices, to follow new developments reported in the media, and to engage in public decision making, all related to physics. The researchers used questionnaire data from students and teachers, field notes of teacher meetings and of occasional classroom observations, and interview data from students and teachers. At least three major results emerged from this research program. First was the difficulty encountered finding real-life contexts that involved only canonical physics content, due to the fact that science-related issues are largely interdisciplinary (e.g. “Music” touches significantly on physiology and aesthetics). This research result exemplifies the historical evolution of 19th century professionalised scientific disciplines into 21st century collectivized science (described earlier). Unfortunately, the PLON’s results were educationally constricted by the political realities of a national curriculum structure that required separate disciplines. The second major result related to meaningful learning of canonical physics: it did not improve significantly in PLON units, adding further evidence to the inherent difficulty of
meaningful learning experienced by most students (reviewed earlier). The third major result was the proposal of a useful four-phase pattern for R&D: (1) studies of first version materials (formative assessment), (2) studies of second version materials (formative and tentative summative assessment), (3) in-depth studies into problems related to humanistic science materials in general, and (4) studies into the goals of the project (summative assessment).

Other R&D studies have involved students more directly and substantially in the development of classroom materials (Aikenhead, 1983, 1994a, 2000b; Solomon, 1981, 1983). For instance, in Aikenhead’s (1994a) first phase R&D into the production of an integrated STS science textbook, he collaborated extensively with grade 10 students by teaching a first version himself, a version to which students actively contributed material. In phase 2, he observed three teachers daily as they taught a draft of the student text by using a draft teacher guide. This resulted in refinements to both. These classroom materials had developed in situ, as daily research on student preconceptions of canonical concepts, for instance, immediately led to changes in the text as suggested by the practical actions of students and teachers. The next revision was piloted by a diverse group of 30 teachers whose written and focus-group feedback fine-tuned the materials for commercial publication. This R&D project established that students can contribute significantly to a textbook’s content, structure, and language, and that most students respond eagerly to this type material. But unlike the PLON project, resources were only available for formative assessment research.

Developmental Research

A post-PLON research program expanded R&D into developmental research: “a cyclic process of reflection on content and teaching/learning process, small-scale curriculum development and teacher preparation, and classroom research of the interaction of teaching and learning processes” (Kortland, 2001, p. 10). These are research studies into producing PLON-like modules but whose validity rests on the study’s transferability to other teaching contexts (e.g. the improvement of science teaching, and the development of didactical theories), rather than on the quality of the specific materials only (Eijkelhof, 1990; Kortland, 2001; Lijnse, 1995). For instance, Eijkelhof (1990) demonstrated how a Delphi study could produce have-cause-to-know science and authentic contexts for school science (reviewed earlier) that lead to science materials integrated around risk and safety assessment (e.g. a PLON module “Ionizing Radiation”). Kortland (2001) explored the topic of decision making in the context of developing an ecology module on waste management (reviewed later in “Student Learning”). The production of high quality classroom materials is only one principal outcome to developmental research.
Post-PLON developmental research laid the foundations for developing a grade 10 humanistic science curriculum in The Netherlands between 1996 and 2003 (Algeme Natuurwetenschappen) often named “the public understanding of science” curriculum (De Vos & Reiding, 1999; Eijkelhof & Kapteijn, 2000). Interestingly, the final responsibility for polishing and publishing these classroom materials was turned over to commercial publishers.

Action Research

Action research is small-scale, classroom R&D, largely initiated by teachers to find solutions to their practical problems (Keeves, 1998). Some action research has produced humanistic science materials (Aikenhead, 2002a; Blunck & Yager, 1996; McFadden, 1980, 1996; Pedretti & Hodson, 1995; Rye & Rubba, 2000). Unfortunately, most action research that produces classroom materials is quite idiosyncratic and this inhibits their transferability. One notable exception was the Atlantic Science Curriculum Project that worked 15 years to publish a Canadian textbook trilogy SciencePlus (McFadden, 1991, 1996) and then an American textbook trilogy SciencePlus Technology & Society (McFadden & Yager, 1997). Three other exceptions include: the Science and Technology in Action in Ghana Project (Anamuah-Meusah, 1999); the Science, Technology, Environment in Modern Society (STEMS) project in Israel (Dori & Tal, 2000; Tal, Dori, Keiny & Zoller, 2001); and the Science Through Applications Project in South Africa (Gray, 1999). The Israeli and South African projects produced a number of modules by teams of teachers supported by parents and the community’s industries, over a one-year and three-year period, respectively. The Israeli and South African projects’ formative assessment targeted teachers’ professional growth, but not the classroom materials themselves, unlike the Ghanaian project.

A more modest action research project, Rekindling Traditions, investigated ways to engage First Nations (Native American) communities in collaborating with a science teacher and students to develop local classroom materials that integrate First Nations science with Euro-American science (Aikenhead, 2002a). The resultant six teaching units illustrate a cultural orientation to a humanistic perspective in the science curriculum, from which the traditional science curriculum is viewed as a foreign culture to be appropriated by students.

Research into the development of classroom materials reviewed here did not reveal their influence on teachers, for instance, whether the materials dictated the taught curriculum to the teachers, or whether the teachers modified the materials to conform with a teacher’s personal orientation to a humanistic science curriculum. This crucial process is explored next.
Teacher Orientation

Teachers construct their own meaning of any intended curriculum as they negotiate an orientation toward it and decide what to implement, if anything, in their classroom. Over the years, researchers have studied teachers’ rejection, acceptance, and idiosyncratic modulation of an intended humanistic science curriculum, beginning at first with simplistic assumptions about “teacher-proof” curricula (Solomon, 1999a; Welch, 1979) and then evolving into more detailed ideas such as: curriculum emphases (Roberts, 1982); holistic teacher-beliefs and value systems (Aikenhead, 1984; Cronin-Jones, 1991; Lantz & Kass, 1987; Mitchener & Anderson, 1989); and more highly complex research frameworks, for example, “science teacher thinking” “teacher practical knowledge” and “pedagogical context knowledge” with which teachers make decisions and take action (Barnett & Hodson, 2001; Clandinin, 1985; Clandinin & Connelly, 1996; Duffee & Aikenhead, 1992; Roberts, 1998). The more recent research provides greater insights than earlier research.

Two general conclusions about teachers’ orientations can be drawn from the literature reviewed earlier in this paper. First, the historical research would predict that in any era a small proportion of science teachers would be predisposed in varying degrees to an ideology supportive of a humanistic perspective for school science. Thus, there will always be a few science teachers who teach from a humanistic point of view (humanistic science teachers), and who gladly volunteer for any research study, R&D project, developmental research, or action research that promises to enhance their humanistic orientation. History similarly predicts there will be a nucleus of teachers committed to “the pipeline” ideology that promotes pre-professional training, mental training, and screening students for university entrance. These teachers (“pipeline” enthusiasts) will resist and even actively undermine any humanistic innovation in school science (Aikenhead, 1983; Blades, 1997; Carlone, 2003; Fensham, 1992; Rowell & Gaskell, 1987). There exists a third group of science teachers who can be persuaded to move toward either ideology for a variety of different reasons (middle-of-the-road teachers). A similar triad of teachers (those who accept, reject, or alter, a humanistic curriculum) emerged from two studies of high school teachers faced with implementing an STS curriculum and textbook in the US (Mitchener & Anderson, 1989) and STS modules in the UK (McGrath & Watts, 1996). The relative presence of these three groups of teachers in any research study will greatly affect the nature of its conclusions. For instance, in one of the most insightful in-service programs for a humanistic science curriculum (Leblanc, 1989), its leaders ensured that a high proportion of participants came from the first and third teacher groups (humanistic and middle-of-the-road teachers), and the leaders selected judiciously a small number of high-profile teachers from the second group (“pipeline” enthusiasts). After three years of periodic intensive in-service sessions, supported by university research scientists and enriched by classroom trials of materials by participants
and then followed by in-depth group reflection, the province of Nova Scotia formally implemented an STS science curriculum supported by all the in-service teachers, including “the pipeline” enthusiasts of group 2. No follow-up study was reported, however.

Elmore (2003) drew upon a great deal of research and experience with school innovation when he cryptically characterized a typical, science education, innovation study as follows: a gathering of “the faithful” (i.e. humanist science teachers of group 1) to show that the innovation can work on a small scale, and then leave “the virus” (i.e. the innovation) to populate the system on its own because the innovation is such a good idea (i.e. educationally sound). This approach to changing school science has continually failed, due mostly to a scaling-up problem that creates a non-transfer problem (from group 1 participants to group 2 and 3 teachers), which in turn creates a political problem arising from ideological conflicts.

The majority of the research literature on teacher orientation to a humanistic science curriculum is comprised of small-scale studies necessarily comprised of a few volunteer science teachers to initiate or participate in the novel project, which did not have sufficient resources to expand in scale or over time (Anderson & Helms, 2001).

A second general conclusion can be drawn from earlier sections of this paper. Because a key ingredient to humanistic curriculum is relevance, and because relevance has different operational definitions from project to project, it is very difficult to compare research studies without oversimplifying their common attributes.

With these two broad limitations in mind, the research into science teachers’ orientation to a humanistic curriculum is reviewed in terms of (1) challenges to changing a traditional science curriculum into a humanistic one, (2) some teachers’ decision not to implement it, (3) some teachers’ success at implementation, (4) components to a teacher’s orientation, (5) pre-service experiences in teacher education, and (6) school politics. Each is explored in turn.

Challenges to Curriculum Change

Normally science teachers are attracted to, and uniformly socialized into, specific scientific disciplines in university programs where teachers are certified to be loyal gatekeepers and spokespersons for science; and in return they enjoy high professional status and a self-identity associated with the scientific community (Bartholomew et al., 2002; Cross, 1997; Cross & Ormiston-Smith, 1996; Cross & Price, 2002; Gallagher, 1998; Gaskell, 1992, 2003; Goodson, 1987; Roberts, 1988; Venville et al., 2002). As a consequence, teachers favour abstract decontextualized “pure science,” and marginalize student-centred perspectives and utilitarian issues related to everyday life; as occurred historically in the 19th century. At the same time, a teacher’s loyalty to the academic science community, and to its myths,
becomes well established and hence a teacher’s orientation to a traditional science curriculum is set (Abd-El-Khalick & BouJaoude, 1997; Aikenhead, 1984; Allchin, 2003; Davis, 2003; Duschl, 1988; Kilian-Schrum, 1996; Milne & Taylor, 1998; Nadeau & Désautels, 1984; Olson, 1997). This orientation includes the transmission of an established body of knowledge and technique that uses weak evidence and inductive overgeneralizations to persuade students of the correctness of a scientific worldview steeped in positivism and realism (Bartholomew et al., 2002; Osborne, Duschl & Fairbrother, 2003).

When STS was first proposed for school science, Gaskell (1982) clearly forewarned that a consensus among science teachers could not be achieved due to the deep-rooted values, ethics, and politics inherent in STS (humanistic) content, content that science teachers tend to assiduously avoid, for example: theory-laden observations, biased technical data, the epistemology and sociology of scientific knowledge, ethics-laden scientific questions, and politics-laden scientific communication. Gaskell (1982) and Gallagher (1987) also questioned the capability of science teachers steeped in empirical reductionist worldviews to engage competently with ethical, economic, and political issues in the classroom. Although research has by and large confirmed these predictions, it has afforded helpful insights into the complex world of science teaching.

A number of research studies (from surveys to case studies) have focused on teachers’ prerequisite knowledge related to teaching humanistic content (Abd-El-Khalick & Lederman, 2000; Cunningham, 1998; Cross & Price, 1996; Gallagher, 1991; Herron, Lamb & Morris, 2003; Lederman [review], 1992; Pedersen & Totten, 2001; Rampal, 1992; Rubba, 1989; Rubba & Harkness, 1993; Shapiro, 1996), especially when a humanistic perspective is first introduced into a country, such as in South Korea (Lee, Choi & Abd-El-Khalick, 2003) or Lebanon (Abd-El-Khalick & BouJaoude, 1997). The results generally showed inadequate and discrepant background understanding by teachers (with one exception; King, 1991). However, a prerequisite understanding may not necessarily be a determining influence on a teacher’s initial orientation to a humanistic perspective (Abd-El-Khalick, Bell & Lederman, 1998; Bartholomew et al., 2002; Tsai, 2001). At one extreme, some teachers gain an understanding only through implementing a humanistic perspective (Aikenhead, 2000b; Bencze & Hodson, 1999; Elmore, 2003; Fensham & Corrigan, 1994; Sáez & Carretero, 2002; Tal et al., 2001; Tsai, 2001). At the other extreme, some teachers maintain their traditional preconceptions (e.g. positivism or scientism) in spite of explicit instruction in the content, or in spite of teaching a humanistic perspective over a period of time (Gallagher, 1991; Herron et al., 2003; Hlady, 1992; Yerrick, Parke & Nugent, 1997). In short, a prerequisite understanding may or may not be a necessary influence, although by itself it is certainly an insufficient influence, on a teacher’s decision to implement a humanistic perspective.
More salient influences on a teacher’s humanistic orientation have been documented: a teacher’s values, assumptions, beliefs, ideologies, self-identities, self-images, and loyalties to traditional school science. All research unanimously and unambiguously confirms one result: changing any one of these salient influences is very difficult for most middle-of-the-road teachers, and is usually impossible for “the pipeline” enthusiast (Aikenhead, 1984, 2000b; Anderson & Helms, 2001; Briscoe, 1991; Cronin-Jones, 1991; Cross, 1997; Davis, 2003; Gallagher, 1991; Hart & Robottom, 1990; Herron et al., 2003; Lantz & Kass, 1987; Kortland, 2001; Lumpe, Haney & Czerniak, 1998; McRobbie & Tobin 1995; Millar & Hanes, 2003; Mitchener & Anderson, 1987; Mitschke, 1993; Osborne et al., 2003; Roberts, 1998; Sáez & Carretero, 2002; Tobin & McRobbie, 1996; Walberg, 1991; Yerrick et al., 1997). Taken together this cluster of salient influences has been referred to by some researchers as the culture of school science (Aikenhead, 2000a; Bianchini & Solomon, 2003; Brickhouse & Bodner, 1992; Lee et al., 2003; Medvitz, 1996; Munby, Cunningham & Lock, 2000; Osborne, 2003; Pedersen & Totten, 2001; Solomon, 1994e, 2002; Tobin & McRobbie, 1996; Venville et al., 2002; Vesilind & Jones, 1998), and consequently, implementing a humanistic science curriculum is judged by teachers to be either culturally safe or unsafe (McGinnis & Simmons, 1998). “These teachers are moulded by the culture and habitus of the culturally accepted practice of science teaching – an activity in which they have engaged, often for many years. Breaking that mould is, therefore, neither straightforward nor simple” (Osborne et al., 2003, p. 11).

Teachers often speak about their orientation to a humanistic science curriculum in terms of their comfort level. From their research, Barnett and Hodson (2001) concluded, “Knowledge that enables teachers to feel more comfortable in the classroom and to enhance their sense of self is likely to be embraced; knowledge that increases anxiety or makes teachers feel inadequate will almost certainly be resisted or rejected” (pp. 431-432).

Decisions Not to Implement

When asked if teaching from a humanistic perspective is a good idea (terms such as “socially relevant” are actually used), most science teachers (about 90%) overwhelmingly endorse it (Bybee, 1993; Hart, 1989; Lee et al., 2003; Pedersen & Totten, 2001; Rhoton, 1990; Rubba, 1989). Yet when asked about implementing such a curriculum, teachers provide many reasons for not doing so. A lack of available classroom materials is often mentioned; but as reviewed earlier, when teaching materials do become available, teachers point to other reasons for not implementing a humanistic perspective. These reasons are listed here but in no particular order of importance because their presence and priority change from study to study: unfamiliarity with student-centred, transactional, teaching and assessment methods (e.g. group work or divergent-thinking); greater than normal emphasis on oral and written language, and
the complexity caused by combining everyday and scientific genres; lack of confidence with integrated content; fear of losing control over the class (e.g. open-ended activities and unpredictable outcomes – teachable moments); uncertainty about a teacher’s role in the classroom (e.g. facilitator) in spite of attending in-service workshops; a reliance on a single national textbook that contains little or no humanistic content; an unease with handling controversial issues, or even group discussions of a social or ethical nature; uncertainties over assessing students on “subjective” content; inadequate background knowledge and experiences (i.e. pre-service teacher education programs); no opportunity to work with an experienced competent teacher or with scientists in industry; lack of school budget to support the innovation; lack of administrative or colleagues’ support; lack of parental or community support; no clear idea what the humanistic innovation means conceptually or operationally; predictions that students will not appreciate or enjoy philosophical, historical and policy issues in a science class (e.g. “students want to light Bunsen burners and get the right answer”); a preoccupation with preparing students for high-stake examinations and success at university; pressure from university science departments to raise standards and cover more content in greater depth; an unease over the reduced time devoted to canonical science content and to covering the traditional curriculum; pressure to comply with state content standards defined by the current reform movement; identifying oneself with scientists (i.e. lecturer expert) rather than with educators; the fact that non-elite and low achieving students enrol in humanistic science courses; greater need for cultural sensitivity with some humanistic topics such as social justice in the use of science and technology; the survival mode of beginning teachers discourages them from taking seriously humanistic ideas developed in their teacher education courses (Aikenhead, 1984, 1994a; Bencze et al., 2002; Bianchini, Johnston, Oram & Cavazos, 2003; Bybee [review], 1993; Bybee & Bonnstetter, 1987; Carlson, 1986; Cross & Price, 1996; Driver, Newton & Osborne, 2000; Eijkelhof, 1990, 1994; Eijkelhof & Kortland, 1988; Gallagher [review], 1987; Gaskell, 1992; Grady et al., 2002; Gray, 1999; Hofstein, Aikenhead & Riquarts, 1988; Hodson, 1993; James, 1985; King, 1991; Levinson, 2003; McClelland, 1998; McGinnis & Simmons, 1998; McGrath & Watts, 1996; Mitchener & Anderson, 1989; Monk & Osborne, 1997; Munby et al., 2000; Osborne et al., 2003; Pedersen & Totten, 2001; Pedretti, 1999; Russell, McPherson & Martin, 2001; Schwartz & Lederman, 2002; Shymansky & Kyle [review], 1988; Solomon, 2002; Rhoton, 1990; Roberts, 1988, 1998; Tsai, 2001; Walberg, 1991). One is faced with an inescapable conclusion: there are daunting challenges to educators wishing to change the traditional science curriculum into a humanistic one.

Even under circumstances supportive of teaching from a humanistic perspective, willing teachers will modulate a humanistic science textbook or other resources to conform to their specific epistemic and sociological beliefs and to their goals for teaching science (Aikenhead, 1984; Barnett & Hodson, 2001;
Carlone, 2003; Herron et al., 2003; Hlady, 1992; Ryder, Hind & Leach, 2003). Hlady documented how science teachers: (1) consciously omitted textbook passages that offered ideas at odds with the teachers’ understanding, (2) reinterpreted passages for their students in a way that changed the textbook’s meaning completely, or (3) personalized sections of the textbook in such a way as to change its intent, for instance, they presented an anecdotal lecture to avoid the decision-making perspective intended by the textbook.

A parallel but different avenue of research looked at willing science teachers (humanistic teachers) who possessed a contemporary understanding of humanistic content, but whose taught curriculum did not convey that content to students (Abd-El-Khalick et al., 1998; Brickhouse, 1989; Lederman, 1992; Munby & Russell, 1987). This research discrepancy challenged the notion that teachers who understand humanistic content will teach it, a notion that has sustained many in-service workshops since the 1960s. The discrepancy arose during research into factors affecting the acquisition of humanistic content by students (the learned curriculum; see section “Student Learning”). Abd-El-Khalick and colleagues (1998) listed constraints felt by instructors knowledgeable in humanistic content. Their list overlaps with the general list of reasons given by teachers not to implement a humanistic science curriculum. Their list includes: lower priority given to humanistic outcomes than to canonical science outcomes; preoccupation with classroom management weakened by student-centred instruction; teachers’ discomfort with their understanding humanistic content in spite of the evidence to the contrary; and lack of resources and time to locate resources. Other researchers discovered more pervasive influences inhibiting humanistic science teachers from practicing a humanistic perspective, influences such as the school’s social organization and the school culture (Carlone, 2003; McGinnis & Simmons, 1998; Medvitz, 1996; Munby & Russell, 1987). These influences can operate by simply overwhelming humanistic teachers’ best intentions to include a humanistic perspective in classroom practice – the taught curriculum. In a related study, Kleine (1997) conducted a detailed qualitative study into the inclusion of humanistic content in the taught curriculum of four science teachers with diverse university undergraduate degrees in history, philosophy, botany, and education. (Lower secondary science teachers in North America tend to have diverse backgrounds.) Under close scrutiny, Kleine could not detect any differences among the teachers’ humanistic taught curriculum, although she did note that the teachers’ humanistic understandings were often relegated to a secondary consideration in their decisions about what to teach. Perhaps the four teachers were overwhelmed by primary considerations (listed above). In short, teachers’ humanistic conceptual understanding does not necessarily influence classroom practice – the taught curriculum. To ameliorate this problem, Monk and Osborne (1997) proposed a pedagogical model that integrates humanistic content with teachers’ main aims for teaching science.
In terms of the research itself, interpretive (qualitative) studies tended to provide rich in-depth data situated in a particular context (e.g. Carlone, 2003; Herron et al., 2003; McGinnis & Simmons, 1998; Mitchener & Anderson, 1989; Pedretti & Hodson, 1995) that allowed the reader to consider complex relationships and subtle nuances and qualifications, features necessarily overlooked in quantitative studies. For example, Carlone (2003) presented evidence (discussed below) to explain paradoxes in her ethnographic study of a humanistic physics course, *Active Physics*, in a large high school; contractions such as, stakeholders celebrated its legitimacy as an innovation but curtailed its growth within the school. Explanations for these types of dynamics can emerge from research within a quantitative paradigm but such explanations are merely speculations for variance in data. However, the interpretive research projects were characterized by inconsistencies from study to study, likely due to the small number of participants (from 2 to 14) and their idiosyncrasies. Inconsistencies were also found among the quantitative studies, and therefore their generalizability was compromised, often because their sample selection was either narrow or non-random. Some quantitative studies purposefully selected a narrow sample in order to influence policy makers or administrators (e.g. within one particular educational jurisdiction), an instance of the politics of research, perhaps.

Success at Implementation

Successful implementation of humanistic science teaching has occurred under favourable circumstances. Success seemed to be associated with teaching grades 7 to 10 rather than higher grades, perhaps because teachers were not confronted as much with the litany of obstacles to implementation listed above. Action research studies have been consistently successful, perhaps because of their relatively high proportion of human resources for the participating teachers and their relatively high proportion of eager participants (humanistic science teachers). Research has identified the following favourable circumstances: involvement of teachers in policy and curriculum development; involvement of teachers in producing classroom materials; establishment of supportive networks of teachers that included teachers experienced with humanistic science teaching who take leadership roles; a predisposition toward exploring new avenues of pedagogy and student assessment; a willingness to deal with degrees of uncertainty in the classroom; a substantial in-service program offered over a long period of time, coordinated with pre-service methods courses and student teaching where possible; teacher reflection via diaries or journals and via discussion; a recognition of the rewards from becoming socially responsible in their community, from enhancing their curriculum development and writing skills, and from improving their vision of science teaching; a responsive and caring project staff to provide the top-down guidance for achieving a balance with grass-roots initiatives; contact with working scientists who convey intellectual,
moral, and political support; an openness to evidence-based decisions founded on formative assessment and classroom experiences; and a focus on individual, autonomous, professional development into becoming, for example, a continuous learner rather than a source of all knowledge (Anderson & Helms [review], 2001; Bartholomew et al., 2002; Blunck & Yager [review], 1996; Briscoe, 1991; Cho, 2002; Eijkelhof & Kapteijn, 2000; Fensham & Corrigan, 1994; Gray, 1999; Hart, 1989; Hart & Robottom, 1990; Keiny, 1993, 1996; Kilian-Schrum, 1996; Kortland, 2001; Leblanc, 1989; Ogborn, 2002; Osborne et al., 2003; Pedretti & Hodson, 1995; Roberts, 1988, 1998; Rubba & Harkness, 1993; Sáez & Carretero, 2002; Solomon, 1999a; Tal et al., 2001; Wang & Schmidt, 2001; Yager & Tamir [review], 1993).

Teachers in one study summarized their development and implementation achievements realistically and metaphorically: “Progress as a tension between a blessing and a curse” (Keiny, 1999, p. 347).

Some large scale research projects hold promise for supporting teachers’ attempts at transforming their science teaching into a humanistic perspective: the Iowa Chautauqua Program (Blunck & Yager, 1996; Yager & Tamir, 1993), replicated in South Korea (Cho, 2002) and in India (Banerjee, 1996); the “Science Education for Public Understanding Program,” SEPUP, in the US (SEPUP, 2003; Thier & Nagle, 1996); the UK “Public Understanding of Science” syllabus (Hunt & Millar, 2000; Millar, 2000; Osborne et al., 2003); the Dutch “Public Understanding of Science” curriculum (De Vos & Reiding, 1999; Eijkelhof & Kapteijn, 2000); and the Israeli “Science, Technology, Environment in Modern Society” curriculum (Dori & Tal, 2000; Tal et al., 2001). Individually these projects exemplify the many, empirically derived, favourable circumstances (listed above) that influence a teacher’s orientation to a humanistic perspective on school science.

By way of an example, one in-depth research study offered insight into features of middle-of-the-road teachers who composed and taught humanistic science lessons in spite of a lack of curriculum materials. Bartholomew and colleagues (2002) in the UK followed and supported 11 volunteer teachers whose background understanding was unknown but who were interested in implementing the UK national science curriculum’s “ideas about science,” specific ideas empirically derived from a large Delphi study (reviewed earlier in this paper). The researchers were interested in “what it means to integrate teaching about the nature of science, its practices and its processes, with the body of canonical content knowledge in a way which reinforces and adds to the teaching of both” (p. 11, emphasis in the original). The researchers identified 10 orientations within five “dimensions of practice” in order to characterize their less successful and more successful teachers (respectively):

1. Teachers’ knowledge and understanding of humanistic content – from “anxious about their understanding” to “confident that they have a sufficient understanding.”
2. Teachers’ conceptions of their own role – from “dispenser of knowledge” to “facilitator of learning.”
3. Teachers’ use of discourse – from “closed and authoritative” to “open and dialogic.”
4. Teachers’ conception of learning goals – from “limited to knowledge gains” to “includes the development of reasoning skills.”
5. The nature of classroom activities – from “student activities are contrived and inauthentic” to “activities are authentic and owned by students.”

These dimensions are not mutually independent, but they do help to detail teachers’ orientations to a humanistic perspective, more so than vague feelings of comfort or discomfort.

Small-scale studies have also provided the research community with fruitful methodologies or findings. Several studies are reviewed here. In a case study of two exemplary, humanistic, chemistry teachers, Garnett and Tobin (1989) discovered that in spite of their similar humanistic orientation, each used distinctly different teaching strategies – whole-group and individualized instruction. Working closely with 14 secondary teachers, Luft (2001) found their beliefs and practices related to student-centredness changed differentially depending on the experience of the teacher: neophyte science teachers “changed their beliefs more than their practices, whereas the experienced teachers demonstrated more change in their practices than their beliefs” (p. 517). Geddis’ (1991) case study of a teacher introducing controversial issues into his science class traces how the classroom discourse improved the more the teacher paid attention to (1) the ideology of the knowledge presented, (2) the ideology inherent in the teacher’s instruction, and (3) the intellectual context of that instruction. Briscoe’s (1991) case study of one teacher’s experience changing his beliefs, changing his metaphors that described his teaching role (his image or vision of teaching), and changing his classroom practices, shows that teachers “need time to reflect on their own practices, assign language to their actions, and construct new knowledge which is consistent with the role metaphors they use to make sense of changes in their practice” (p. 197).

On a larger scale, Kilian-Schrum (1996) investigated (through interviews, classroom visits, and a questionnaire) what 400 teachers were going through as they attempted to implement a provincial STS curriculum in Alberta, supported by authorized textbooks produced specifically for the curriculum. She concluded that one’s self-image as a science teacher and one’s loyalty to a scientific discipline both have to change before the teacher’s taught curriculum approximated the intended curriculum. To examine this confluence of the intended and taught curricula more closely, McClelland (1998) and Jeans (1998) videotaped lessons of a willing sub-sample of 12 of these Alberta teachers as they taught what they felt was a humanistic science lesson that integrated STS and canonical science content. (Edited versions were to be shown as model lessons at in-service workshops.) The videotapes were analyzed and each teacher was then interviewed about the lesson and about the researchers’ interpretations of the lesson. Unexpectedly McClelland (1998) found a greater diversity of teacher orientations toward humanistic
school science among the grades 10 to 12 teachers than among the grades 7 to 9 teachers. And by focusing on classroom events in the videotapes, Jeans (1998) was able to extend Briscoe’s (1991) research methods and identify each teacher’s image (or vision) of humanistic science teaching *in action*, as opposed to an image arising from interviews alone. Both McClelland (1998) and Jeans (1998) were aided in their analysis by two different clue structures: teacher practical knowledge (reviewed just below in “Components to a Teacher’s Orientation”) and an eight-category scheme devised by Aikenhead (1994d, 2000b) for describing both the importance afforded STS content in a curriculum and its infusion with canonical science content. The low-importance end of the continuum has three categories that do not alter the traditional scientist-centred structure of the curriculum: (1) a little STS content for motivational purposes only, (2) casual infusion of more STS content but with no coherent purpose, and (3) a purposeful infusion giving even more time to STS content. Category (4) continues to integrate the two types of content but in a *student-centred* fashion, though only within a single scientific discipline. A category (5) STS curriculum continues to integrate both types of content in a student-centred fashion, but it also integrates scientific disciplines as required by the humanistic context. The proportion and importance of STS content increases with ensuing categories until category (8), which most science teachers would view as social studies with a little canonical science thrown in. Jeans (1998) was able to locate teachers along this continuum (e.g. teachers were at categories 2, 3, 5 and 6) and compare their “images in action” with the intended curriculum’s image represented by category (4) in Aikenhead’s scheme. Jeans’ research included videotaped micro-teaches by pre-service science teachers (reviewed below in “Pre-Service Experiences”). The research studies empirically validate two conclusions: the phrase “successful implementation of a humanistic perspective” has many meanings for different teachers, and these meanings can be described by various schemes.

Mitchener and Anderson’s (1989) case study of 14 teachers implementing a humanistic science curriculum explained how decisions to accept, alter, or reject the new course were all made on the basis of the *same* set of concerns (five were identified: concerns over reduced canonical science content, discomfort with small group instruction, uncertainties over student assessment, frustrations with the non-academic type of student attracted to the new course, and confusion over the teacher’s role). The researchers could not distinguish between the accepting teachers and the rejecting teachers based solely on the teachers’ concerns, yet the teachers’ orientations (in this case, their “beliefs and values”) obviously differed.

And lastly, three different case studies of innovative teachers documented how the teachers coped with negative reactions from their colleagues, administrators, and parents, and how this affected the extent to which the teachers’ taught curriculum matched the intended humanistic curriculum (Aikenhead, 1983;
Carlone’s (2003) study reinforced earlier research findings that showed both positive and negative influences by students on their teacher’s decision to implement or to modify a humanistic perspective (Anderson & Helms, 2001; Hodson, 1994; Kapuscinski, 1982; Kilian-Schrum, 1996; McRobbie & Tobin, 1995). The researchers strongly recommended that innovators take into consideration students’ ideas, goals, and conventions when student roles are changed, for example, from passive to active roles, or from playing Fatima’s rules to engaging in critical thinking. Osborne and colleagues (2003, p. 19) pointed out a related key finding in their research into the UK syllabus Public Understanding of Science: “teaching a course which is enjoyed by students is…much more engaging and motivating for the science teacher.”

Components to a Teacher’s Orientation

To give clarity to the holistic complexity of life in a science classroom, researchers have attempted to articulate frameworks that encompass science teachers’ beliefs and values, and recognize contextual features of a teacher’s actions. These contextual features have included the social system of the school, as Stake and Easley (1978, p. 16.21) concluded, “What [science] teachers do with subject matter is determined by how it sustains and protects them in the social system [of the school]. Subject matter that did not fit these aims got rejected, neglected, or changed into ‘something that worked’.”

Life in a science classroom also features an individual teacher’s wealth of past experiences (e.g. as a member of a family, and as a university student) that shaped a teacher’s understanding and metaphorical images of science teaching, and that interact with the current features of school science (Aikenhead, 1984; Jeans, 1998; Kleine, 1997; Munby et al., 2000; Roberts, 1998; Russell & Munby, 1991). Tobin and McRobbie (1996), for instance, focused on teachers’ actions, determined by a teacher’s beliefs, behaviours, and the context of that action. Krull-Romanyslyn (1996) drew upon a large-scale STS in-service project in Alberta (170 teachers) to delineate a science teacher’s “functional paradigm” and upon the successful strategies that caused a shift in a teacher’s functional paradigm. Duffee and Aikenhead (1992) proposed a heuristic model for “teacher practical knowledge” (TPK) to explain the holistic complexity of classroom life by assuming behaviour results from decisions made consciously or unconsciously by teachers. These decisions are based on a teacher’s practical knowledge, comprised of many interacting sets of personal ideas, for instance, practical principles, rules of practice, values, and beliefs that integrate past experiences, such as teaching experiences, educational experiences, life experiences, and one’s personal background and worldview. These ideas interpret the current teaching situation (e.g. the intended curriculum, specific students in the classroom, physical classroom features, colleagues, administration, and community) before a decision for action is made (Brooks, 2000;
Clandinin, 1985; Clandinin & Connelly, 1996; David, 2003; Hlady, 1992; Mitschke, 1992). All these considerations are filtered through a teacher’s vision or image of how teaching should be, before a final decision for action is taken. Most decisions reflect this image (Briscoe, 1991; Hand & Tregast, 1997; Russell & Munby, 1991). TPK emphasizes the individual teacher as decision maker influenced by a myriad of practical considerations. Barnett and Hodson (2001, p. 433) have expanded TPK into “the work culture of teachers, derived from their roles as institutional, social, and political actors.” These researchers coined the phrase “teacher context knowledge” (TCK) to draw attention to “what good teachers know, do, and feel is largely about teaching and is situated in the minutiae of everyday classroom life” (p. 436). TCK emphasizes the institutional, social, and political influences on teacher behaviour.

By identifying the complexities inherent in a teacher’s orientation, heuristics such as TPK and TCK (both empirically derived from research) compel science educational researchers to consider a much deeper analysis of teachers’ orientations toward changing the traditional science curriculum into a humanistic one, a change for most teachers as painful and personally challenging as a Kuhnian paradigm shift is for most scientists (Mitroff, 1974). If a middle-of-the-road teacher is to successfully negotiate a humanistic orientation to science teaching, there are many personal deep-seated traits, values, beliefs, and conventions, that must change. To quote a teacher in Roberts’ (1998) Science Teachers Thinking study, “We had to learn a whole new way of teaching.” For a “pipeline” enthusiast to change, however, it could involve, in some cases, changing a person’s worldview or personality. And all of this must take place within a supportive school and community (Aikenhead, 2000a; Carlone, 2003; Elmore, 2003; Ryder et al., 2003).

In retrospect, it seems sensible that many studies into the implementation of a humanistic science curriculum selected humanistic science teachers in order to establish that such a curriculum can be implemented. It was only when the research realistically involved middle-of-the-road teachers and “pipeline” enthusiasts did problems arise that forced researchers to produce richer data, analyzed in greater depth. One simple solution to the problem of implementing a humanistic science curriculum seems obvious: produce many humanistic teachers in pre-service teacher education programs (Brickhouse, 1989; Koulaidis & Ogborn, 1989; Rowell & Cawthron, 1982; Wang & Schmidt, 2001). Researchers have explored that avenue.

Pre-Service Experiences

As with in-service studies, researchers of pre-service science teachers’ orientation to a humanistic perspective first focused on documenting students’ understanding. While many students expressed naïve and simplistic ideas (Cunningham, 1998; Nieswandt & Bellomo, 2003; Stuart & Thurlow, 2000; Tsai,
2001), and while some students expressed more contemporary and complex ideas (students with strong academic backgrounds in the history, philosophy, and sociology of science, and those with scientific experience in industry and government labs), evidence showed that this understanding did make a noticeable difference in practical teaching settings generally supportive of such innovations (Bianchini et al., 2003; Cunningham, 1998; David, 2003; King, 1991; Nieswandt & Bellomo, 2003; Schwartz & Lederman, 2002). One exception is Jeans’ (1998) analysis of 35 videotaped STS micro-teach lessons (described above) that clearly showed his pre-service teachers were not appreciably including their humanistic ideas in their lessons (i.e. they were in the bottom two categories of infusion of STS content with canonical science content, that is, STS content for motivation only, and casual infusion; described above). Jeans concluded that these pre-service teachers mimicked the pure content orientation of their recent university science classes and succumbed to peer pressure to demonstrate subject matter expertise. David (2003) and Schwartz and Lederman (2002) discovered a different reason to explain the reluctance of pre-service teachers to include humanistic content in their lessons: novice teachers naturally lack confidence in teaching canonical science content, and until a reasonable confidence can be attained, other instructional outcomes are relegated to a low priority. Background knowledge of humanistic content seems to exert an influence in some pre-service settings, but not in all; especially when pre-service teacher apprentices are placed in an unsupportive school setting (Abd-El-Khalick et al., 1998).

Researchers have assessed university courses that purport to transmit a contemporary understanding of humanistic content to pre-service science teachers. Their disappointing results show that some university students do not easily reconstruct naïve and simplistic preconceptions into contemporary conceptions (Abd-El-Khalick & Lederman, 2000; Cunningham, 1998; Gallagher, 1991; James, 1985; Lederman, 1992), likely because those preconceptions are anchored in personal beliefs, values, ideologies, identities, allegiances, and goals. The university transmission model is not very effective in this context (Bencze & Hodson, 1999; Rubba & Harkness, 1993; Solomon, 1999a). Changing personal deep-seated ideas about humanistic content related to science often requires much more than a methods course; it takes a whole university (Abd-El-Khalick & BouJaoude, 1997; Cunningham, 1998; Nieswandt & Bellomo, 2003).

Transactional and transformational approaches to pre-service humanistic science content have been researched. These approaches are usually experiential, reflective, collaborative, and critical (Bencze & Hodson, 1999; Bianchini & Solomon, 2003; Solomon, 1999a). They address aspects of teacher development (professional, social, and personal; Bell, 1998) embraced by teacher practical knowledge (TPK) and teacher context knowledge (TCK). Evidence supports the greater success of transactional and transformation approaches over transmission approaches. For instance, Lin’s (1998) research into training
pre-service teachers on how to develop and teach chemistry through the history of science provides both quantitative and qualitative data. Modest gains on quantitative measures were interpreted through interview data to support the conclusion that when students understand the history of science, they tend to use that knowledge, rather than their intuition (preconceptions), to discuss humanistic content in science class.

Still, the most influential pre-service experience from the point of view of a practicing teacher is invariably student teaching or internship in which a novice pre-service teacher apprentices with an experienced teacher (Brickhouse & Bodner, 1992; Roberts & Chastko, 1990; Richardson-Koehler, 1988; Russell et al., 2001). Only when pre-service teachers are placed in humanistic-supportive apprenticeships can their humanistic perspective develop further (Bianchini & Solomon, 2003; Nieswandt & Bellomo, 2003; Tsai, 2001), otherwise “pipeline” enthusiasts and similarly committed middle-of-the-road teachers direct their apprentices to forget the ivory tower humanistic perspectives on school science presented in their pre-service courses (Abd-El-Khalick et al., 1998; Barnett & Hodson, 2001; Broadfoot, 1992; Munby et al., 2000; Russell et al., 2001). And the vicious cycle reproduces the status quo; another political reality.

School Politics

In the review of research into formulating an intended humanistic curriculum (the section “Curriculum Policy” above), political dynamics were a critical force, as explained, for instance, by actor-network theory (Gaskell & Hepburn, 1998). In research related to the taught curriculum reviewed here, tension continues between educationally sound arguments for a humanistic perspective in a teacher’s orientation to school science, on the one hand, and the political reality of institutional expectations, rituals, customs, ceremonies, beliefs, and loyalties favouring the status quo, on the other.

The in-service and pre-service humanistic science projects (reviewed above) largely failed to achieve the radical changes in school science envisioned by their project leaders. When analyzing these failures, many researchers chose not to address explicitly the power of political reality but instead focused on non-politicized, practical, epistemological, and academic theory-building matters, that is, educationally sound arguments (e.g. Anderson & Helms’ [2001] thoughtful review of Standards). Other researchers, however, have placed political reality explicitly on their agenda because the enactment of an intended humanistic science curriculum into a taught curriculum takes place not only with individual teachers and their unique orientations to humanistic school science, it takes place within a political arena of students, colleagues, administrators, the school culture, and the immediate and extended community (Aikenhead, 2000a; Bianchini & Solomon, 2003; Carlone, 2003; Fensham, 1992; Gaskell, 1989, 2003; Pedretti &
Hodson, 1995; Medvitz, 1996; Roberts, 1988). This political arena has been researched explicitly at the school level.

Humanistic science is integrative by nature and Venville et al.’s (2002) review of curriculum integration sheds light on school politics in which status is a principal factor (Goodson, 1987). Status in most school cultures is high for courses that are (1) rigid in their course content, (2) highly differentiated and insulated from other subjects, and (3) academically and idealistically objective. On the other hand, status is low for courses that are: (1) flexible in their content to achieve relevance and timeliness, (2) amenable to overlap with other subjects, and (3) utilitarian, relevant, and subjective. Status is animated by the language used within a school, for example, “hard” and “soft” sciences. Clearly, humanistic science courses currently fall in the low status category, and this directly affects who teaches them (Carlone, 2003; Gaskell, 1989), which in turn sustains their low status. For example, teachers with a general science background who normally taught home economics and technology courses were recruited to teach the humanistic “Science & Technology 11” course in British Columbia, largely because many regular high school science teachers refused to take it on. Consequently, a low status was quickly conferred on this innovative curriculum in many schools, in spite of the endorsement it received from the provincial Ministry of Education, from David Suzuki (a renowned television scientist), and from the Science Council of Canada; all high status agencies (Gaskell, 1989).

Roberts’ (1988) research into the politics of the science curriculum recognized the roles of status and loyalty within school politics.

If one wants to promote science teacher loyalty to a science curriculum proposal: guarantee the status of the content by enshrining it in an acceptable, recognized examination, and secure the support of the subject community. Otherwise the spectre is ever present, for the teachers, that the proposal’s academic status will degenerate to utilitarian and pedagogic [student-centred] limbo. … [Loyalty] is quite a different matter from the need for in-service education to ensure that the teachers understand a new proposal. (p. 48, emphasis in the original)

Teacher loyalty forms a bridge between teacher orientation and school politics.

In the US, Carlone (2003) conducted a highly informative, ethnographic case study of this bridge, showing specific tensions between support for, and constraints on, a humanistic physics course, Active Physics (Eisenkraft, 1998). The study took place in a large upper-middle class high school proud of its graduates’ post-secondary enrolment figures, proud of its five different grade 11 and 12 physics courses each with multiple sections, and proud that 50% of its students enrolled in first-year physics. Active Physics, one of three first-year physics courses (grade 11), had six sections, compared to 37 sections of regular physics offered at this school. Backed by the status of both the American Association of Physics
Teachers and the American Institute of Physics, *Active Physics* is a reform-based curriculum that contextualizes physics content in social issues, technology-centred lab activities (tool use), and everyday events (i.e. a combination of “functional,” “personal curiosity,” “need-to-know,” and “wish-they-knew” science). Instruction emphasized a social constructivist view on learning. The course’s two, humanistic, well credentialed, physics teachers (Ms. Carpenter and Mr. Stewart, a minority among nine other physics teachers) had initiated the course and had taught it four years, successfully preparing students for grade 12 advanced placement physics. By Roberts’ (1988) standards, the course met the conditions for being enshrined as acceptable in this school.

Not only does Carlone’s case study concretely and holistically illustrate research findings concerning teachers’ decisions to implement or not to implement (reviewed above), it clarifies how status is dynamically played out in this school’s politics. For example, “Ms. Carpenter said that she thought she had a large role in maintaining the survival of *Active Physics* because she was more ‘political’ than Mr. Stewart. She did more of the public relations work with *Active Physics* in that she spent more time trying to convince others of its legitimacy” (p. 322). “Interestingly, this demonstration of legitimacy was enough to ensure the survival of *Active Physics*, but not enough to ensure its growth and Mr. Stewart and Ms. Carpenter’s prestige within the department” (p. 326). Many reasons accounted for this, but only a few are summarized here. Neither teacher had political access to the many students in regular physics classes who seemed to garner personal status as academic students by pejoratively calling *Active Physics* “blow up” (i.e. easy) physics. The teachers of regular physics protected their own superior position in the school hierarchy of status (Cross & Ormiston-smith, 1996) in a variety of ways: by rationalizing (e.g. we must protect the sanctity of physics), by belittling (e.g. *Active Physics* is really grade 9 science), and by marginalizing (e.g. the professional interaction between *Active Physics* teachers and the other teachers was restricted). Although the administration proudly provided substantial financing to implement this tool-centred course, it restricted the number of sections offered and thus, it did not allow the course to expand. Nor did the administration provide sufficient political support to ameliorate the isolation between the innovators and the other physics teachers. Perhaps the administrators were simply balancing the politics of the school in two ways: (1) wanting to look innovative to the public by offering a radically different physics course, but at the same time, maintaining an aura of academic (traditional) excellence by ensuring most students took regular physics; and (2) balancing teachers’ loyalties within the school: loyalty to the radically new course and to the status quo course. Carlone (2003) pointed out, however, that this isolation provided Mr. Stewart and Ms. Carpenter “the freedom to enact their visions of good science education without having to coordinate their curriculum’s content and methods with other teachers who may have had different ideologies” (pp. 325-326). Of the 11 physics teachers at the school, two were
humanistic teachers, some were “pipeline” enthusiasts, and some were likely middle-of-the-road teachers who chose to side with their status quo colleagues.

Carlone’s case study details the daunting challenges and political limitations facing educators wishing to change the traditional science curriculum into a humanistic one, but it joins with others (e.g. Aikenhead, 2000a; Gaskell, 2003; Elmore, 2003; Medvitz, 1996; Osborne et al., 2003; Roberts, 1988) when it concludes that the powerful 19th century legacy of school science can be challenged successfully on a small scale, but challengers must renegotiate the culture of school science and some social structures of privilege and power along the way. Ms. Carpenter and Mr. Stewart became politicized at the school level, but that was not sufficient to ensure “the virus” of innovation (Elmore, 2003) would infect the whole system of the school. Yet, they simply did not have the time and energy to become politicized at the regional or nation level, as Pedretti and Hodson (1995) proposed teachers do.

Conclusion

The challenge of change within a classroom is one issue. The challenge of a large-scale implementation of humanistic school science requires an actor-network larger than two teachers. Political reality dictates that an expanded actor-network would need to be formed in concert with socially powerful groups, for example, a school system administration that embraces a concern for accountability (Elmore, 2002), or a much more pervasive group such as local or national industries and corporations (Dori & Tal, 2000; Gaskell, 2003). The challenge to enact a humanistic science curriculum at the school level comes down to an issue of scale (moderate or ambitious), of resources to engage in the appropriate politics of change (altering the curriculum’s status perceived by stakeholders, altering teachers’ loyalties, and altering the assessment system), of finances and infrastructure (to support teachers and students), and of the availability of science teachers who already have, or will develop, an orientation to such a curriculum. These local issues must be placed in the broader context of curriculum policy development (reviewed above) and placed on the political agenda to renegotiate the concept of status itself in school culture.

Teacher orientation is a dynamic entity that interacts with, and on occasion is modified to varying degrees by, the politics of change and the many elements important to teacher development (Aikenhead, 2000b; Bencze & Hodson, 1999; Elmore, 2003; Fensham & Corrigan, 1994; Sáez & Carretero, 2002; Tal et al., 2001; Tsai, 2001). One key dynamic is the impact the taught curriculum has on students’ learning, a topic to which we now turn.
Student Learning

The learned curriculum, planned or unplanned, is given high priority in arguments concerning educational soundness. As is evident throughout this review, a humanistic science curriculum has various interrelated expectations or outcomes, summarized here: (1) to make the human aspects of science more accessible and relevant to students (e.g. its sociology, philosophy, and history, as well as its interrelationships with society); (2) to help students become better critical thinkers, creative problem solvers, and especially better decision makers, in a science-related everyday context; (3) to increase students’ capability to communicate with the scientific community or its spokespersons (i.e. listen, read, respond, etc.) in order to feel more at home in one’s culture, among other reasons; (4) to augment students’ commitment to social responsibility; and (5) to generate interest in, and therefore, increase achievement in learning canonical science found in the traditional curriculum. (Purposefully missing from this list of outcomes are lofty and non-assessable aims such as an empowered citizenry, an enlightened democracy, and wise and responsible decision makers.) Researchers engaged in summative assessment of humanistic science modules and courses have operationalized and prioritized the above five common outcomes differently. This makes comparisons among studies somewhat tenuous but renders the instruction relevant to most students. One must live with this paradox because there is no such thing as a standard, yet contextualized, humanistic science curriculum.

In the world of political reality (a world that accepts playing Fatima’s rules as legitimate learning), the learned humanistic curriculum would be of interest to stakeholders only if there were a negative assessment of canonical content acquisition for students enrolled in a humanistic science course. However, when this assessment is shown to be equal or sometimes greater than the achievement in traditional science courses (as is the case, reviewed above in “Curriculum Policy”), student learning disappears from the agenda, to be replaced by other concerns with humanistic school science, such as the need to retrain science teachers, the lack of widespread implementation, and an inability to sustain special support (Walberg, 1991). Consequently, we can expect research on student learning to be of interest only to curriculum policy makers and science teachers whose orientations are amenable to humanistic school science. This narrow expectation concerning the importance of student learning is a political reality.

Research into the learned humanistic science curriculum is reviewed in the following sequence: canonical science content acquired in humanistic science courses, evidence gathering techniques for assessing humanistic content, summative assessment in quasi-experimental studies, other investigations in humanistic science education, and student decision making.
As stated in expectation number 5 (above), researchers anticipated significantly increased achievement in canonical science acquisition by students in a humanistic science course (e.g. Aikenhead, 1980; Eijkelhof & Kortland, 1988; Eylon & Linn, 1988; Häussler & Hoffmann, 2000; Walberg & Ahlgren, 1973; Yager, 1983), yet these high expectations rarely materialized (e.g. Eijkelhof & Lijnse, 1988; Irwin, 2000; Kortland, 2001; Wiesenmayer & Rubba, 1990; Welch, 1973). This ubiquitous research finding supports the conclusion that most students encounter extreme difficulty when they attempt to learn canonical science meaningfully at school, no matter how relevant the humanistic context (Aikenhead, 1996; Eijkelhof, 1990; Hennessy, 1983; Lijnse, 1990; Osborne et al., 2003; Solomon, 1983). This finding was explained by Solomon (1987, 1988b) when she clarified how a relevant social context (in which the canonical content is embedded) provokes affective and value-laden connections in students’ minds, thereby making the situation far more complex to think through, especially for less able students. Research into student learning when engaged in socio-scientific decision making (reviewed below) collaborates and articulates Solomon’s claim. More recently, researchers have drawn upon cultural anthropology to describe this complexity further in terms of differing worldviews (Cobern, 1996) or in terms of students feeling as if they are in a foreign culture that does not engage their self-identities (Aikenhead, 1996; Aikenhead, 2000a; Aikenhead & Jegede, 1999). Moreover, as reviewed above in “Curriculum Policy”, canonical science content is most often not directly useable in everyday situations. Another paradox presents itself: the greater the social or cultural relevance associated with canonical content, the greater the student motivation but the greater the complexity to learn it meaningful.

These two factors (motivation and complexity) may cancel each other out yielding null results in achievement, that is, equal achievement in learning canonical science between students enrolled in humanistic science courses and students in traditional scientific courses (Aikenhead [review], 1994b; Banerjee, 1996; Blunck & Yager [review], 1996; Bybee [review], 1993; Cho, 2002; Eijkelhof & Lijnse, 1988; Galili & Hazan, 2001; Irwin, 2000; Kelly, 1981; Klopfer & Cooley, 1963; Pederson, 1992; Wiesenmayer & Rubba, 1990; Welch, 1973). Motivation can overcome complexity occasionally and lead to greater achievement favouring students enrolled in humanistic science courses (Blunck & Yager [review], 1996; Häussler & Hoffmann, 2000; Mbajiorgu & Ali, 2002; Meyers, 1992; Poedjiadi, 1996; Rubba & Wiesenmayer, 1991; Solomon et al., 1992, 1996; Sutman & Bruce, 1992; Wang & Schmidt, 2001; Winther & Volk, 1994). Other research (reviewed above in “Curriculum Policy”) suggested that only when personal action is at stake (i.e. very high motivation) do most students or citizens work through the complexity to learn enough content to take action; but then the content learned meaningfully is not...
likely to be the “pure” science found in the traditional curriculum (Jenkins, 1992; 2002; Lawrence & Eisenhart, 2002; Layton, 1991).

In short, humanistic science curriculum developers take on an extremely high, and likely inappropriate, standard of excellence in learning canonical science when they expect meaningful learning to occur and when they embed that learning in relevant everyday contexts.

Evidence Gathering Techniques for Humanistic Content

Over the past 50 years, the evidence gathering techniques for assessing student learning in the domain of humanistic conceptual content (expectation number 1, above) have developed dramatically, from a quantitative paradigm (Aikenhead [review], 1973; Cheek, 1992; Lederman [review], 1992), to an interpretive (qualitative) paradigm (Aikenhead, 1979, 1988; Aikenhead, Fleming & Ryan, 1987; Aikenhead & Ryan, 1992; Driver et al., 1996; Lederman, Abd-El-Khalick, Bell & Schwartz, 2002; Wade, Lederman & Bell, 1997), and to a situated-cognition approach within the interpretive paradigm (Gaskell, 1994; Solomon, 1992; Welzel & Roth, 1998). The target content of each instrument or protocol varies greatly from study to study. Content associated with the philosophy of science (i.e. epistemology, ontology, and some axiology) became known as the “nature of science” (Lederman, 1992) while content associated with various sociologies of science and societal contexts of science and scientists has had many labels, such as the social aspects of science. Some researchers have expanded the category “nature of science” to include some social aspects of science (e.g. Knain, 1997; Lederman et al., 2002; McComas & Olson, 1997; Millar & Osborne, 1998). All of these categories are embraced as humanistic content in this review of research.

More importantly, consensus has not been reached on what ideas represent the most acceptable or defensible views, that is, what content is “correct” (e.g. Alters, 1997; Smith et al., 1997). Contested areas of scholarship remain, for instance, the realism-constructivism debate, or the cultural nature of Western science. The central issues here for researchers are validity and trustworthiness.

Moreover, many individual research studies have narrowly focused on only three or four humanistic ideas (due to time and resource limitations) and these ideas varied from study to study. Consequently, a plethora of instruments and protocols have been published over the years, representing the full range of contested humanistic content. These instruments are not reviewed here (see, for example, Abd-El-Khalick & Lederman, 2000; Aikenhead, 1973; Lederman, in press; Wade, Lederman & Bell, 1997), but their diversity is noted to draw attention to the potential problem of inconsistency among research studies using different evidence gathering techniques.
Researchers working within the quantitative paradigm claim to have measured students’ attainment of humanistic ideas and have sorted students into philosophical categories or into dichotomies of achievement (e.g. literate and illiterate). This paradigm is characterized by the judgment of students based on external criteria, such as a panel of experts or theoretical positions accepted by scholarly academic communities. These quantitative instruments generally suffer: (1) an ambiguity problem arising from researchers erroneously assuming that their meaning ascribed to a statement is exactly the meaning read into the statement by students (Aikenhead, 1988; Aikenhead et al., 1987); (2) a validity problem caused by the “correct” responses varying as the developer’s viewpoint (Lederman et al., 1998); or because when a panel of experts decides what is correct, there is often a problem with a panel selection bias and a low inter-judge reliability (Manassero-Mas, Vázquez-Alonso & Acevedo-Díaz, 2001; Rubba et al., 1996; Vázquez-Alonso & Manassero-Mas, 1999); or because in some cases, the validity and reliability of instruments have not been substantiated adequately; and (3) an ambiguity problem arising from the narrow scope of outcomes assessed by pencil and paper, multiple-choice type instruments, outcomes that fail to capture the rich and diverse array of anticipated outcomes for humanistic science courses (Cheek, 1992), for example, those outcomes stated in expectation numbers 1 to 4, above.

Researchers working within the interpretive (qualitative) paradigm for their summative assessment are primarily interested in clarifying and understanding a student’s view and conveying it to others. To accomplish this task, a variety of protocols have been developed (Aikenhead et al., 1987; Aikenhead & Ryan, 1992; Driver et al., 1996; Leach et al., 1997; Lederman, in press; Lederman & O’Malley, 1990; Lederman et al., 2002; Solomon, 1992; Solomon et al., 1994). The varied characteristics of these protocols are captured in the following three points:

1. Interviews (semi-structured to non-structured), versus written responses (open-ended to convergent, i.e. using pre-established responses).

2. General questions posed without a context provided (e.g. Do scientists’ personal values ever affect the research results they obtain?), versus contextualized questions embedded in clearly described situations or in a particular task undertaken by students (e.g. learning about a particular scientific controversy, such as the dispute surrounding Wegener’s continental drift hypothesis, and then discussing specific focus questions in small groups).

3. Questions that make the humanistic content explicit for students such that students knowingly discuss the explicit content, versus questions that leave the humanistic content implicit but is inferred by researchers who analyze student responses.

Two further characteristics of interpretive protocols in general should be added to this list and are stated here as dichotomies for the sake of clarity:
4. Students’ personal knowledge about school science, versus students’ declarative knowledge about science and scientists in their authentic workplaces (Gaskell, 1992; Hogan, 2000; Larochelle & Désautels, 1991; Leach et al., 1997; Solomon et al., 1994).

5. Knowledge understood by students well enough to articulate in an interview, versus knowledge understood and believed strongly enough by students to be guided by it implicitly as they participate in a discussion or simulation (Dahncke, 1996; Driver et al., 1996; Gaskell, 1994; Solomon, 1992, 1994d; Welzel & Roth, 1998).

Research studies have often used various combinations of these protocol characteristics to augment the trustworthiness of their data. In addition, several studies have combined the quantitative and interpretive paradigms to achieve a balance of evidence gathering techniques to answer different sorts of research questions; often interviewing a small sample of students after a large sample of students has responded to a questionnaire, in order to reduce the inherent ambiguity in the survey data; but sometimes first interviewing participants and then constructing a survey to determine the extent to which the participants’ views are shared by a larger sample of students.

The fifth characteristic of interpretive protocols (stated directly above) introduces a situated-cognition (ethnographic) approach, still within the interpretive paradigm. Based on their empirical evidence, Welzel and Roth (1998) questioned the assumption that interviews capture students’ conceptual ideas accurately. Three points were argued: interviews themselves are contrived because they are not situated in the context of action; Welzel and Roth’s data suggested that students’ humanistic concepts are not highly stable from context to context, contrary to what science educator’s had assumed; and ambiguity can plague interviews, too (estimated at 5% by Aikenhead [1988]). Thus, to understand what students have learned, researchers need to listen to student conversations, note the actions of students as they engage in a meaningful task, or interview them about that specific task. (This research technique is similar to analyzing videotapes of teachers in action, rather than interviewing teachers about their recalled actions, reviewed above in “Teacher Orientation.”)

Sutherland (2003) illustrated Welzel and Roth’s recommendation when she had First Nations students discuss critical incidents, from which she interpreted humanistic ideas about science held by the students, over a number of different contexts represented in her different critical incidents. Sutherland searched for consistency among contexts, unlike Leach et al. (1997) who found in their UK students a tendency to treat each context as a separate case, causing inconsistencies to arise in students’ responses, inconsistencies that, according to Leach and his colleagues, reflected the multifaceted domain of science. Bell and Lederman (2003) found critical incidents to enhance their evidence gathering techniques in their inquiry into the way university scientists came to a decision on science-related social issues.
Ethnographic techniques for gathering evidence typically include students being observed during a school science activity and their words and actions interpreted by researchers as manifesting certain humanistic concepts about science. Leach and colleagues (1997) critiqued this technique as having a school science context, and therefore concluded that observers may be detecting sophisticated versions of Fatima’s rules, rather than humanistic concepts guiding practice. Solomon (1992) addressed these problems when she showed students actual TV clips of science-based controversial topics (e.g. kidney donation) and had students engage in free discussion in small groups. These discussions were subsequently analyzed. Gaskell (1994) modified Solomon’s evidence gathering technique into two stages: first, a socio-scientific issue (e.g. sun-tan parlours) was presented to students as a TV clip or as a newspaper article; and secondly, a related story personalized the issue for them. Students were interviewed on two occasions, once after the first presentation, and again after the personal story. During the second interview, Gaskell challenged students’ original key ideas to determine how strongly students held them and what other ideas supported their original key idea: “It is in the dynamics of coping with challenges to their points of view that students articulate the array of elements that they associated with an issue and also the strengths and weaknesses of the links between the various elements or points” (p. 312). 

Gaskell’s and Solomon’s protocols yield trustworthy data and high transferability to everyday events outside of school, and they afford insight into citizens making a decision on a socio-scientific issue (a principal component to a humanistic science curriculum, reviewed below). On the other hand, the protocols are labour intensive and limited to a few issues found in the mass media.

There is no one best technique or instrument for gathering evidence, each has advantages and limitations. In the interpretive paradigm of research, for example, one of the most comprehensive protocols, Views on Science-Technology-Society, VOSTS (Aikenhead, Fleming & Ryan, 1989) catalogued humanistic content found in contemporary literature and transposed it into 114 novel multiple-choice items developed collaboratively with students (Aikenhead & Ryan, 1992). Each item contextualized an issue about which students were asked to express a view, plus their reason for holding that view. The development process itself established the instrument’s trustworthiness, while its test-retest reliability was independently demonstrated (Botton & Brown, 1998). Although VOSTS was developed within the interpretive paradigm of research, marking schemes have been constructed for studies in the quantitative paradigm (Manassero-Mas, Vázquez-Alonso & Acevedo-Díaz, 2001; Rubba, Schoneweg-Bradford & Harkness, 1996; Vázquez-Alonso & Manassero-Mas, 1999). But VOSTS is limited in at least three specific ways: students typically can only respond to about 15 to 20 items in one sitting, thus, choices must be made; VOSTS does not provide the flexibility to probe students’ responses as interviews do, thus, student responses are constricted; and, similar to a humanistic perspective itself, VOSTS is not
universal, therefore when it is used in settings culturally different than Anglo Canada, researchers must empirically modify and validate the items for use in that culture (e.g. in Québec – Aikenhead, Ryan & Désautels, 1989; in Portugal – Nunes, 1996; in Spain – Manassero-Mas & Vázquez-Alonso, 1998; in the United Arab Emirates – Haidar & Nageeb, 1999; in Taiwan – Lin (1998); and in Nigeria – Mbajiorgu & Ali, 2002), otherwise problems arise (e.g. in Lebanon – Abd-El-Khalick & BouJaoude, 1997).

Lederman and his colleagues (2002) designed the Views of Nature of Science (VNOS) purposefully avoiding the response constrictions of VOSTS. VNOS-form C is a 10-item, open-ended questionnaire, of which most items are decontextualized. Part of the protocol for using NVOS-form C is a follow-up interview schedule to investigate students’ views further, for instance, to discover how students spontaneously contextualized the items as students responded to them. Similarly, Driver and her research colleagues (1996) avoided the constrictions of VOSTS and developed a complex protocol (Images of Science Probes) that engaged students in a double task: a class presentation introduced students to, for instance, a science-related dispute (e.g. the safety of irradiated food), and was followed by a small-group discussion of some key questions about the dispute. Researchers then conducted semi-structured contextualized interviews with pairs of students to focus on general humanistic concepts related to (depending on which of the six research probes were used): science as a social enterprise (three key concepts), the nature or status of scientific knowledge (five key concepts), and the purposes of scientific work (one key concept). Six probes allowed researchers to check for consistency of students’ key concepts from one context to another. The research team inductively developed interpretive girds to help future researchers interpret students’ interview responses. Both the VNOS-form C (Lederman et al., 2002) and the Images of Science Probes (Driver et al., 1996) provide flexible techniques for gathering evidence in depth, even though the approach is labour intensive and the breadth of topics is necessarily restricted to a few key humanistic concepts. However, given the marginalized status of a humanistic perspective in the intended and taught curricula in most schools today, this restriction may not be a liability at the present time.

The evidence gathering techniques reviewed above relate to conceptual understanding of humanistic content (expectation number 1). Other outcomes have undergone assessment using: standardized tests of knowledge about scientific processes, attitudes toward science, and creativity and problem solving in science contexts (Yager & Tamir [review], 1993; Zoller, 1990); and novel methods more tailored to the particular instructional setting, for instance: assessment embedded in the instruction using everyday events (Thier & Nagle, 1994, 1996); assessment of students’ ability to pose questions and engage in higher-order thinking (Zoller, 1994a, 1994b); formal case study assessment of student attitudes (Dori & Tal, 2000); participant-observation and interviewing (Urevbu, 1994); formal compilation of
relevant student actions within the parameters of computer simulations (Dahncke, 1996) or outside of school in the real world (Dori & Tal, 2000; Jiménez-Aleizandre & Pereiro-Muñoz, 2002; Rubba & Wiesenmayer, 1991, 1999); formal interviews with students (Tsai, 2000); interviews along with a repertory grid (Shapiro, 1996); simple straight-forward questionnaires developed by the researcher (e.g. Solbes & Viches, 1997); and informal assessment via interviews with students and parents (Dori & Tal, 2000).

Summative Assessment in Quasi-Experimental Studies

Researchers invariably design summative assessment studies by crafting educationally defensible research questions, while at the same time, considering the political context of their work (Welch, 1979). Given that humanistic perspectives are generally ignored or marginalized by traditional school science, researchers who embrace a humanistic ideology will design their summative assessments to demonstrate the advantages of their innovation over the status quo, and thereby attempt to sway policy makers and science teachers oriented to “the pipeline” ideology. Because the implicit target audience of this research tends to emulate experimental methods, a strong argument for humanistic science education must be based on quantitative evidence derived from quasi-experimental research designs. This was particularly true of studies prior to 1990, but since then, emphasis in the research literature has clearly shifted to qualitative studies. Perhaps the research community heeded Welch’s (1969) warning about the pitfalls of overly simplistic “horse race” evaluation studies (experimental versus control groups) and became more concerned with understanding what was going on in humanistic science classes, an area of research, for example, targeted by Eijkelhof and Lijnse’s (1988) fourth phase of their developmental research (reviewed above in “Classroom Materials”), or underscored by their claim that not enough was known about how to reach the expectations of a humanistic science curriculum (Eijkelhof et al., 1996).

By the 1900s it was evidently clear in a literature review by Aikenhead (1994b), and in two reviews of the extensive Iowa Chautauqua Program by Yager (1996b) and Yager and Tamir (1993), that sufficient summative evaluation studies had been published to warrant the following research synthesis:

1. Students in humanistic science classes (compared with traditional science classes) can significantly improve their understanding of social issues both external and internal to science, and of the interactions among science, technology, and society; but this achievement depends on what content is emphasized and evaluated by the teacher. The teacher makes the difference.

2. Students in humanistic science classes (compared with traditional science classes) can significantly improve their attitudes toward science, toward science classes, and toward learning, as a result of learning humanistic content.
3. Students in humanistic science classes (compared with traditional science classes) can make modest but significant gains in thinking skills such as applying canonical science content to everyday events, critical and creative thinking, and decision making, as long as these skills are explicitly practiced and evaluated in the classroom.

4. Students can benefit from studying science from a humanistic perspective provided that: the humanistic content is integrated with canonical science content in a purposeful, educationally sound way; appropriate classroom materials are available; and a teacher’s orientation toward school science is in reasonable synchrony with a humanistic perspective.

According to a number of science education researchers (e.g. Monk & Osborne, 1997; Schibeci, 1986), the most compelling single summative assessment study was the complex, multi-faceted, randomized research design for Harvard Project Physics (HPP), reviewed by Welch in 1973 who stated that compared to their counterparts in non-HPP classes, “students in HPP find the course more satisfying, diverse, historical, philosophical, humanitarian, and social; … the historical approach is interesting …” (p. 375). Welch also reported that standardized measures of humanistic conceptual content achievement (i.e. pre-posttest gain scores on Klopfer’s “Test on Understanding Science” and Welch’s “Science Process Inventory”) showed no significant difference between the HPP and non-HPP groups. However, as Aikenhead (1974) discovered, Welch (1973) and Welch and Walberg (1972) reached their conclusion based on compromised data that contained: (1) 3.5% frivolous responses by uncooperative students (e.g. a few students penciled in the response boxes on the machine-scored answer sheet in a way that spelled out an obscene expletive suggesting a physical impossibility), and (2) 12% incomplete responses that dramatically skewed the pre-posttest gain scores. By deleting the frivolous and incomplete answer sheets, Aikenhead recalculated the gain scores and found the HPP group had significantly out performed the non-HPP group (raw gain scores of 7.95 points and 3.39 points, respectively).

Aikenhead (1974) posited two conclusions about quantitative research. First, researchers need to take the time to ensure they have “clean” data to analyze. This is particularly true today for data collected digitally. Unfortunately, several publications concerning the effects of teaching the history of science (e.g. Abd-El-Khalick & Lederman, 2000, p. 696) have claimed there is inconclusive evidence to support any advantage to such an approach, citing the HPP null results (Welch, 1973; Welch & Walberg, 1972) that were based on compromised data.

A second conclusion was posited by Aikenhead (1974, p. 23) when he rhetorically asked, “What does it mean to a curriculum developer or teacher for group E [experimental] to score 3.77 points more than group C [control]?” Such ambiguous summative data have moved many researchers into the interpretive paradigm of research.
Since the early 1990s, only a few studies have used a quantitative quasi-experimental design, and their findings have reinforced the four conclusions stated above. For example, Solbes and Vilches (1997) conducted several studies with 103 teachers over a three-year period when an STS curriculum was introduced into Spain. Their conclusions highlighted improved student attitudes and interests in studying physics and chemistry (questionnaire data) and the dramatic differences perceived by students between the humanistic and traditional curricula. Based on student learning data, Galili and Hazan (2001) in Israel documented various advantages attributed to teaching an optics course from an historical perspective. In Taiwan, Tsai (1999, 2000) investigated the relative effect of STS and traditional science classrooms on students’ cognitive structures. The results from a questionnaire and from a “flow map” analysis of in-depth interviews delineated specific benefits that accrued from the STS classes, including more “constructivist views of science” and a better understanding of “the importance of social negotiations in the scientific community and cultural impact on science” (1999, p. 1201). Furthermore, Tsai’s (2000) research suggested that students’ epistemic beliefs may influence their receptivity to humanistic science, thereby helping to explain an earlier conclusion in this review (“Teacher Orientation”) that students could inhibit the implementation of humanistic science, especially students with a positivistic or empiricist view of science. A much different type of study by Wiesenmayer and Rubba (1999) focused on the citizenship behaviours of grade 7 biology students in order to determine the effects of “STS issue investigation” and “action instruction” on those behaviours. By combining quantitative and qualitative evidence gathering techniques, the researchers were able to describe the extent and complexity of students making a decision and then acting on that decision. The humanistic treatment enhanced students’ ability to take informed action on science and technology-related societal issues, compared with the control group. This result was associated with teachers being able to adapt the teaching strategies required of action instruction. A study in Indonesia (Poedjiadi, 1996) assessed the effectiveness of an STS approach for lower secondary students by analyzing pre and posttest scores between two experimental and two control classes (rural and urban communities were represented in a 2 by 2 design). Videotapes of lessons and classroom visits ensured an STS approach took place in the experimental classrooms. Significant findings were: greater comprehension of humanistic content, a stronger attitude toward social responsibility, and a higher interest in studying canonical science. A preliminary study in Nigeria by Urevbu (1994) involved two teachers in different schools teaching a three-month author-developed STS module for the first time. Daily participant-observations documented how the teachers treated the module as an integrated curriculum but generally ignored teaching the relationships between science/technology and society, and how each teacher approached the unit in idiosyncratic ways. Enthusiasm and interest by students were key results to the research. Although this study may well have been grounded in educational soundness, its
initiation may have been motivated by the political agenda to involve the teachers in action research to implement a humanistic science module, thereby creating professional development possibilities for the schools. The old deficit model of assessment continues to hold sway in quasi-experimental studies, especially in the political arenas of curriculum policy and summative assessment, even though the model can create false crises (Gibbs & Fox, 1999).

A number of small-scale quasi-experimental studies have been reported in the literature but are not reviewed here because they contained insufficient information about their evidence gathering techniques or their research design had a serious weakness.

Other Investigations in Humanistic Science Education

In an extensive 40-country study of science education, TIMSS included a cluster of humanistic themes around the history, philosophy, and sociology of science (Wang & Schmidt, 2001). Using data tabulated from several domains of inquiry within TIMSS (e.g. curriculum analysis, textbook analysis, teacher questionnaire, and students’ scores on canonical science content), the researchers concluded that the engagement of students in humanistic content was significantly associated with their general school science performance, in the handful of countries that provided such a curriculum. Whether the humanistic science instruction caused this increase in achievement is not known for certain, but the finding adds to the growing evidence that time spent on humanistic content does not compromise students’ achievement in canonical science, but on occasion will increase it modestly. Fensham (1994) suggested two reasons for the paucity of humanistic items on TIMSS achievement tests: they are very difficult to compose due to their contextualized nature; and they generally have low status among the 40 participating countries, poignantly documented in Wang and Schmidt’s (2001) data.

Yet useful research findings have accumulated in the research literature to support and guide the expansion of humanistic school science worldwide. With the development of each new evidence gathering technique in humanistic science, a status report was often published to provide base-line data for a general sample of students (Driver et al., 1996; Lederman et al., 2002; Ryan & Aikenhead, 1992). These results can also provide politically useful data to highlight failures of the traditional science curriculum (Leach et al., 1997), particularly when a humanistic perspective is being introduced, or re-introduced, into a country (e.g. Naider & Nageeb, 1999; Manassero-Mas & Vázquez-Alonso, 1998). For instance, Leach and colleagues (1997, p. 161) concluded, “By the end of their compulsory science education at the age of 16, many UK students tend to portray scientific activity as an individual inductive process. This raises serious questions about the feasibility of promoting understanding of the nature of the
scientific enterprise [a humanistic perspective] amongst students through the science curriculum as currently formulated."

UK students conceived science as a social enterprise in rather simplistic ways, for example (Driver et al., 1996): disagreements between scientists were quickly explained by the biases of scientists or the lack of facts (but students ignored, or did not know about, scientists’ different but legitimate value positions or their different conceptual perspectives) (p. 131); scientific controversies were thought to be resolved by empirical evidence alone (p. 128); scientists were expected to produce unambiguous and incontrovertible facts, that is, conclusive evidence and not circumstantial evidence (p. 131); and students showed little awareness of the internal and external social factors at play in the development and extension of scientific knowledge (p. 133). The UK students did, however, have a rich enough prerequisite knowledge of human nature and social institutions to apply that knowledge rationally to scientific controversies (p. 133) but students needed the guidance of a humanistic science teacher (“explicit curricular interventions,” p. 134) to help them apply their prerequisite general knowledge instead of their simplistic preconceptions. Similar types of conclusions were reached by other status studies using different instrumentation (e.g. Lederman, in press; Lederman et al., 2002; Ryan & Aikenhead, 1992). For instance, VOSTS data in Canada (Aikenhead, 1997) indicated that 17 year-olds held one of three different positions concerning the influence of national cultural norms and values on science: a small majority acknowledged the influence of culture on science; a large minority questioned the degree to which cultural influences override a scientist’s individuality; and a small minority embraced a positivist-like posture, similar to many of their science teachers (Bingle & Gaskell, 1994). Students’ preconceptions were documented in a cross-national (Spain and Canada) VOSTS study by Vázquez-Alonso and Manassero-Mas (1994) who showed that 17-year-old students in both countries equally valued the social responsibility of scientists and believed scientists are genuinely concerned about the potential effects of their work. In addition, both groups of students felt that when those consequences were unpredictable, society and individual users must share responsibility.

By analyzing answers to a national examination for an STS syllabus in the UK in the 1980s, Solomon (1988a) concluded that explicit instruction had made a difference to students’ capability to construct plausible arguments from opposing points of view on a science-related topic, although the humanistic content in the syllabus was challenging to most students. About a decade later a new humanistic syllabus appeared, “Science for Public Understanding” (Millar, 2000), and its impact on students was assessed by Osborne and colleagues (2003). This integrated science course was designed for post-compulsory students who wanted to broaden their understanding of science (generally enticed-to-know science, as described in “Curriculum Policy” above). The 78 teachers who participated in the study
had exemplary credentials, by and large, and taught from a textbook especially developed for the syllabus (Hunt & Millar, 2000). The research data came from questionnaires, examination papers, classroom observations, and interviews with teachers and with students. “Science for Public Understanding” was highly successful at attracting non-science students into the course, which they found interesting, enjoyable, and equally difficult compared to examination results of other courses. This was a major achievement for a senior high school level science course, according to the researchers, who were particularly impressed by the students’ high degree of interactivity and their authentic engagement with various aspects of the course.

Student interest was also cited as a major achievement in Häussler and Hoffmann’s (2000) humanistic physics curriculum in Germany (primarily “functional science,” reviewed above in “Curriculum Policy”). Graduates of the course perceived physics “more as a human enterprise and less as a body of knowledge and procedures” (p. 704) and expressed an interest structure very similar to the Delphi study’s results that established the course content in the first place. In short, these students and the stakeholders participating in the Delphi study shared a similar understanding of relevance. Moreover, students also valued the curriculum’s cultural relevance indicated by their increased self-esteem from being successful achievers, a fundamental outcome to any learned curriculum.

Students’ ability to interpret the news media is another expectation of most humanistic curricula (Fensham, 2000b; Thier & Nagle, 1994). Ratcliffe (1999) investigated the evaluation reports (critiquing science articles in the New Scientist) written by three groups: school students (11 to 14 year-olds), college science students (17 year-olds), and science baccalaureate graduates (22 to 35 year-olds). Although the skills increased with formal training, years of experience, and self-selection into science, as one would expect, Ratcliffe discovered that the skills of evidence evaluation (a component of “functional science”) were evident across all three populations, and she suggested that these abilities could be developed further in school science through explicit teaching.

The impact on student learning (11 to 14 year-olds) by history of science materials was investigated by Solomon et al. (1992) in an 18-month action research project, in which data were gathered by interviewing students after they completed an activity, by an open-ended questionnaire, and by a four-item multiple-choice questionnaire. Classrooms were observed and teachers interviewed. Interestingly, students’ facile, media-icon, image of scientists were not replaced by realistic images developed through learning the humanistic content, but instead, these realistic images were added to the preconceptions in students’ minds (i.e. concept proliferation rather than concept replacement). From a student’s point of view, learning meant they now had a choice between two images, and the choice depended on context. This result has implications for the importance of context in the assessment of student learning. Solomon
and her colleagues’ evidence also suggested that learning scientific theories was more durable because some students had learned the reasons for accepting one theory over another, and the stories from the history of science smoothed the path for their own conceptual change.

In a follow-up one-year study, more focused on seven images of scientists and their experiments, Solomon and colleagues (1994) confirmed earlier results and further concluded: “the stories of the actual activities of scientists are memorable enough to create a valuable library of epistemological ideas” (p. 372), but the stories do not erase simplistic icon images of scientists. (This result was also found in Lin’s [1998] research with pre-service teachers; reviewed above in “Teacher Orientation.”) Extending their research program into a large-scale study of 1000 students (aged 13, 15, and 17 years), Solomon and colleagues (1996) focused on the possible interaction between two domains of knowledge: ideas gained through one’s own activities in school science, and ideas about the authentic activities of professional scientists. Based on data from a six-item questionnaire, developed systematically over several stages, the following findings were warranted: students were unfamiliar with scientific theories per se, students could be categorized as being “explainers” or “imaginers” and each group was predisposed to different sorts of learning, and a developmental sequence emerged in which students’ cartoon-like images of scientists developed into more authentic or realistic images. Moreover, there was a highly significant correlation between holding an authentic image of scientists and achievement on canonical science content.

Socially responsible action by students is a valued aspect of the learned curriculum for many humanistic science curricula (Cross & Price, 1992, 2002; Hines, Hungerford & Tomera [review], 1987; Solomon, 1994b,d; Ramsay, 1993; Rubba [review], 1987). Accordingly, Solomon (1990, 1992, 1996) initiated a three-year study in which teachers infused humanistic content purposefully throughout their science courses by using actual “news clips” from television to initiate open, informal, small-group, student discussions on emotion-laden science-related topics (e.g. incidence of leukemia), with little structuring from the teacher. By analyzing the transcripts of these discussions and pre/post questionnaires, Solomon (1990) discovered, along with Fleming (1986b) and Levinson (2003), that only a simple familiarity with scientific terms used in the news clips (i.e. enticed-to-know science) made participation in the discussions easier and more effective, as well as being familiar with civic knowledge and moral reasoning (e.g. Solomon, 1994b). The variety and complexity of students’ moral and ethical reasoning do not usually include a student’s epistemology of science (Fleming, 1986a; Zeidler, Walker, Ackett & Simmons, 2002), but did so for some students in Solomon’s study. Solomon also concluded that students tended to become more cognizant of their civic responsibility to be self-reliant in making up their own minds on an issue. But when analyzing the three years of student transcripts, she was unable to detect a pattern of association between student knowledge or attitudes and their actual behaviours as recorded in
the transcripts; a finding at odds with some modestly positive assessments of student action resulting from specific humanistic science experiences (Pereira, 1996; Solomon & Thomas, 1999; Wiesenmayer & Rubba, 1999). The relationship between student knowledge/attitude and responsible action is fraught with complexity (Fishbein & Ajzen, 1975). Quantitative syntheses of research described this relationship as a meagre correlation (Posch, 1993) or a small effect size of 0.3 (Hines et al., 1987). Qualitative studies have pointed to important mitigating circumstances on action (Dahncke, 1996; Kortland, 1992; Solomon, 1994d): social pressure, economic constraints, cultural factors, and students’ belief in their capacity to bring about change (i.e. potential political potency). This last item has actually been used to criticize humanistic school science: “Without the necessary freedom of access to information, and knowledge of the politics of decision-making in the adult world, a focus on STS issues at school level could be nothing more than a recipe for frustration, holding out the prospect of influence without providing the necessary equipment and conditions” (Layton, 1986, p. 118). However, the research reviewed here suggests that socially responsible action can be enhanced by a humanistic curriculum for some students with certain teachers. A major component to this responsibility, as Layton pointed out, is one’s willingness to engage in thoughtful decision making.

Student Decision Making

The wise use of knowledge, scientific or otherwise, enables people to assume social responsibilities expected of attentive citizens or key decision makers employed in public service or business and industry. Thus, decision making is often at the centre of relevance in a humanistic science curriculum, and it serves as a classroom vehicle to transport students into their everyday world of: need-to-know science, functional science, enticed-to-know science, have-cause-to-know science, personal-curiosity science, and culture-as-science. Generally the classroom objective is to create a sound simulation of an everyday event, the type that led researchers to conclude (reviewed above in “Curriculum Policy”): When people need to communicate with experts and/or take action, they usually learn the science content required. That content will often be action-oriented science (citizen science), that is, interdisciplinary canonical science deconstructed and then reconstructed to fit the unique circumstances of the everyday event (Jenkins 1992, 2002; Lawrence & Eisenhart, 2002; Layton, 1991). But decision making necessarily encompasses a wide scope of other types of knowledge: always values and personal knowledge, and sometimes technology, ethics, civics, politics, the law, economics, public policy, etc. (Aikenhead, 1980; Driver et al., 2000; Grace & Ratcliffe, 2002; Jiménez-Aleizandre & Pereiro- Muñoz, 2002; Kolstø, 2001a; Patronis & Spiliotopoulou, 1999; Thomas, 2000). In research into conflicting testimonies of scientific experts on science-related controversial issues, for instance, even the scientific
technical information itself was found to carry political-ideological baggage (i.e. values); and rather than achieving a clear resolution on an issue, more scientific information invariably caused greater polarization (e.g. Aikenhead, 1985; Gaskell, 1982; Graham, 1981; Longino, 1983). Fensham (2002, p. 16) concluded: “The reason that different groups of scientists can often differ in their assessment of such issues is not so much that one group is right and the other wrong; rather it is that both are right, but about different aspects of the issue … [depending] on the wider value positions of the groups themselves.”

Several avenues of research into student learning have been pursued in the context of decision making. Outside the milieu of school science, Fleming (1986a,b) meticulously examined how 17 year-old students individually reached decisions on proposed socio-scientific issues, for example, accepting employment in a nuclear power plant. Using multistage interviewing techniques, he came to the conclusion that students made their decisions primarily by reasoning in the domains of “moral issues” or “personal reasoning” (i.e. devoted to the maintenance of the self), rather than by evidence-based reasoning endemic to scientific decision making (Duschl & Gitomer, 1996; Osborne et al., 2003; Thier & Hill, 1988). (Adults sometimes reason in the domain of “social conventions,” but no evidence of this surfaced in Fleming’s student data.) Fleming’s participants ignored relevant scientific information offered to them because they perceived scientists as interested only in progress unrelated to human welfare. More recent research adds weight to these results; most students’ worldviews of nature are dramatically different from their science teacher’s (Cobern & Aikenhead, 1998), suggesting a more fundamental reason (e.g. cultural self-identity) for the divide between Fleming’s students’ decision making and scientific evidence-based decision making. Curriculum policy makers, of course, had assumed the latter should be evident. Fleming’s research seriously questioned the importance of using scientific knowledge when making a decision on a socio-scientific issue in the everyday world, a finding replicated many times in the literature (e.g. Irwin & Wynne, 1996; Kortland, 2001; Layton et al., 1993; Ratcliffe, 1997b; Solomon, 1988b, 1992; Tytler et al., 2001a).

Therefore, Fleming’s research challenged science educators to design relevant decision-making events for the classroom in which students would learn how to use scientific ideas and data appropriately rather than ignore them completely. Several researchers rose to the challenge. Their studies vary in terms of: the focus of the research, the age of students, the socio-scientific issue’s emotional overtones, and the use of a normative or descriptive models of decision making (Ratcliffe, 1997b). Related to this last item, it was found that decision-making models from sociology and psychology failed to account for the complexities of classroom decisions associated with socio-scientific issues (Aikenhead, 1989), thus, different models needed to be developed.
The PLON module “Ionizing Radiation” was designed to help high school students “make decisions in matters of personal and social relevance related to the risks of ionizing radiation” (Eijkelhof, 1990, p. 166). The module’s scientific knowledge (have-cause-to-know science and have-need-to-know science) was derived from a Delphi study, reviewed above in “Curriculum Policy.” R&D formative evaluative data showed that students rarely drew upon this knowledge when they were engaged in risk-assessment decisions (fairly high emotion-laden issues); this in spite of students’ high interest in the module. In school science, relevant contexts alone did not overcome the powerful constraints of students’ preconceptions (“lay-ideas” or “undeveloped scientific ideas,” p. 140), according to Eijkelhof. In short, and yet again, meaningful learning of canonical science concepts is very difficult for most students in school science no matter what the context is. (Eijkelhof recommended that a relevant context be accompanied by some type of instruction that pays “attention to lay-ideas and the dissimilarities between scientific and lay-ideas;” p. 142.) In terms of a humanistic science curriculum, however, Eijkelhof (p. 166) questioned the efficacy of decision making as a viable aim for the unit “Ionizing Radiation,” but suggested a more modest aim of teaching citizen science (e.g. learn to appreciate the effectiveness and limitations of radiation safety measures, or learn how to be careful with ionizing radiation). Overt instruction on how to make a reasoned decision was not part of the module.

Kortland (1992) extended an R&D project into a developmental research project for a PLON-like module about sustainable development, “Garbage: Dumping, Burning, and Reusing/Recycling.” The module emphasized helping 13 and 14 year-old students make better decisions by structuring the decision-making process in particular ways, guided by a normative decision-making model. In just one classroom, he investigated a scheme for assessing students’ decision-making skills by collecting data (i.e. student work and transcripts of discussions and interviews) on the quality of their arguments: particularly the range, depth, and explicit weighing of arguments. Kortland’s preliminary study concluded that students were held back more by a lack of content knowledge about garbage management than by “deficiencies” in decision-making skills. Based on Eijkelhof’s (1990) call to seriously consider students’ preconceptions (“lay-ideas”), on Lijnse’s (1995) teaching/learning model of “didactic structure,” and on R&D evaluation data from the first version of the module, Kortland (1994, 1996) constructed a four-tiered developmental, decision-making scheme to guide humanistic science educators in their own development of curriculum materials aimed at enhancing students’ decision-making skills (i.e. their ability to present an argued point of view). Applying this scheme to a second version of the module, Kortland discovered the interplay between group decisions and individual decisions, and an improvement on some aspects of argumentation by students (i.e. validity and clarity using criteria for evaluating alternatives) but not on the range of criteria (e.g. personal interests, society’s interest, and interests of nature) considered by students.
when they formulated a decision on, for instance, buying milk in a glass bottle or in a carton container (a low emotion-laden issue). Results from further in-depth research (Kortland, 2001) reinforced the crucial role of the teacher in determining what students learn, and the necessity of conducting this type of research after a trial teacher has practiced and polished the instructional methods (in this case, didactical structuring of decision making). Moreover, the role of content knowledge (primarily citizen science, in this case) became evident: “A small majority of the students expressed that, in order to be able to make a choice, knowledge is needed about the contribution to depletion and pollution of the packaging materials concerned” (p. 161). In addition to noting the effectiveness of his normative decision-making model, Kortland pointed out an important methodological finding: students’ oral or written presentations of their argued point of view often failed to communicate the quality of thinking that had actually gone into the decision. He therefore recommended promoting his instructional decision-making model to the rank of meta-cognition (the ability to regulate and control one’s own cognitive processes), to ensure greater student improvement in persuasively articulating their own decision, that is, to become better decision makers through overt instruction.

The research above suggests that the use of scientific concepts in a socio-scientific decision is predicated on three factors: (1) the relevance of the concept to the decision issue (e.g. need-to-know science of action science, not wish-they-knew science of canonical abstract science); (2) students’ meaningful understanding of the concepts; and (3) when the first two factors are fulfilled, students’ ability to perceive the connection between the concept and decision issue (i.e. the context). Solomon’s (1987, 1988b) analysis of contextualized science being unpredictably value-laden for students is germane here. Obviously, more research was required to shed light on these factors and others.

Ratcliffe (1997b) developed a descriptive model of small-group decision making, a model that structured a series of decision-making exercises she embedded logically in a teacher’s regular science course (two classes of 15 year-olds) over a period of several months. In addition to her interest in students’ use of scientific ideas, Ratcliffe’s research focused on how students actually conducted their decision making, and what values guided them. Data came from pre- and post-interviews, transcripts of small-group discussions, and students’ written work handed in. The socio-scientific content represented moderate to low emotion-laden issues, for example: What are you prepared to do to use energy more efficiently? and Which materials would you choose for a replacement window frame? Ratcliffe observed in students “an ability to identify suitable options” and “an ability to identify criteria at some stage in the discussion but difficulty in using them systematically in reasoning” (p. 175). Although little scientific information was overtly sought by students (the link to science was seldom obvious to students), a modest amount of information was drawn from their science class. She also discovered that students who already
possessed reasonable decision-making skills improved upon these skills through group argumentation, but for students with low-level skills, peer discussions did not yield reasoned arguments. Ratcliffe empirically identified the following key features of successful small-group decisions: “understanding procedures for rational analysis of the problem; awareness and use of available information; clarification of the concerns and values raised by the issue; recognition of how scientific evidence may assist in the decision; motivation to engage fully in discussing the issue; and consideration of and respect for differing viewpoints about the issue” (p. 167). Students were guided by different sets of values depending upon the socio-scientific issue. For example, when deciding the issue of energy use, students talked mostly about cost, effectiveness/reliability, and energy considerations; when deciding on replacement window frames, students talked mostly about cost, effectiveness/reliability, energy considerations, environmental considerations, selfishness, and aesthetics. Similarly, Fleming (1986a) mentioned an issue’s saliency influenced the type of reasoning students used in reaching a decision. Ratcliffe expressed disappointment over a lack of development in groups’ systematic reasoning over the course of the study. (No discussion on the teacher’s role, or lack of role, was presented. Perhaps greater gains may have emerged from more active direction and involvement by the teacher.) Underscoring Kortland’s (2001) conclusion about metacognition and decision-making models, Ratcliffe (1997b) concluded that the decision-making process needed to become the object of overt reflection by students. She also concluded that 15-year olds were able to begin to participate in thoughtful decision making, a finding shared by Driver et al. (1996) in their research on students resolving scientific controversies, but not shared by Pedretti (1999) whose evidence showed that 12 year-olds can reach a considered decision (on whether or not to cite a mine near a town) when involved in the interactive Ontario Science Centre.

Ratcliffe (1997a) explored 15 year-old students’ systematic reasoning during decision-making activities in five schools in the UK to test the efficacy of two taxonomies, one based on Piagetian stages and the other based on normative and descriptive decision-making models. Both instruments were found to be effective for quantitative research because they correlated with the study’s qualitative results. These results, along with Koker’s (1996) related work in environmental education, led Reiss (1999) to conclude that science teachers who lack specialized knowledge in moral philosophy can still assess students’ ability to reason ethically on science-related social issues. For example, Solomon’s (1994b) categories of moral statements proved to be very useful to Pedretti’s (1999) research into student decision making at the Ontario Science Centre.

In an elaborate study involving a class of 38 grade 11 students (17 to 21 years of age) in authentic, community-based activities conducted in a Spanish school, Jiménez-Aleizandre and Pereiro- Muñoz (2002) explored the students’ scientific knowledge and argumentation skills required to reach socio-
scientific decisions on environmental management, and compared these skills to those of scientific experts. The researchers elaborated Kortland’s (1996) emphasis on argumentation, drew on Ratcliffe’s (1997b) decision-making model, and followed Duschl and Gitomer’s (1996) notion of authentic problem solving. The students’ success at applying canonical science and at approximating expert arguments was attributed to the students becoming “a knowledge-production community” (as opposed to passive consumers of knowledge), a role that judiciously combined values with scientific ideas and data. The authenticity reached in this study mirrors the real-world case-study research into citizens acting upon a science-related issue (reviewed in “Curriculum Policy,” e.g. Ryder, 2001). On the one hand, the study exemplifies the conclusion repeated just above that when people believe they need to take action, they tend to learn the science required. On the other hand, a unique feature of this study compromises its transferability to other classrooms: the class was taught by one of the researchers whose orientation to humanistic science would likely be unusually strong. Other studies reviewed here were conducted in classrooms of regular humanistic science teachers or middle-of-the-road science teachers. Nevertheless, Jiménez-Aleizandre and Pereiro- Muñoz’s (2002) excellent research design sets a high standard for others to follow. A modest version on this research design was reported by Patronis and Spiliotopoulou (1999) in which 14 year-old students’ argumentation was studied, as well as individual, small-group, and full-class decision making on the authentic community-based issue of designing a local road in Greece. Thomas (1985), Zeidler (1997), and Driver et al. (2000) investigated student difficulties with this type of argumentation. Their research provides cautionary practical advice for humanistic science educators.

In a further study, Grace and Ratcliffe (2002) involved 15-16 year-old students (four classes in different schools) making decisions about conservation management (elephants in Africa and puffins in the UK, both endangered species but perhaps remote enough to be moderately low in emotional response by most students). The researchers focused on students’ use of biological concepts and students’ values. To ensure that the concepts taught to students in their science class were realistically relevant to the two scenarios (elephant and puffin conservation), the researchers acquired a list of appropriate biology concepts (mostly have-cause-to-know science) by interviewing 12 conservation expert managers and then seeking the views of 34 experienced teachers via a questionnaire on the efficacy of teaching those concepts (a less formal method than a Delphi study). As in Ratcliffe’s (1997b) previous study, both scientific concepts and values were used by students. However, in spite of a greater use of scientific concepts in this later study, students still weighted values more heavily than biological concepts. Perhaps the biology concepts taught to the students in the Grace and Ratcliffe (2002) study may have represented content whose scientific validity was highly secure (“ready-made science;” Kolstø, 2001a), whereas the concepts critical to resolving the conservation issue from a student’s point of view may have had a much
more tentative validity (“science-in-the-making,” Kolstø, 2001a). Scientists themselves will disagree over
the latter, creating more uncertainty, and thus by default, giving students more reason to emphasize values
when making a socio-scientific decision in the context of uncertain science. As quoted above, Fensham
(2002) recognized that salient features of a controversial socio-scientific issue relate differently to
scientists’ differing value positions (ideologies), thereby causing disagreement among scientists, and
hence, creating controversy.

How does a student (or teacher) make a decision in the context of conflicting expert advice from
scientists? Some researchers investigated epistemological aspects to this research question (Duschl &
Gitomer, 1996; Thier & Hill, 1888), noting the following three requirements of a student to communicate
effectively with others about a socio-scientific issue: (1) to learn to ask pertinent questions, obtain
evidence, and use it as the basis for decision making; (2) to understand the characteristics and limitations
of scientific evidence; and (3) to understand the nature of scientific inquiry in order to critique its resultant
knowledge. The disappointing results from the Driver et al. (1996) study in the UK, reviewed above,
demonstrate that traditional science curricula do not prepare students for these requirements. The research
question (How does a student make a decision in the face of conflicting expert advice?) was also
addressed on sociological and axiological grounds by Gaskell (1994) and Kolstø (2000, 2001a,b) who
concluded that students need to identify the value positions (ideologies) held by scientists on each side of
a debate, and need to have access to appropriate social criteria for judging credibility of scientists.
Identifying value positions turns out to be “a more important determinant of trust about the scientific
information than is their own knowledge of science” (i.e. canonical science content; Fensham, 2002, p.
16). In short, humanistic content (i.e. knowledge about science and scientists) is more relevant than
canonical science content in the context of conflicting expert advice (Aikenhead, 1980, 1985). The greater
the reliance on science-in-the-making, the greater the controversy and the greater the need to determine
the credibility or trustworthiness of the sources of scientific information, and consequently, the greater the
reliance on values. This point helps to explain the apparent low status, or non-existence, of canonical
science in decision making on science-related controversial issues. One extreme case is Levinson’s (2003)
research into student decision making on testing fetuses for certain medical conditions (e.g. Tay Sachs
and Down’s Syndrome). During class discussions, scientific conceptual confusions were not clarified and
greater scientific confusions may have ensued as a result, because the focus of the students’ discussions
was firmly on their value positions (ideologies) due to the high emotion-laden issues discussed (e.g.
abortion). Levinson, however, placed blame on the complexity and difficulty of addressing ethical issues
by teachers trained in science. Most researchers whose work is reviewed in this paper did recognize the
high pedagogical demands placed on teachers implementing socio-scientific decision making in their
science classes (e.g. Gaskell, 1982; Osborne et al., 2003; Reiss, 1999). Researchers need to provide appropriate support and coaching for teachers who collaborate in their research studies, for example, as Pedretti (1999) did by drawing on Solomon’s (1994b) categories of moral statements.

Much more detail about students’ decision making came from Kolstø’s (2000, 2001a,b) research that drew upon a bona fide international and local issue (in Bergen, Norway) concerning the location of high voltage power transmission lines (above or below ground) and the degree of risk of childhood leukemia from above ground lines. His research focused on (1) the strategies used by 15 and 16 year-old students in their science class to resolve the problem of whose information to trust, and (2) how 22 diverse students in four high schools actually made their own decision individually. Similar to the design employed by Driver et al. (1996) to investigate students’ reaction to scientific controversies, Kolstø’s (2000a) four teachers took a class period to present information about the socio-scientific issue using local media as well as excerpts from research reports. Then during the second day, students discussed the issue in groups of four or five, made a group decision, and wrote down their arguments and the expected counter arguments. Employing an intricate in-depth analysis of these students’ discussions, Kolstø (2001b) mapped out the trust factor of students in terms of categories (and sub-categories) of strategies they used (i.e. acceptance of knowledge claims, evaluation of statements, acceptance of authority, and evaluation of authority). Unlike Kortland (1994) and Ratcliffe (1997b), Kolstø (2000a) purposefully did not include a decision-making model to guide students because he wanted to investigate students’ untutored ways of making a socio-scientific decision. In-depth interviews with 22 students led Kolstø (2001a) to discover five different ways individual students had made their decisions (i.e. five descriptive decision-making models): relative risk model, play safe model, uncertainty model, small risk model, and pros-and-cons model (a more normative prescriptive prototype for students, drawing upon the other four models). Students varied in the importance they attached to canonical science knowledge (i.e. voltage, electric current, magnetism, etc.), with some students saying it was desirable but not necessary to make their decision on the location of the transmission lines (a finding repeated in most studies reviewed here). Values, on the other hand, were a constant feature in each decision-making model. Students had discussed the credibility of scientists, the degree of consensus among scientists, the epistemic nature of scientific proof, and other considerations related to trustworthiness. Kolstø concluded that disagreements among expert scientists made the activity more authentic though more difficult for students. Given the high degree of student individuality discovered by Kolstø, humanistic curriculum developers and teacher educators have a more detailed and realistic understanding of science-related decision making. In addition, research from adjacent cognate areas outside the domain of socio-scientific decision making can
be transferred to decision making, for instance, research into judging scientists’ knowledge claims from an epistemological perspective (e.g. Norris, 1995; Norris & Phillips, 1994; Phillips & Norris, 1999).

In addition to the decision-making models used by Kortland (1994) and Ratcliffe (1997b), other models have been explored in R&D studies by Aikenhead (1992, 1994a) and Dahncke (1996), and in a synthesis study by Cross and Price (2002). In all cases, values clarification and science content (need-to-know science and canonical science) were integrated into a normative model for teaching students decision-making skills.

The research on decision making reviewed here consisted of preliminary studies into a highly complex field. It revealed: the influence of age (normally age 15 is a minimum); the influence of an issue’s emotional level (low to high); the interplay among relevant scientific knowledge, values, and decisions; the complex influence of activity authenticity on this interplay; and the influence of teachers’ overt instruction guiding students to follow a decision-making model that combines values with appropriate scientific ideas and data. By knowing students’ pre-instructional ways of making a socio-scientific decision, humanistic curriculum developers and teachers have clearer challenges to meet. The research also uncovered useful distinctions, for example, between ready-made science and science-in-the-making. Such distinctions must become standard humanistic content for thoughtful decision makers, otherwise cynicism toward all of science may result from students’ misunderstanding that science-in-the-making is as authoritative as ready-made science (Thomas, 2000).

Perhaps the most pervasive result from the research into student decision making is the priority students gave to values over scientific evidence. This result may be due to the fact that values are more important in our culture for deciding on most socio-scientific issues, even for science teachers and scientists themselves. Lawrenz and Gray (1995) discovered that science teachers with science degrees did not use science content to make meaning out of an everyday event, but instead used other content knowledge such as values. Bell and Lederman (2003) investigated how 21 university research scientists made socio-scientific decisions (e.g. fetal tissue implantations, global warming, and smoking and cancer). Using questionnaires and telephone interviews, the researchers concluded that all participants considered the scientific evidence, but they “based their decisions primarily on personal values, morals/ethics, and social concerns” (p. 352). Should students be any different?

Conclusion

The research literature unequivocally demonstrates that student learning (defined by various objectives) does occur to varying degrees as a result of a humanistic science curriculum. Science educators’ early naivety about this learning has been replaced by a more realistically complex, intricately
interconnected, series of paradoxes and trade-offs. Relevant contexts alone did not necessarily nurture greater canonical science attainment (although nothing of significance is lost on this count, as well). Values and self-identity necessarily play a large role in focusing students’ attention on both humanistic and science content: the more emotional the context of instruction or the more uncertain the relevant scientific information, the more important values become, and thus, the less attention paid to content. Students tended to learn more humanistic content the more explicit it appeared in their classroom instruction and assessment. Constructivist learning principles apply to humanistic content. However, the more overt this humanistic content became, the greater disruption it caused to status quo teaching, and thus, the greater challenge it was to teachers’ ability to achieve concordance among the intended, taught, and learned curricula.

One ubiquitous research result from studies into student learning in humanistic school science was the positive reaction of most students. Häussler and Hoffmann (2000) found the positive reaction manifested itself as stronger self-esteem from being successful achievers. More studies should collect data on students’ self-esteem or self-identity, because self-esteem and self-identity represent fundamental outcomes of any science curriculum. Ramsden (1992) was surprised, however, to discover a different reaction from her students who had enjoyed a relevant science curriculum. They seriously questioned whether it was really proper school science. In general, the positive reaction of most students to humanistic school science was likely due to a number of factors: a genuine interest on the part of students, a happy diversion from teacher-centred instruction, and a selection bias in the research sample (favouring the large majority of students who generally find the traditional curriculum boring and irrelevant). This last point infers a cautionary note that the small minority of science-proficient students who embrace “the pipeline” ideology for school science will likely not respond positively to a humanistic perspective in their science courses. Similarly, students who equate school science with future earnings, even though school science holds no intrinsic value for them, will likely resist a humanistic perspective (Désautels, Fleury & Garrison, 2002).

Although constructivist learning principles do apply to humanistic content, more appropriate principles are found in an emerging research methodology within the interpretive paradigm: “phenomenography” (Erickson, 2000). At the centre of phenomenological research is a commitment to understanding how students experience the world and learn to act in the world. Individual students are not categorized, but instead their relationship to their immediate setting is clarified by this research. Affective and cognitive components merge. The phenomenological research approach has not yet been used in any science education study, but it offers a promising new avenue for future research.
Discussion of the Research

This discussion does not summarize the conclusions posited throughout this review of research, but it seeks to synthesize several interrelated salient points concerning the strengths, weaknesses, and fruitful directions for further research.

Credibility

Since WW II, the renaissance of a humanistic perspective in the science curriculum encouraged researchers to produce new knowledge in the attempt to establish credibility of this perspective in the eyes of science teachers, science educators, and policy makers. The review of this research provides strong evidence supporting the educational soundness of a humanistic perspective for the intended, taught, and learned curricula. The good news is the issue of credibility need not monopolize research agendas in the future.

The bad news is this educationally sound prepositional knowledge has had little impact on classroom practice in particular or on the political reality of science education in general. The influence of research on classroom practice was recently investigated by Ratcliffe and colleagues (2003, p. 21) who concluded: “Unless research evidence, including that from highly regarded studies, is seen to accord with experience and professional judgement [and ideology] it is unlikely to be acted on.” However, they also concluded that research is more influential on the “development of national policy on science education.” Again, the educationally sound defers to political reality. As mentioned above, Elmore’s (2002) cryptic account of innovative projects explains this failure: small-scale studies have involved “the faithful” to establish the soundness of a humanistic perspective, but researchers assumed that this “virus” (i.e. the innovation) will populate the system because the evidence shows it is educationally sound. This strategy has not worked. For researchers, therefore, the issue of credibility is now a political issue predominantly, not an educational issue, and future research programs will need to reflect this reality.

Relevance

Two issues are considered here: canonical science content and humanistic science content. The relevance of canonical science outside “the pipeline” is problematic for most students and for most employers, and is specious for science educators. Ample research accumulated over the years has told us exactly what students clearly exclaimed 30 years ago: school science (canonical content) is irrelevant to their lives and their self-identities. Future research agendas that focus on students attaining canonical science in any context are bound to simply repeat what is already well documented in the literature: canonical science is all but irrelevant for most students, and any attempt to make it appear relevant will be
undermined by students playing Fatima’s rules. In other words, learning canonical science meaningfully when it is contextualized in an everyday event is an unrealistic and inappropriate objective for most students. Yes, canonical science does have a place in humanistic school science, but that place is subordinate to many types of relevant science (i.e. have-need-to-know science, citizen science, etc.). The “mental training” argument supporting canonical science works equally well educationally when supporting, for instance, functional science or personal-curiosity science. But within the ideology of “pipeline” enthusiasts who place idealistic abstraction superior to pragmatic concreteness, the mental training argument will be a political issue, not an educational one.

As for humanistic content, more research into the various types of relevant science will be helpful to curriculum policy makers, as Millar’s (2000) and Law et al.’s (2000) work clearly suggests. Future research questions might include: What understandings of science (all types of science) and journalism are of critical value to consumers of the mass media? or How can school science engage students’ self-identities, or is this not feasible?

Research into students’ learning humanistic content has established a wealth of warranted claims that do not need further replication, unless a political reason surfaces. This is not the case, however, for decision making and critical thinking, processes centrally relevant to a humanistic perspective. The research programs of, for example, Kolstø, Kortland, Ratcliffe, and Zoller need to be extended so we can better understand the complexities involved with teaching these key processes, complexities such as the expression of arguments orally and in writing, and the interplay among values, knowledge, context, and self-identities. The researchers’ recommendation for overt instruction of these processes will demand meta-cognitive learning by students, a challenge in itself (Fensham, 1992). Resistance from students may emerge from their feelings that socio-scientific issues are personally affective rather than publicly cognitive (Solomon & Thomas, 1999), and therefore, ought not to be open to the scrutiny of rational ideologies espoused in school science. The issue here is one of engaging students’ self-identities (e.g. Brickhouse et al., 2000), self-efficacies (e.g. Lyons, 2003), or self-esteem (e.g. Häussler & Hoffmann, 2000). Community-based science curriculum and instruction holds promise here (e.g. Bouillion & Gomez, 2001; Cajas, 1998; Dori & Tal, 2000; Jiménez-Aleizandre & Pereiro-Muñoz, 2002; Solomon, 1999b).

Because teachers are pivotal to creating a taught curriculum, continued research into understanding their successes and failures at learning humanistic content and teaching science from a humanistic perspective will be valuable (e.g. Bartholomew et al., 2002; Tal et al., 2001). The complexities of teaching are no longer expressed as relationships among variables captured by statistical analysis (the quantitative paradigm), but can now be better appreciated through heuristic models such as teacher
practical knowledge, TPK (e.g. Duffee & Aikenhead), and teacher context knowledge, TCK (Barnett & Hodson, 2001). Fine-tuning these types of schemes affords deeper insight into the taught curriculum and into what is actually involved in changing the taught curriculum. Because pre-service apprenticeships in schools are critical to a novice teacher’s loyalty to a humanistic perspective, R&D in this vulnerable area would be particularly fruitful.

Although research related to the educational soundness of relevant school science is not yet complete, it is sufficiently rich to encourage some researchers to look elsewhere for fruitful research programs, for instance, in political arenas of research (discussed below) that address science content relevant to the enculturation of students into their local, national, and global communities; for instance, content described above as science-as-culture. The anticipated negative reaction of “pipeline” enthusiasts to protect the “sacred cow” traditional curriculum will likely recast the humanistic political initiative as an assault on science itself (Cross, 1997b). This negative reaction is not an educational problem but a political one, which itself is ripe for research by science educators.

Research Paradigms and Methodologies

It is convenient to reflect on educational research in terms of three paradigms (Ryan, 1988): quantitative, interpretive (qualitative), and critical-theoretic. A science educator trained in the natural sciences may feel comfortable in the role of disinterested observer (quantitative paradigm), but most of the research reviewed in this chapter emphasized the role of a curious empathetic collaborator (interpretive paradigm). Yet, if curriculum researchers expect to effect significant changes in school culture and classroom practice, they will also need to be seen as passionate liberators (critical-theoretic paradigm) generating emancipatory knowledge/practice in the face of seemingly unchangeable organizational structures, relationships, and social conditions (e.g. Barton’s, Hodson’s, Keiny’s, or Solomon’s research programs: Barton & Yang, 2000; Keiny, 1996; Pedretti & Hodson, 1995; Solomon et al., 1992).

Most of the research literature reviewed in this paper has reported on preliminary small-scale studies necessarily comprised of a few volunteer science teachers to initiate or participate in a novel humanistic project. One exception was the research on Harvard Project Physics (Welch, 1973), but it occurred in the 1960s at a time when a good science curriculum was deemed to be a teacher-proof curriculum (Solomon, 1999a), when in-service programs simply transmitted the new curriculum’s philosophy to passive teachers (White & Tisher, 1986), and when research strictly conformed to the quantitative research paradigm. This paradigm emphasized measurement of outcomes evaluated against expert judgments or against criteria from academic theoretical frameworks.
Research into humanistic science curricula has evolved dramatically since the 1960s. Increasingly, teachers and now students tend to be collaborators in the development of curriculum policy and classroom materials (e.g. Aikenhead, 1994a; Roberts, 1988, 1995), along with stakeholders other than university science professors and professional science organizations. Successful in-service programs tend to be transactional (e.g. the Iowa Chautauqua Project; Yager & Tamir, 1993) and transformational (typically action research projects, discussed below). Today, research into humanistic science curricula most often follows the interpretive research paradigm, in which researchers attempt to clarify and understand the participants’ views and convey them to others or incorporate them into a curriculum or classroom materials (e.g. Eijkelhof & Lijnse, 1988; Gallagher, 1991; Häussler & Hoffmann, 2000). Developmental research (Kortland, 2001) as a methodology has promise, depending on the scale of the research agenda. It will be fruitful to the extent that it encompasses a broad range of topics simultaneously (from pre-service teacher preparation, to classroom materials development, to student outcomes such as change in self-esteem), but it will be meagre to the extent that it focuses on students’ learning canonical science content. Interpretive research studies have developed educationally sound knowledge and outcomes, but they have not had the political impact needed for significant change in most science classrooms.

Often associated with the critical-theoretic paradigm of research, action research has combined educationally sound knowledge with politicization to create classroom change towards a more humanistic science curriculum (Hodson, 1994; Keiny, 1993), for example: Barton (2001b); Bencze, Hodson, Nyhof-Young and Pedretti (2002); Geddis (1991); Ogborn (2002); Pedretti and Hodson, 1995; Solomon et al. (1992); and Tal et al. (2001). Although these studies have established the effectiveness of action research as a methodology, the studies are limited by their scale because they have usually involved only a tiny proportion of excellent teachers (Solomon, 1999a).

Scale

As an alternative to small-scale studies that have dominated the research literature, Elmore (2003) counselled researchers to treat a school jurisdiction as the unit of analysis through enacting large-scale projects. However, a change from traditional to humanistic school science may require even a broader context for research than just a school system, or a teacher education program, or a state curriculum. Significant change requires a multi-dimensional context of scale that includes diverse stakeholders of social privilege and power, over a long period of time (Anderson & Helms, 2001; Sjøberg, 2002). The most effective curriculum research would explore the interaction of research, political power, policy, and practice (Alsop, 2003), or at least combinations of these components. Research agendas associated with classroom change have investigated the interaction between political power and practice at the school
level (e.g. Carlone, 2003) and have extended it into policy formulation (e.g. Gaskell, 2003; Gaskell & Hepburn, 1998). These studies penetrated the political core of curriculum policy and they hold promise for future R&D and developmental research.

If research into a humanistic curriculum is to be more than an academic exercise acted out on a small scale, it must also reformulate itself into a framework of cultural change, because a humanistic perspective will significantly alter the culture of school science and the culture of schools (e.g. Aikenhead, 2000a; Brickhouse & Bodner, 1992; Elmore, 2003; Medvitz, 1996; Munby et al., 2000; Pedretti & Hodson, 1995; Solomon, 1994c, 2002; Tobin & McRobbie, 1996; Venville et al., 2002; Vesilind & Jones, 1998). Curriculum change can be nurtured and sustained only if the school culture is changed. Change will entail renegotiating values and concepts related to the status of school subjects, which in turn entails altering the school system’s administrative structures, expectations, beliefs, values, and conventions. It is at this level that pre-professional training courses for science-proficient “pipeline” students are conceptualized, administratively on par with auto mechanics or beautician courses. Although school culture is a central feature of a research context, the national culture must be considered as well (Solomon, 1997b; Walberg, 1991), because countries that embrace education stances Solomon (1999b) classified as “humanism” and “naturalism” tend to be amenable to a humanistic perspective in science education, while countries that embrace “rationalism” are not.

Implications for Future Research Studies

To investigate the interaction of research, political power, policy, and practice, with the expressed purpose of facilitating changes to school culture and classroom practice, researchers must address the politics of revisiting the aims of science education currently encased in 19th century ideologies. In doing so, one fundamental dilemma must be resolved explicitly and continuously within each research project: does the curriculum aim to enculturate students into their local, national, and global communities (as some other school subjects do), or does it aim to enculturate students into a scientific discipline? Science educators, who believe both are necessary to supply “the pipeline” with sufficient number of students, seem to ignore the research that places responsibility for supply clearly on university undergraduate programs, and seem to ignore the research on student achievement in those programs. One recognizes the act of ignoring these evidence-based findings as more of a political act warranted by personal values and ideologies than as a rational defence of a curriculum policy. Educational soundness gives way to political reality.

Research into educationally sound knowledge by itself (i.e. most of the research reviewed in this paper) may be necessary for political reasons from time to time, for instance, to re-invent the discover
that the traditional science curriculum fails most students for various reasons (e.g. Reiss, 2000). Of particular interest would be research into Fatima’s rules played by various types of students and science teachers, related to high-stakes testing, educational politics, and ideologies. Future research into humanistic science curricula, however, would best be served by amalgamating the educational with the political, because educationally sound research by itself has had little political consequence, whereas politically savvy actions by students can even be effective (Aikenhead, 1983; Eijkelhof & Kapteijn, 2000).

To achieve this amalgamation, research into consensus making on curriculum policy promises to be a fruitful agenda for future research and development. Of all the policy formulation processes reviewed in this paper, deliberative inquiry holds greatest potential for devising an educationally sound humanistic perspective in the science curriculum, while at the same time providing a political forum for negotiations among various stakeholders. During a deliberative inquiry meeting, research concerning major failures of the traditional curriculum can be scrutinized, research concerning successes at learning science in non-school settings can be debated, and research on relevance can help clarify participants’ values (e.g. Orpwood, 1985). For instance, research on relevance might include: (1) studies (Delphi projects included) into what science-as-culture is most worthwhile learning within a particular school system (e.g. Who is engaged with science in the community? and How?); (2) studies into what science-related knowledge/practice do local workers in science-related careers actually use on the job, day to day; (3) studies into how science-proficient students use science in their everyday lives, compared with how science-shy students cope with similar situations; and (4) studies into how professional scientists actually use science in their everyday lives (e.g. Bell & Lederman, 2003). These research projects would be politically more effective if they involved clusters of science teachers conducting the research (action research or otherwise), and if they involved stakeholders representing many jurisdictions, especially those currently holding greatest power over deciding curriculum policy.

Deliberative inquiry (i.e. consensus-making R&D) will have greater impact on classroom practice: the larger the project’s scale (e.g. SCC, 1984), the more culturally transformational it is (e.g. Leblanc, 1989), and the more it embraces all three research paradigms appropriately (a feature of scale). Worthwhile research would investigate the influence of participant-stakeholders in the consensus making process; for example, the influence of: who they represent, their selection process, their assigned versus enacted roles (the dynamics of deliberative inquiry), and the actor-networks they bring into the deliberation and develop as a result of the deliberation (e.g. Carlone, 2003; Gaskell & Hepburn, 1998). R&D on actor-networks themselves could be a primary focus of a deliberative inquiry, forging networks to enhance a clearer and more politically endorsed humanistic perspective (e.g. Gaskell, 2003).
In short, the most promising but most challenging direction for future research is action research on the grand scale of deliberative inquiry involving a large educational jurisdiction and a broad array of stakeholders judiciously (i.e. politically) chosen so that the political elite is represented, but its status quo science education is actually debated and renegotiated. This needs to take place over a several year period while further research is conducted at the request of the deliberative inquiry group. Significant change to school science must be measured by decades of ever increasing, deliberate implementation, as vicious cycles favouring the traditional science curriculum are eroded by an evolving core of humanistic science teachers.

In the future, preliminary small-scale research studies can still be worthwhile: “Rather than viewing the powerful sociohistorical legacy of science as an oppressive structure that limits the potential of reform, we can view the meanings of science in local settings as partially fluid entities, sometimes reproducing and sometimes contesting sociohistorical legacies” (Carlone, 2003, p. 326). But small-scale studies will lose significance unless they explicitly embed themselves in a larger, articulated, politico-educational agenda for humanistic school science.

Future research programs will be strengthened by establishing alliances between researchers in humanistic science education and researchers in educational cultural anthropology (e.g. McKinley, in press). But caution is advised over becoming sidetracked by certain new research methods such as “design-based research” (e.g. The Design-Based Research Collective, 2003) because their ultimate aim is to refine theories of learning or didactical structures, aims that embrace educational soundness but assiduously avoid political reality. Rather than focus on the question, “How do students learn?”, two fundamental political questions must be posed: “Why would students want to learn?” and “Who will allow them to learn it?”
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