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SPECIAL ISSUE: AFFECT

Attitudes towards science: a review of the literature and its implications

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This article offers a review of the major literature about attitudes to science and its implications over the past 20 years. It argues that the continuing decline in numbers choosing to study science at the point of choice requires a research focus on students' attitudes to science if the nature of the problem is to be understood and remediated. Starting from a consideration of what is meant by attitudes to science, it considers the problems inherent to their measurement, what is known about students' attitudes towards science and the many factors of influence such as gender, teachers, curricula, cultural and other variables. The literature itself points to the crucial importance of gender and the quality of teaching. Given the importance of the latter we argue that there is a greater need for research to identify those aspects of science teaching that make school science engaging for pupils. In particular, a growing body of research on motivation offers important pointers to the kind of classroom environment and activities that might raise pupils' interest in studying school science and a focus for future research.

Introduction

The investigation of students' attitudes towards studying science has been a substantive feature of the work of the science education research community for the past 30–40 years. Its current importance is emphasized by the now mounting evidence of a decline in the interest of young people in pursuing scientific careers (Department for Education 1994; Smithers and Robinson 1988). Combined with research indicating widespread scientific ignorance in the general populace (Durant and Bauer 1997; Durant, Evans, and Thomas 1989; Miller, Pardo, and Niwa 1997), and an increasing recognition of the importance and economic utility of scientific knowledge and its cultural significance, the falling numbers choosing to pursue the study of science has become a matter of considerable societal concern and debate (for example, House of Lords 2000; Jenkins 1994; Lepkowska 1996). Consequently, the promotion of favourable attitudes towards science, scientists and learning science, which has always been a component of science education, is increasingly a matter of concern. However, the concept of an attitude towards science is somewhat nebulous, often poorly articulated and not well understood. This paper offers, therefore, a review of current knowledge about attitudes towards science, what influences there are on their formation, and their impact on subject choice.

Concerns about attitudes to science are not new. Nearly 30 years ago, Ormerod and Duckworth (1975) began their review on the topic of pupils' attitudes to science in the UK with the following comment:

In 1965 a thorough inquiry began into the flow of students of science and technology in higher education. The final report (Dainton 1968) laid particular emphasis on the phenomenon which had become known as the 'swing from science'. Several explanations were suggested for the swing, among them a lessening interest in science and a disaffection with science and technology amongst students.

In the intervening period, particularly the past decade, evidence would suggest that the problem has become even more acute and the topic has been the subject of considerable exploration, both at an empirical and theoretical level, although predominantly in the US. As a consequence, our understanding of the nature of the problem has possibly improved, although possibly not our understanding of its remediation.

Attitudes: the cause for concern

One of the major causes for concern is the enduring 'swing away from science' in many countries. In England and Wales, for instance, the stark nature of the decline in the numbers *choosing* to do three sciences at 16 for A-level, the point of choice in the English system, is shown by some English and Welsh data on student subject choice published in 1994 (Department for Education 1994) (table 1). No data has been collected since but, with the proliferation of a choice of mixed A-levels from science and the humanities, there is no reason to suggest that the situation has significantly changed. The effect the combinations on A-level *results* achieved is presented in table 2 (Department for Education 1994).

Table 1. Percentage of pupils age 16 and over in maintained and private schools taking A-levels

<i>Year</i>	<i>Science and mathematics only (%)</i>	<i>Science and mathematics and other subjects (%)</i>	<i>Other subjects only (%)</i>
1980	29.6	27.6	42.7
1993	16.6	34.8	48.7

Table 2. Percentage of combinations of A-level subjects passed for school leavers and further education students (three or more A-levels)

<i>Year</i>	<i>Science or science and mathematics only</i>	<i>Science or mathematics and other subjects</i>	<i>Other subjects only</i>
1980	37	27	36
1991	16	40	43

What tables 1 and 2 show vividly is that the percentage of students pursuing science, or science and mathematics *only* post-16 has declined by more than one-half. This phenomenon, which began in the 1980s, is due largely to the growth in the numbers pursuing mixed A-levels and some growth in the numbers choosing arts and humanities. For even though, from 1980 to 1991, the proportion of A-level students passing A-level physics rose from 4.6% to 4.9% and those passing chemistry rose from 3.8% to 5.1%, during the same period the proportion passing English A-level rose from 5.7% to 14.1%.

More recent data for the uptake of the three sciences at A-level reveals the absolute nature of the problem and the long-term decline in student numbers (figure 1).

Moreover, analysis by gender shows that the male to female ratio remains stubbornly high at 3.4 : 1 in physics, while it is at least approximately equal in chemistry. Biology, by contrast, is still dominated by girls, with 1.6 girls to every boy, although the numbers choosing to study it have remained relatively stable – a reflection, perhaps, of the fact that it is the leading science of the late twentieth century.

Since only those students who take science, or science and mathematics, are able (without further remedial courses) to pursue further a scientific education and scientific careers, the decline in the number of science-based students as a proportion of all students eligible for higher education in the UK has raised concerns about the nation's economic future (Dearing 1996; Roberts 2002). At the core of such concerns is a recognition that the nation's standards of 'achievement and competitiveness, is based on a highly educated, well trained and adaptable workforce', and that the low uptake of mathematics and science and the negative attitudes towards these subjects poses a serious threat to economic prosperity. For

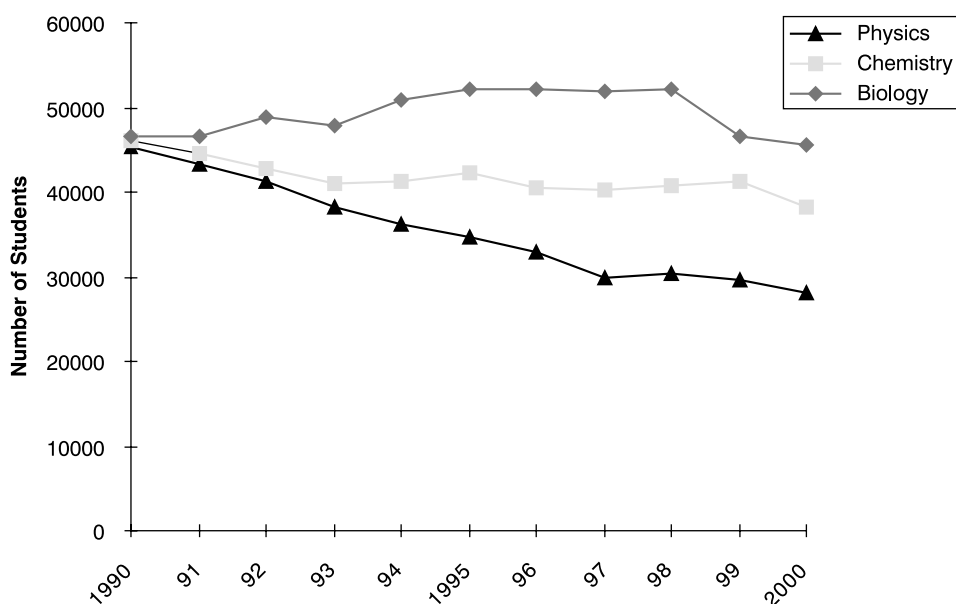


Figure 1. Data for numbers of students examined in physics, chemistry and biology from 1990 to 2000 in England and Wales at A-level. (Data provided by UK Examination Boards and HMSO.)

while some may question the instrumental value of scientific knowledge (De Boer 2000) for the individual, the increasing dependence of contemporary life on sophisticated artefacts makes us communally dependent on individuals with a high level of scientific and technological expertise and competence.

Dearing is not alone. During the past decade there have been a number of reports warning of a potential problem both in the UK (Haskell and Martin 1994; Her Majesty's Government 1993; Nottingham Skills & Enterprise Network 1992) and the US, where such concerns have been voiced in the influential report *Before it's too late* (National Commission on Mathematics and Science Teaching for the 21st Century 2000). Within teaching, the OECD has published a report indicating that teacher supply faces a 'meltdown' (O'Leary 2001). European concerns led the French to make science education a priority of their presidency of the European Union in 2000 and to organize a special one-day conference with representatives drawn from the US and Europe in Washington. Another report undertaken by the UK Government (Department for Education and Employment 1996) suggested that there will be a 12% increase in the demand for science and engineering professionals by the year 2006 and suggested that if these projections are fulfilled and not met it is likely that the pool on which employers can draw will (a) be severely curtailed and (b) not necessarily of the best quality. Moreover, there is also the concern that the calibre of entrants to higher education in science and engineering is poor (Higher Education Funding Council 1992).

Some commentators do question the validity and reliability of these reports (Coles 1996; Tarsh 1994), arguing that there is little evidence from employers themselves of such concerns. Furthermore, similar concerns were articulated in the late 1960s and the predicted dire economic consequences have not occurred. Shamos (1995), moreover, argues that such problems are traditionally dealt with in terms of the laws of supply and demand – industries experiencing shortages will simply raise the salaries of qualified engineers and technicians to a point where the solution will rapidly solve itself. However, the authors of this review are of the opinion that while these may be legitimate points, (a) they are insufficient to allay the concern, and (b) that a modern society where society and technology is a prominent and important aspect of the society can ill afford to produce nearly three times (table 2) as many arts and humanities specialists as it does science specialists. Furthermore, the data in table 3 demonstrate that there is at least a clear association

Table 3. Number of engineers and scientists per million of the population

<i>Country/region</i>	<i>Number of engineers and scientists per million of the population (1993)</i>
Japan	3548
The US	2685
Europe	1632
Latin America	209
Asia	99
Africa	53

between economic performance and the numbers of engineers and scientists produced by a society (Kennedy 1993), and that educating more children in mathematics and science is, at the very least, very unlikely to have a negative effect on the economic well-being of any society.

Moreover, irrespective of the economic affects, the decline of interest in science remains a serious matter of concern for any society attempting to raise its standards of scientific literacy. For if, as Sir Neil Cossons (1993) argues:

the distinguishing feature of modern Western societies is science and technology. Science and technology are the most significant determinants in our culture. In order to decode our culture and enrich our participation – this includes protest and rejection – an appreciation/understanding of science is desirable.

Then it is essential to educate as many children as possible to the highest level possible within the constraints of the school curriculum. And, we would contend, the *sine qua non* of the public appreciation of science is the public engagement with science – something that is the product of positive attitudes generated through formal science education, or at the very least neutral attitudes. For attitudes, once formed, are enduring and difficult to change (Ajzen and Fishbein 1980). What, then, can we learn from the research literature about attitudes to science?

What is meant by ‘attitudes towards science’?

Even a cursory examination of the domain reveals that one of the most prominent aspects of the literature is that 30 years of research into this topic has been bedevilled by a lack of clarity about the concept under investigation. An early notable contribution towards its elaboration was made by Klopfer (1971), who categorized a set of affective behaviours in science education as:

- the manifestation of favourable attitudes towards science and scientists;
- the acceptance of scientific enquiry as a way of thought;
- the adoption of ‘scientific attitudes’;
- the enjoyment of science learning experiences;
- the development of interests in science and science-related activities; and
- the development of an interest in pursuing a career in science or science related work.

Further clarity emerged with the drawing of a fundamental and basic distinction by Gardner (1975) between ‘attitudes towards science’ and ‘scientific attitudes’. The latter is a complex mixture of the longing to know and understand, a questioning approach to all statements, a search for data and their meaning, a demand for verification, a respect for logic, a consideration of premises and a consideration of consequences (Education Policies Commission 1962); and this aspect has been explored in some depth in a seminal review by Gauld and Hukins (1980). In essence, these are the features that might be said to characterize scientific thinking and are cognitive in nature. However, a clear distinction must be drawn between these attributes and the affective ‘attitudes towards science’, which are the feelings, beliefs and values held about an object that may be the enterprise of science, school science, the impact of science on society or scientists themselves. It is the latter that constitute the majority of Klopfer’s attitude components. These attitudes *towards* science, and what is known and understood about their formation and change during adolescence, are the singular focus of this paper.

The first stumbling block for research into attitudes towards science, is that such attitudes do not consist of a single unitary construct, but rather consist of a large number of subconstructs all of which contribute in varying proportions towards an individual's attitudes towards science. Studies (Breakwell and Beardsell 1992; Brown 1976; Crawley and Black 1992; Gardner 1975; Haladyna, Olsen, and Shaughnessy 1982; Keys 1987; Koballa Jr. 1995; Oliver and Simpson 1988; Ormerod and Duckworth 1975; Piburn 1993; Talton and Simpson 1985, 1986, 1987; Woolnough 1994) have incorporated a range of components in their measures of attitudes to science including:

- the perception of the science teacher;
- anxiety toward science;
- the value of science;
- self-esteem at science;
- motivation towards science;
- enjoyment of science;
- attitudes of peers and friends towards science;
- attitudes of parents towards science;
- the nature of the classroom environment;
- achievement in science; and
- fear of failure on course.

The second stumbling block towards assessing the significance and importance of attitudes is that they are essentially a measure of the subject's expressed preferences and feelings towards an object. However, of themselves, they will not necessarily be related to the behaviours a pupil actually exhibits. For, as several commentators have pointed out (Brown 1976; Potter and Wetherall 1987), behaviour may be influenced by the fact that attitudes *other* than the ones under consideration may be more strongly held; motivation to behave in another way may be stronger than the motivation associated with the expressed attitude; or, alternatively, the anticipated consequences of a specific behaviour may modify that behaviour so that it is inconsistent with the attitude held (e.g. a pupil may express interest in science but avoid publicly demonstrating it among his/her peers who regard such an expression of intellectual interest as not being the 'done thing').

Consequently, it is behaviour rather than attitude that has become a focus of interest and that has led researchers to explore models developed from studies in social psychology; in particular, Ajzen and Fishbein's (1980) theory of reasoned action, which is concerned fundamentally with predicting behaviour. This theory focuses on the distinction between attitudes towards some 'object' and attitudes towards some specific action to be performed towards that 'object' (e.g. between attitudes towards science and attitudes towards doing school science). Ajzen and Fishbein argue that it is the latter kind of attitude that best predicts behaviour. Thus, their theory represents a relationship between attitude, intention and behaviour. Behaviour is seen as being determined by intention, and intention, in turn, is a joint product of attitude towards the behaviour and the subjective norm (i.e. beliefs about how other people would regard one's performance of the behaviour). The theory of reasoned action has been successfully applied to some attitude and behaviour studies in science education (for example, Crawley and Black 1992; Crawley and Coe 1990; Norwich and Duncan 1990). For instance, Crawley and Coe (1990), Koballa Jr. (1988) and Oliver and Simpson (1988) have all found that social

support from peers and attitude towards enrolling for a course are strong determinants of student choice to pursue science courses voluntarily, which suggests that the theory has at least some partial validity. The main value of such a theory is its help in determining salient beliefs that can then be reinforced or downplayed to affect relevant behavioural decisions by students such as 'girls don't do science'. Furthermore, this theory points towards the need to draw a demarcation between school science and science in society. It is the perception of school science, and the feelings towards the 'behaviour' of undertaking a further course of study in that context, which are most significant in determining children's decisions about whether to proceed with further study of science post-16.

However, ultimately, some doubt is cast on what is being measured by the many instruments that have been devised to assess attitude. Potter and Wetherall (1987), arguing from qualitative data on attitudes toward race, show convincingly that attitude instruments measure only one aspect of individual's views. Rather, any good understanding of attitude towards an object is only revealed by a study of the attitude in the context of its use. In essence, what Potter and Wetherall's work points to is that many attitude instruments only measure what is the tip of the iceberg – the most obvious and evidently displayed attitudes towards an object. Fundamentally, attitude cannot be separated from its context and the underlying body of influences that determine its real significance. In the case of school science, this points to the need to move away from general quantitative measures of attitude constructs and, instead, to explore the specific issue of students' attitudes to *school science*, and their attitude to studying further courses in science *in school* with a view to gaining information of their effect on student subject choice.

The measurement of attitudes towards school science

The following sections draw on a range of attitude studies to discuss issues of how attitudes are measured, what attitudes are found, and what factors influence attitudes. When general references are made to studies of 'attitudes towards science', these studies focus on attitudes that are a product of students' experience of school science and, unless otherwise specified, refer to their attitude to school science. Recognition of the difficulty of measuring attitudes towards school science comes in the diversity of methods researchers have taken in its measurement, which we review beneath.

Subject preference studies

Some measure of attitudes towards school science can be obtained by asking pupils to rank their liking of school subjects, which has been the approach taken by Whitfield (1980) and Ormerod (1971). Their relative popularity then gives some indication of students' attitudes towards the subject. Whitfield's analysis of 1971 IEA data for English students provided a graphic illustration (figure 2) that physics and chemistry were two of the least popular subjects post-14 and that these were distanced in pupils' minds from biology, a finding noted also by Ormerod and Duckworth (1975) and confirmed as still extant in a small but significant study by Havard (1996) and by Osborne and Collins (2000). The latter study was innovative in its use of focus groups to explore 16-year-old student's views and attitudes

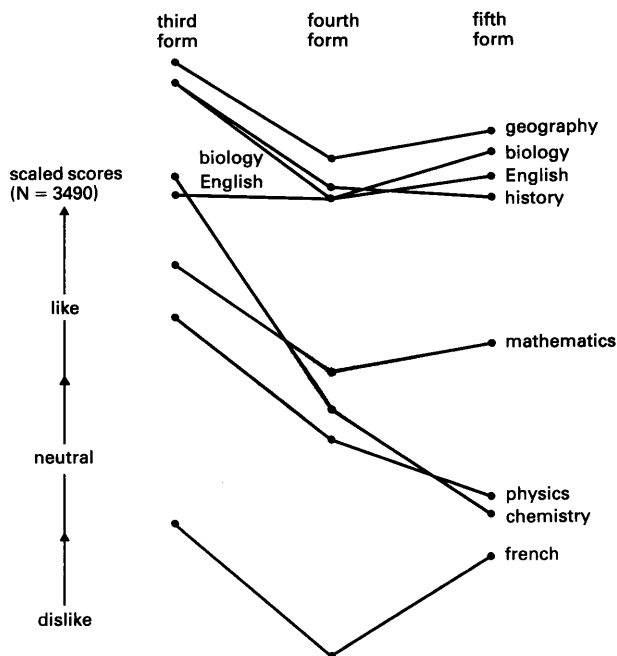


Figure 2. Attitudes toward secondary school subjects (Whitfield 1979).

towards science in depth. Perhaps surprisingly, chemistry was found to be less appealing than physics.

Whitfield (1980) argued that the rejection of science was accounted for by the perception that it was a difficult subject but his findings, based on data collected in the 1970s, now lack significance because of the considerable changes that have occurred in the science curriculum (in particular, the move to balanced or integrated science) since his study was conducted. The work of Osborne and Collins (2000) would suggest that, for many, the contemporary curriculum may suffer from the obverse problem with too much emphasis on undemanding activities such as recall, copying and a lack of intellectual challenge.

Perhaps surprisingly, Whitfield's type of study has not been repeated on a large scale. However, a recent study by Lightbody and Durnell (1996a) in one school, using a slightly more sophisticated preference ranking system, has shown that boys were far more likely to report liking science than girls – a finding given additional salience by the work of Jovanic and King (1998), which suggests that one of the major factors in girls' antipathy towards science is their perception that they are better at other subjects. Preference ranking is simple to use and the results of such research are easily presented and interpreted. Its fundamental problem is that it is a relative scale. Hence, it is possible for a student with an extremely positive attitude to all school subjects to still rank science as the least popular, and yet still have a much more favourable attitude than another student who has a strong dislike for all subjects and ranks science first. Neither is it suitable for the measurement of attitude change as its blunt nature may not expose changes in attitudes as a student's attitude to other subjects may change as well. However, this would suggest that it is an instrument not to be used in isolation rather than discarded totally. The simple

nature of this technique still provides an effective answer to the question that is essentially that asked by teachers and schools – ‘How popular is science compared to other subjects?’. It is therefore surprising that such surveys have not been repeated more often.

Attitude scales

More commonly, attitudes have been measured through the use of questionnaires that commonly consist of Likert-scale items where students are asked to respond to statements of the form:

- Science is fun.
- I would enjoy being a scientist.
- Science makes me feel like I am lost in a jumble of numbers and words.

Each item is a component in a summated rating scale that consists of a number of opinion statements reflecting either a favourable or unfavourable attitude to the object (construct) being studied. The subject is then normally offered a five-point choice consisting of ‘strongly agree/agree/not sure/disagree/strongly disagree’ to indicate their own feelings. Such items have normally been derived from the free response answers generated by students, which is the major justification for their validity. These open responses are then reduced to a set of usable and reliable items that have been piloted and further refined by statistical analysis to remove those that fail to discriminate. Such scales have been widely used and extensively trialled, and are the major feature of research in this domain. Possibly the most well known and well used is the scientific attitude inventory developed by Moore and Sutman (1970). However, this has been criticized by Munby (1983) for the inconsistent results it produces and its lack of reliability. Moreover, a feature of this scale is that all the attitude objects are concerned with aspects of science in society and not attitude to science as a school subject. The result has been the development of a plethora of scales that give differing degrees of emphasis to a broader range of attitude objects. More well-known examples are the instrument developed by Simpson and Troost (1982) for their large-scale study using 4500 students drawn equally from elementary, junior high and high schools in North Carolina, and the Attitudes toward Science Inventory (Gogolin and Swartz 1992) that is itself a modification of an instrument developed by Sandman (1973) to assess attitudes towards mathematics. Another is the Views on Science–Technology–Society instrument developed by Aikenhead, Ryan, and Fleming (1989), although this placed more emphasis on determining students’ views of the nature of science. However, their items were determined from views expressed by students and, for this reason, their instrument is often seen as offering greater validity than others. It has been adapted most recently by Bennett (2001) to determine undergraduates’ views of chemistry and develop profiles of students who held positive and negative views of the subject.

The problem of interpreting the significance of these multiple components of attitudes towards science has been clearly identified by Gardner, who comments:

An attitude instrument yields a score. If this score is to be meaningful, it should faithfully reflect the respondent’s position on some well-defined continuum. For this to happen, the items within the scale must all be related to a single attitude object. A disparate collection of items, reflecting attitude towards a wide variety of attitude objects, does not constitute a scale, and cannot yield a meaningful score. (1975: 12)

In short, if there is no single construct underlying a given scale, then there is no purpose served by applying a summated rating technique to produce a unitary score. Gardner illustrates his point effectively by use of a 'dining room table analogy'. The weight, length and height can all be measured meaningfully, but adding these three variables together to form some kind of 'Dining Table index' simply produces a meaningless, uninterpretable variable. The best that can be done is to ensure that the components are valid and reliable measures of the constructs they purport to measure and look for the significance of each of these aspects.

Even then, many instruments suffer from significant problems as, statistically, a good instrument needs to be *internally consistent* and *unidimensional* (Gardner 1995). Internal consistency is commonly determined through the use of a measure known as Cronbach's alpha and is often quoted in much of the research literature on the measurement of attitudes. However, while unidimensional scales will be internally consistent (since they all measure the same construct), it does not follow that internally consistent scales will be unidimensional. This is because a scale may be composed of several clusters of items each measuring a distinct factor. In this situation, as long as every item correlates well with some other items, a high Cronbach alpha will still be obtained. It is important that the unidimensionality of scales are tested using an appropriate statistical technique (e.g. factor analysis). If a scale does measure what it purports to measure, then the variance should be explained by a loading on a unitary factor.

Similar points, to varying degrees, can be made about the use of semantic differential scales where a word or phrase representing the attitude object (e.g. 'science laboratory', 'science lesson') is presented and followed by a bipolar pair of adjectives such as 'interesting/dull'. The adjectives are generally separated by a seven-point scale and the individual responds by marking their views on the scale.

Interest inventories

Less suspect, but more restricted, are interest inventories that attempt to measure science interest. A common technique is to present respondents with a list of items and then ask them which ones they are interested in. However, such inventories are generally restricted to their specific focus, yielding only a limited view of what may or may not be formative on attitudes to science.

Subject enrolment

Another major source of data – and a source of increasing concern – are the data on enrolments to subjects. In England and Wales, for instance, physics has been the subject of a continuing 15-year decline in numbers enrolling and passing the A-level (figure 1). However, any attribution of significance to such data as a *sole* measure of interest in science is questionable, and subject choice can be highly affected by changes in society that affect the structure of economic opportunities, the desire not to foreclose opportunities, the perceived difficulties of the subject and, particularly in the case of boys, the association of subject with gender identity – all of which may well be independent of interest in science.

Qualitative methodologies

Attempts to measure attitudes towards school science have, in the main, shown a reliance on quantitative methods based on questionnaires. A common criticism of all attitude scales derived from such instruments is that, while they are useful in identifying the nature of the problem, they have been of little help in understanding it, which has led, more recently, to the growth of qualitative methodologies. Even then, in all of the research so far published, only a few studies have attempted to explore the issue of student attitudes through the use of clinical or group interviews (Baker and Leary 1995, Ebenezer and Zoller 1993; Gogolin and Swartz 1992; Osborne and Collins, 2000; Piburn 1993; Woolnough, 1994). Ebenezer and Zoller, and Woolnough, used interview data from approximately 70–100 students to assist in interpreting and explaining their findings. So far, only two studies of high school students – those of Piburn and of Osborne and Collins, with 149 and 144 students, respectively – have relied solely on interview data. While such studies are subject to restrictions of their generalizability, the richness of data does seem to give more insight into the origins of attitudes to school science than quantitative methods indicating that both methodologies have value. For instance, it is difficult to see how the following perception of the nature of science could ever be elicited through survey methods:

- Cassie: With science it's solid information and you've got to take it down.
 Cheryl: . . . so when they teach you science you know that this is it, okay? There is nothing, you can't prove it wrong,
 Leena: In what way does that make it different to other subjects though?
 Shakira: I mean you just have to accept the facts don't you? (Osborne and Collins, 2000: 24)

What are young people's attitudes towards science?

The previous criticisms imply that, for all findings about attitudes to school science, the reliability and validity of the instrument must be examined very carefully by inspecting the constructs within the instrument rather than the overall measure. For instance, Hendley, Parkinson, Stables, and Tanner's (1995) study of 4023 Key Stage 3 pupils in Welsh schools uses overall means obtained from a Likert questionnaire. Their findings show that, out of the four core subjects – science, English, mathematics and technology – science is the least popular. However, on a five-point scale the difference is 0.37, which lies well within the standard deviation of the most popular subject (technology), and even then the paper fails to indicate whether the mean value of 3.26 is weighted positively or negatively. This view of science is confirmed by a smaller scale qualitative study based on interviews with 190 pupils (Hendley, Stables, and Stables 1996). When asked which three subjects they liked best, science was ranked fifth out of 12 subject. However, this contrasts strongly with the response to the question 'Which three subjects do you like least?', where science emerged as the most disliked subject and, interestingly, least preferred by boys. Hendley, *et al.* conclude that science is a 'love-hate' subject that elicits strong feelings in pupils.

Other recent research into subject preference has been conducted by Colley, Comber, and Hargreaves (1994), who found that there were significant gender differences among 11-year-old to 13-year-old pupils with girls favouring English and humanities, and boys favouring PE and science.

Change during compulsory schooling

A clear feature of the research is the decline in attitudes towards science from age 11 onwards that is documented by a number of studies (Breakwell and Beardsell 1992; Brown 1976; Doherty and Dawe 1988; Hadden and Johnstone 1983; Harvey and Edwards 1980; Johnson 1987; Simpson and Oliver 1985; Smail and Kelly 1984; Yager and Penick 1986). These all show how children's interest and attitude to science declines from the point of entry to secondary school. More worrying, at least in the UK, is some evidence that children's attitudes towards school science are declining even in primary schools (Murphy and Beggs 2001; Pell and Jarvis 2001). Nevertheless, in most countries, the evidence would suggest that children enter secondary school/junior high with a highly favourable attitude towards science and interest in science, both of which are eroded by their experience of school science, particularly for girls (Kahle and Lakes 1983). Such findings need to be qualified by the rider that other research shows that attitudes to all subjects decline in general during adolescence (Eccles and Wigfield 1992; Epstein and McPartland 1976). However, noting these findings about science, Hadden and Johnstone (1983) were forced to conclude that:

Tragically, it would appear that school has done nothing for them in terms of stimulating their interest in science.

In fact, Hadden and Johnstone's data show no improvement in attitude towards science from the age of 9 onwards, which leads to the speculation that, in some senses, school science education might do more harm than good!

The picture is confused by measurements of attitude undertaken by the TIMSS survey (Beaton, Martin, Mullis, Gonzalez, Smith, and Kelley 1996). For instance, in England, 78% reported as liking science or liking science a lot. More than 80% of pupils reported liking integrated science in Iran (93%), Singapore (92%), Thailand (90%), Kuwait (89%) and Columbia (87%). These data would suggest that the decline in interest may not be linear, but may accelerate rapidly from 14 onwards.

School science and the nature of the problem

A strong feature of the literature is the apparent contradiction between students' attitudes towards science in general and their attitudes towards school science. Many surveys show repeatedly that students' attitudes towards science itself are positive. For instance, the following data (table 4) from a large-scale survey conducted by the English Assessment of Performance Unit (1988) into why students chose to study science, showed that the majority of 15-year-old pupils find science both 'interesting' and 'useful for jobs', even though it is not considered 'easy'.

Similarly, a large-scale market research survey conducted in the UK for the Institute of Electrical Engineers (The Research Business 1994), based on a sample of 1552 students aged 14–16, found that students saw science as useful (68%) and interesting (58%), and that there was no significant distinction between genders. Again a large proportion saw the relevancy of science as a reason for studying it (53%) and that it offered better employment prospects (50%). Moreover, 87% of students rated science and technology as 'important' or 'very important' in everyday life. What this latter survey reveals is a clear disparity between the students' notions of science, where it is perceived in terms of technological developments in the world

Table 4. Data showing 15-year-old pupils' views about science (as opposed to school science)

Subject	Sample size		'Interesting'		'Useful for jobs'		'Easy'	
	Boys	Girls	Boys (%)	Girls (%)	Boys (%)	Girls (%)	Boys (%)	Girls (%)
	Physics	3551	1433	48	46	63	52	4
Chemistry	2224	1767	53	49	51	53	5	1
Biology	1329	4617	73	72	32	36	8	4

around them associated with personal computers, television/video/ telecommunications and developments in space, and that presented by school science, which in contrast sees the most important aspects of science as a series of milestones represented by the most significant discoveries of the last century (e.g. DNA, penicillin, splitting the atom). Perhaps most fascinating was that, if asked to name famous scientists, the overwhelming majority of students identified Einstein, Newton and Bell, demonstrating a total lack of any *contemporary* role models. This finding would suggest that students' images of science have remained unchanged since the classic study conducted by Mead and Métraux (1957), which found students' perceptions of scientists dominated by the great men (*sic*) of science, and that science education has failed to heed their recommendation to talk less about the scientist, science and *the* scientific method and use, instead, the names of the sciences, biology, physics, physiology, psychology – and speak of what a biologist or a physicist does – that is, the tales of everyday science and scientists.

Students' attitudes towards school science also vary with the specific sciences (Havard 1996, Osborne and Collins 2000; Whitfield 1980). Our work (Osborne and Collins) identifies the key demarcation between the two as one of relevance. Whereas biology, particularly human biology, was relevant and pertinent, addressing pupils' self-interest in their own bodies and concerns about health and disease, the relevance of the physical sciences was difficult for students to identify. For example, one aspect of chemistry that attracted universal antipathy among non-science pupils in this study was the periodic table. Not only did students experience difficulty in memorizing the constituents of the table, but they also failed to perceive its relevance to their everyday lives, either at present or in the future, arguing that they were never going to need to know all those equations or chemicals. In addition, the technology school science dealt with, the Haber process and the Blast furnace, was the technology of yesteryear and not that of their lives – the silicon chip, modern materials, informatics, and medical imaging. Without this essential ingredient of relevance, sustaining interest was then difficult, if not impossible. The move away in many chemistry courses from the manipulation of chemicals, chemical combination and analysis to the theoretical emphasis on intangible and microscopic entities introduces an element that appears to too many pupils to be abstruse and far removed from their daily concerns.

The contradiction between students' interest in science and their liking for school science is also highlighted by the work of Ebenezer and Zoller (1993) where, in a study in the US of 1564 Grade 10 (16-year-old) students, 72% of the sample

of students questioned indicated that they thought science to be valuable and 73% that science in schools is important, but nearly 40% indicated that they found science classes boring. A similar finding is revealed in an earlier survey of Scottish O-Grade candidates' reasons for dropping or continuing science studies post-14 (Centre for Educational Sociology 1978). Even 71% of those who had dropped science still rated it as interesting, 79% thought practical work was enjoyable and 76% that it helped you to understand things in everyday life. Both Ebenezer and Zoller, and Sundberg, Dini, and Li (1994) suggest that this gulf is due to the message presented by school science – that science is somehow disconnected from society and that we should simply study it for its own sake. This disparity, identified by these studies, between the high-tech and socially relevant perception of science held by students and the more theoretical, decontextualized version of school science promulgated by teachers, identifies a major gulf between teachers and their students that may impede effective communication. In essence, the vision that school science offers is a backward-looking view of the well-established scientific landscape, whereas, in contrast, what appeals to and excites students is the 'white heat' of a the technological future offered by science. In short, to capitalize on students' interests, school science needs to be less retrospective and more prospective.

What factors influence students' attitudes towards science?

Gender

Research studies have identified a number of factors influencing attitudes towards science in general. These can be broadly defined as gender, personality, structural variables and curriculum variables. Of these the most significant is gender for, as Gardner comments, 'sex is probably the most significant variable related towards pupils' attitude to science'. This view is supported by Schibeci's (1984) extensive review of the literature, and more recent meta-analyses of a range of research studies by Becker (1989) and Weinburgh (1995) covering the literature between 1970 and 1991. Both the latter two papers summarize numerous research studies to show that boys have a consistently more positive attitude to school science than girls, although this effect is stronger in physics than in biology. Interestingly, Weinburgh's work shows that this effect is highest for 'general science', and her finding raises the question of whether the introduction of 'balanced science' or integrated science courses during the past decade has had a similar effect in increasing the separation between boys' and girls' attitudes to science.

What is clear from an extensive literature on the subject, mainly as a result of a serious consideration and investigation of the problem in the 1980s, is that girls' attitudes to science are significantly less positive than boys (Breakwell and Beardsell 1992; Erickson and Erickson 1984; Harding 1983; Harvey and Edwards 1980; Hendley *et al.* 1996; Johnson 1987; Jovanic and King 1998; Kahle and Lakes 1983; Robertson 1987; Smail and Kelly 1984). More recent studies have been undertaken by Jones, Howe, and Rua (2000) and Sjøberg (2000) using questionnaires with large samples. In the case of the American context, Jones *et al.* were forced to conclude, despite a large number of interventions undertaken in the 1980s and 1990s, 'that the future pipeline of scientists and engineers is likely to remain unchanged'.

The predominant thesis offered to explain this finding is that it is a consequence of cultural socialization that offers girls considerably less opportunity to tinker with

technological devices and use common measuring instruments (Johnson, 1987; Kahle and Lakes 1983; Smail and Kelly 1984; Thomas 1986). For instance, Kahle contends that her data show there is a gap between young girls' desire to observe common scientific phenomena and their opportunities to do so, and the more recent work of Jones *et al.* (2000) would suggest that situation remains fundamentally unchanged. More importantly, Kahle argues that her data show conclusively that 'lack of experiences *in* science leads to a lack of understanding *of* science and contributes to negative attitudes to science' (emphasis added). Similarly, Johnson (1987) argues from her data, measuring a range of common childhood experiences of children, that 'early established differences in the interests and activities of boys and girls result in parallel differences in their science performances.' Jovanic and King (1998) have a similar thesis arguing that girls, rather than boys, make comparative judgements across academic domains. So girls' declining perception of their ability may reflect that, as the year progressed, girls perceived themselves to be better at other school subjects (e.g. English) and, therefore, not as good at science.

However, there is now some evidence beginning to appear that girls no longer hold such a stereotypical aversion to careers in science and are confident of their ability to undertake science courses (Colley *et al.* 1994; Havard 1996; Lightbody and Durndell 1996b; Whitehead 1996). For instance, Archer (1992) has found that girls aged between 10 and 15 reported liking most strongly the three subjects regarded stereotypically as 'masculine' – mathematics, science and games. Moreover, in terms of achievement in science, Elwood and Comber (1995) have shown that the situation has now reached a position, at least in the UK, where girls are doing as well, if not better than boys:

What these figures (1994 GCSE results) show is that in only one of these subjects, biology, are boys substantially ahead of girls, a subject for which girls have traditionally entered in large numbers to meet the requirement of taking a science subject. In all other eleven subjects girls are substantially ahead of boys in the proportion of A*–C grades obtained or else the gap is very narrow between the genders.

These findings suggest that gender itself may now only contribute a minor part in the attribution of success. What remains an enigma is why girls choose not to pursue science even though they are both competent and believe in their capabilities to succeed? Undoubtedly, the feminist perspective on this is that the very nature of science with its claims to universality, and its non-reflexive, value free and objective nature, are inherently at odds with feminine values that value the human and affective aspects of knowledge (Harding 1991; Keller 1985; Watts and Bentley 1993). While this remains an open question, as there are no studies that have specifically explored this aspect, some light is thrown on science's problems by a small-scale unpublished study conducted by Fielding (1998). Her original contribution was to ask girls, whose examination performance in science at age 16 indicated exceptional ability, why they chose not to study science further. Without exception, all of them indicated that they did not choose to pursue further study in science as it would limit their vocational choices to scientific careers – none of which they saw as appealing. Tobias (1990), too, found that students did not choose science because they had a fear of cheating themselves of a 'well-rounded liberal education'. Such findings are further reinforced by the work of Munro and Elsom (2000), which found that the compulsory nature of school science made less demand on science teachers to market their subject and, when they did, they

Table 5. Percentage of female university applicants accepted by subject in 1979 and 2000 (UK universities)

<i>Subject</i>	<i>1979</i>	<i>1992</i>	<i>2000</i>
Medicine	39.5	51.8	57.5
Dentistry	36.7	49.6	57.6
Veterinary science	40.8	58.8	73.9
Physics	14.6	18.0	19.1
Electrical engineering	4.3	9.2	9.0
Computer studies	26.0	14.6	19.0

predominantly emphasized its instrumental value rather than any cultural significance. Their findings would suggest that science teachers, and many of their students, still share Matthew Arnold's nineteenth-century view that scientific training is a form of education that would produce only a 'useful specialist' and not a truly educated man (*sic*). In short, that a knowledge of science has no intrinsic cultural value as knowledge, which is an essential component for the educated woman or man.

One of the major aims of balanced science courses, such as those implemented in the UK, was to remove gender bias in subject choice at age 14. Data published by Elwood and Comber (1995) shows not only that this aim has been achieved with more females entering for science GCSE (50.2% girls, 49.8% boys) despite making up only 49% of the 1994 cohort, but that more are achieving A*-C grades (45.5% girls, 45.3% boys). Moreover, the percentage of female applicants for undergraduate degrees in a range of subjects has increased significantly from 1979 to 2000 (table 5), but not in those associated with the physical sciences.

Viewed in conjunction with the data in figure 1, the data in table 5 show that there is still a substantial bias against physical sciences held by girls, suggesting that at an individual level the overwhelming majority of girls still choose not to do physical science as soon as they can. Contrary to popular belief that more girls choose to study science in a single-sex environment, two more recent studies – the youth cohort study conducted by Cheng, Payne and Witherspoon (1995) and a study based on questionnaire responses from 722 schools (Sharp, Hutchison, Davis, and Keys 1996) – both found that the uptake of physical science by girls in single sex schools was not higher than co-ed schools. The converse, however, that the uptake of arts and humanities was higher in boys only schools, was found to be true.

Whitehead's (1996) research has attempted to explore in more detail the influence of gender stereotyping on choice. She found that, although there were significant gender distinctions within pupils' perceptions of subjects, these were not significant influences on subject choice. Girls doing mainly 'feminine' subjects, who were the focus of her study, described themselves as high on the stereotypical masculine trait of competence and were highly intrinsically motivated. Boys in contrast, taking mainly 'masculine' subjects, were more likely to be extrinsically motivated for status, recognition and a highly paid job describing themselves as high on the traits of competence and aggression. In general, boys are more likely to choose sex-stereotyped careers and she suggests that this reflects a greater need to

establish and strengthen their gender identity than that of girls. Hence, she suggests: 'It is not, therefore, that girls are under-represented in mathematics and the physical sciences, but that boys are greatly over-represented; similarly, in languages, girls appear to be over-represented in these areas only because the boys are so under-represented in them'. Furthermore, she comments that: 'If boys are choosing sex-appropriate subjects in order to conform to traditional notions of masculinity, then this is clearly undesirable both from the point of view of the individual, who may not necessarily be choosing those subjects at which they are most successful, and for society as a whole, as it is unlikely to gain good scientists by such a process of choice'. Such findings would also explain why boys in boys-only schools choose more arts and humanities courses as they are under less pressure to establish and conform to their gender identity.

Evidence that substantiates Whitehead's findings comes from work by Pauline Lightbody in Glasgow (Lightbody and Durndell 1996b; Lightbody, Siann, Stocks, and Walsh 1996). In a small-scale study with 106 pupils using a novel methodology to investigate career aspirations, she found no significant difference between males and females. She explains the discrepancy between this finding and actual career choice as a case of a perception by girls that 'We can, I can't' and that gender stereotyping is so deeply entrenched that it may not even be conscious. She argues that it is not so much that science and technology are perceived as masculine, but more that the current focus of interest on technological matters is not of central interest to girls, and that only a change in content and the style of teaching to show a greater interest in people will lead to a significant increase in the choice of physical sciences by girls.

Environmental factors

Structural variables

Several studies have examined the relationship between socio-economic class and attitudes towards science. Here there are some conflicting results. Most studies have found no significant relationship, although Breakwell and Beardsell's (1992) study did find that class was negatively associated with attitude towards school science – children from lower social class having more positive attitudes. However, this finding is contrary to earlier findings by McEwen, Curry, and Watson (1986) and by Brown (1976), and the role of social class remains unclear. Breakwell's study is interesting in that, somewhat exceptionally, it does try to develop a model to account for children's attitudes. Like other studies (Simpson and Oliver 1990), it finds some evidence for a relationship between parental support and attitudes to science. In particular, Breakwell identifies attitudes to science as being more critically dependent on the support of the mother. However, as she points out, mothers may be unwittingly perpetuating the inequalities in science by encouraging their sons more than their daughters.

Breakwell's research identifies extra-curricular activities as being correlated with parental support, particularly that of the father. However, her findings are somewhat of a contradiction to those of Woolnough (1994) in that she found no correlation between attitudes toward science and involvement in extra-curricular activities, whereas Woolnough found that involvement in these was a significant factor in choosing to study science post-16. Further evidence for the value of

science clubs is provided by Kingsland (1991). However, these findings are not necessarily in disagreement as Breakwell was studying 11–16 year olds ($n = 1800$), while Woolnough's study was with post-16 children who had passed the point of choice and where the value of such activities might be more consciously recognized.

What Breakwell's research does achieve is to find a significant demarcation between liking for *school science*, which is seen as an object solely associated with schools, science laboratories and science teachers; and *societal science* perceived in terms of medical and technological developments as no correlation was found between the two. Breakwell summarizes this finding's significance thus:

Actual experience with science at school does not seem to be related to attitude towards science as a worthwhile societal enterprise and involvement in extra-curricular scientific activities. This supports the notion that science at school and science out of school should be treated as distinct and separate entities.

Another factor that seems to be a significant determinant of attitude towards school science is the attitude of peers and friends (Breakwell and Beardsell 1992; Talton and Simpson 1985). The strongest support for this finding comes from the work of Simpson and Oliver (1985) who found that the relationship increased from age 11 onwards, peaking at age 14. They suggest that the effect is a kind of snowball phenomenon with students becoming influenced by group norms. However, a better explanatory model is provided by Head's (1985) account of adolescence as a period of moratorium where the individual is attempting to establish self-identity and, hence, is more strongly influenced by the normative expectations of peers. For boys, doing science, a subject that both genders perceive as stereotypically male, and in the case of girls *not* doing science, is a means of establishing one's own gendered identity.

Classroom/teacher factors

Several studies have pointed towards the influence of classroom environment as a significant determinant of attitude (Haladyna *et al.* 1982; Myers and Fouts 1992; Talton and Simpson 1987). Classroom environment is generally measured using an instrument devised by Walberg (1969) and developed by Fraser (1986) and, perhaps not surprisingly, shows a positive correlation with attitude. In a detailed study by Myers and Fouts (1992), using 699 students from 27 high schools in America, it was found that the most positive attitudes were associated with a high level of involvement, very high level of personal support, strong positive relationships with classmates, and the use of a variety of teaching strategies and unusual learning activities. Similar evidence that variety is the spice of science education comes from the work of Piburn (1993) who, using data from interviews with 149 students (83 elementary school, 35 junior high school and 31 high school) reports that it is one of the key factors in generating interest in science education, as does the Scottish HM Inspectors of Schools' (1994) report on *Effective learning and teaching in Scottish secondary schools*. Brown (1976) too, in her earlier extensive study of the attitudes to science with 2800 12-year-old to 14-year-old Scottish secondary pupils, concluded that:

It is an examination of the nature of the teacher–pupil interaction in the science classroom; the teacher's patterns of communication with individual pupils and groups of pupils; the

transmission of the teacher's expectations to the pupils; the particular topics that are covered in the lessons; and the strategies and tactics within strategies adopted by the teacher, that we can be hopeful will provide variables that will be profitable in explaining differences in attitudes to science among pupils, and, perhaps tell us why pupils' feelings about science become so negative by the end of S2.

Similar conclusions that 'school, particularly classroom variables, are the strongest influence on attitude toward science' were drawn by Simpson and Oliver (1990) from their extensive and major longitudinal study conducted in North Carolina. Further support for this view on the importance of effective pedagogy is provided by the detailed work of Cooper and McIntyre (1996) in their study of effective teaching in history and English (admittedly not in science, but in subjects that are more popular than science). The latter researchers found that there were common aspects of teaching that were perceived to be effective by both teachers and pupils. These were:

- clear goals for pupil learning;
- clarity of communication of lesson goals and agenda to pupils;
- use of preview and review of lesson content;
- helping students to contextualize content in terms of their own experience and knowledge, as well as in terms of other teaching goals and learning experiences;
- some willingness to allow pupils to have input into goal and agenda setting;
- a supportive social context designed by the teacher to help pupils feel accepted, cared for and valued;
- an ability and willingness to allow for different cognitive styles and ways of engaging with the learning process among pupils, through multiple exemplification, and the use of different types of illustration and mode of presentation, and offering pupils a choice from a menu of possible ways of engaging; and
- a willingness to take into account pupil circumstances and to modify/pace/structure learning tasks accordingly.

Evidence that it is the quality of teaching of school science that is a significant determinant of attitude towards school science has also been found by Woolnough, whose research showed that it was a major factor in continuing with science education post-16. This finding is confirmed by Ebenezer and Zoller's (1993) study of Grade 10 (age 15/16) students' attitudes towards science and by Haladayana *et al.*'s (1982) study (1965 10-year-old, 13-year-old and 15-year-old students) of student attitudes towards science, both of whom found that the most important variable affecting students' attitude was the kind of science teaching they experienced. Further support for the significance of the teacher can be found in the work of Sundberg *et al.* (1994), who examined the attitudes towards science of 2965 college students, of Piburn (1993) and of McMillan and May (1979). A small-scale qualitative study by Hendley *et al.* (1995) of Key Stage 3 pupils' preferred subjects also found that one of the most common reasons given for liking or disliking the subject were teacher-related comments. Woolnough conducted a more extensive study of subject choice in 1991 with 1180 A-level students who had, and had not, chosen to study science using a mix of attitudes questionnaires and interviews. In addition, 132 Heads of science completed a separate questionnaire, and 108 sixth

formers and 84 staff from 12 schools were interviewed. His study identified six factors that were responsible for student choice/non-choice of the sciences. Of these the two strongest factors were the influence of student's positive experience of extra-curricular activities and the nature of in-class activities; that is, the quality of the science teaching. Taken together, this body of findings strongly suggests that the quality of teaching is an important determinant of attitude and subject choice.

The factors Woolnough identified as contributing to such teaching included a supply of well-qualified, enthusiastic graduate science staff (including graduates in physics and engineering), who not only have a good spread of expertise across science, but who also have individual subject loyalty. Good teaching was characterized by teachers being enthusiastic about their subject, setting it in everyday contexts, and running well-ordered and stimulating science lessons. Good teachers were also sympathetic and willing to spend time, both in and out of lessons, talking with the students about science, careers and individual problems. One implication of the introduction of national or standards-based curricula, suggests Woolnough, has been the tendency to restrict and de-skill the good science teacher, with the loss of those 'extra bits', in particular extra-curricular activities, that contribute to good science teaching. One of Woolnough's recommendations for preserving good science teaching is that teachers should teach what they feel comfortable with, as teachers in the study were happiest and most enthusiastic teaching their specialist subjects – a finding that clearly has implications for the organization of the curriculum in separate versus integrated disciplines.

One original study undertaken in the US provides some insight on significance of teachers (Tobias 1990). Tobias' study aimed to explore why so many college students turn away from science in the course of their degree studies and involved a group of post-graduates who had successfully completed their degrees in other subjects. For a fee, the group of surrogate students were willing to re-visit introductory courses in physics and chemistry in order to audit these for the research. They each enrolled for a particular course and participated in it, attending all the lectures and doing the homework assignments and examinations. They were asked to focus their attention on what might make introductory science 'hard' or even 'alienating' for students like themselves. The seven case studies in the report reveal some common problems with introductory courses that were found to be alienating; the courses focused on problem-solving techniques, and lacked an intellectual overview of the subject; there were too many 'how much' questions, not enough discussion of 'how' or 'why'; pedagogy was condescending and patronizing, examinations were not challenging; there was no community or discussion and the atmosphere was competitive. One student summed up the problem as 'the absence of history or context, "the tyranny of technique", the isolation of the learner and the struggle to attend in a sea of inattentiveness' (1990: 59).

These research findings, then, provide strong confirmatory evidence for children's and adults' anecdotal stories about the influence of teachers on students' attitudes to school science and on subject choice. Furthermore, they raise substantial questions about why the pedagogy of some science teachers is so unappealing to the majority of students, suggesting that, while science teachers may be knowledgeable about their subject, they are failing to achieve their primary task of establishing a range of varied learning opportunities and communicating their subject effectively. Havard's (1996) work suggests that the problem lies with physics, as over 50% of his sample indicated that they did not enjoy the subject at all, or very

little, whereas over 60% enjoyed biology a lot or quite a lot. One factor may be that physics is often taught by teachers who lack specialist knowledge and who have little enthusiasm for the subject. In such situations, teachers who lack confidence and familiarity fall back on didactic modes of teaching and the quality of teaching and learning is impoverished. For instance, in England, surveys indicate that there is within the science teaching community a considerable imbalance in the subject specialisms of 'science teachers' that is weighted heavily towards a specialism in biology (Dillon, Osborne, Fairbrother, and Kurina 2000). Moreover, such candidates are normally significantly better qualified and of a higher calibre. The consequence is that biology, wherever it is taught, is more likely to be taught by a specialist with enthusiasm and interest and, as we (Osborne and Simon, 1996) and other workers (Shulman 1986; Turner-Bisset 1999) have shown, teacher subject knowledge *is* a determinant of effective teaching. As Tobin and Fraser (1988), in their study of American teachers point out:

because teachers did not have the content knowledge, errors of fact were made and opportunities to elaborate on student understandings and to diagnose misunderstandings were missed. In some instances, flaws were evident in attempts to explain concepts with which students were having difficulty and, in other cases, analogies were selected which compounded student problems in understanding concepts. The net result of teachers' lack of content knowledge in high school classes was an emphasis on learning of facts and a sewing of seeds for the development or reinforcement of misconceptions.

This argument would also explain Woolnough's (1994) and Sharp *et al.*'s (1996) findings that separate subjects were more successful at engendering interest and take-up of physical science at A-level as they would have predominantly been taught by subject specialists.

Likewise, Sparkes (1995) makes a cogent case that the reason more pupils study physics in Scotland is because physics teaching is carried out almost exclusively by qualified physics teachers.

It is a self-perpetuating cycle. The proportion of youngsters who study physics at the post 16 level is more than three times higher in Scotland than in England. This, in turn, leads to a higher proportion of university students taking physics-based courses and results in a higher output of such graduates. The pool of potential physics teachers in Scotland (taking into account the different populations) is thus twice as great as in England. In turn, this results in more highly qualified physics teachers, better physics teaching in schools, and more physics students. In short, *Scotland has no shortage of physics teachers, because it has no shortage of physics teachers!* (1995: 111; original emphasis)

Finally, these research findings raise the question why, despite the recurrent message of the significance of teachers, and teacher styles, on attitudes towards science, so little research has been attempted to understand what makes for effective teaching of science in the eyes of the pupil. Taken with the comments about the significant formative influence of teachers on students' attitudes to science found in the work of Osborne and Collins (2000), we are forced to conclude that the single most important change that could be made to improve the quality of science education would be the recruitment *and retention* of able, bright enthusiastic teachers of science.

Curriculum variables

By far the largest number of studies conducted in science classrooms have been comparison studies of the influence on students' attitudes of new, as compared with

traditional, curriculum materials or instructional techniques. Most of these studies have been conducted in the US and, apart from a major study focusing on Harvard Project Physics, have been small-scale enquiries. The results have not been conclusive. As Gardner commented (1975), 'in most cases, a particular treatment group's mean attitudes have been shifted a fraction of a standard deviation along the attitude continuum' providing little, if any, meaningful information. Similarly, nearly 20 years later, Simpson, Koballa, Oliver, and Crawley (1994) expressed such a view in perhaps even stronger terms:

The science education literature contains hundreds if not thousands of reports of interventions designed to change attitudes. Development of programs to influence the likelihood of certain science-related attitudes is important because it is assumed that changes in attitude will result in changes in behaviour. Unfortunately, few simple and straightforward generalisations can be made about how and why science-related attitudes change. (1994: 223)

The conclusion is that studies of this type yield little meaningful information about innovations that do or do not positively affect attitude. Thus, the influence of curriculum on students' attitudes remains an unanswered question. The key problem in these studies is that they have entailed making comparisons in student outcome measures between those following an 'experimental' curriculum and those following a 'normal' curriculum without undertaking an analysis of the ways in which the curricula differ. Thus, it is not possible to make any generalizations about the way in which attitudes or other outcome measures are influenced by particular curriculum features. More recent studies, particularly those undertaken from a gender perspective, do indicate that a science curriculum that relates to students' interests and life-world experiences engenders a more positive attitude in both boys and girls to school science. In addition, Woolnough (1994) found that, for a small minority of academic pupils (usually boys), interest and enthusiasm for science was stimulated by the challenge presented by the abstract and mathematical aspects of science, particularly physics, and the desire to explore the subject in more depth.

The evidence to date would suggest that, since the fundamental nature of the problem is negative attitudes towards school science, useful insights could be obtained by *focused studies* of classrooms where *effective teaching of science*, as judged by students, was to be found. For the research evidence shows clearly that it is the teacher variables that are the most significant factor determining attitude, not curriculum variables.

Perceived difficulty of science

Several recent studies (Crawley and Black 1992; Havard 1996; Hendley *et al.* 1996) have identified students' perception of science as a difficult subject as being a determinant of subject choice. In fact, Havard's investigation of the uptake of sciences at A-level, albeit in only four schools, points to the perceived difficulty of science as *the major* factor inhibiting uptake.

Further substance to the notion that physical sciences are perceived as being difficult is provided by the recent analysis of the data collected in the UK on the youth cohort for 1989, 1990 and 1991 using sample sizes of approximately 14,000 for each year (Cheng *et al.* 1995). These researchers found that the most significant factors correlating with uptake of physical sciences were the grades achieved at GCSE in science and mathematics. This suggests that science is only taken by

students who do well and not as an incidental or additional subject. Whether this is a self-imposed restriction or a selection criterion imposed by schools is essentially irrelevant – the fact that only able pupils do physical sciences reinforces the notion that it is for the intelligent and therefore difficult. Is it possible, therefore, that physical sciences now have a similar image in students' minds to that associated with Greek in the 1960s – a subject that was only done by the very able or the slightly eccentric?

Studying science is perceived as a risk. The work of Kahneman and Tversky (1984) provides some insight into the effect of such perceptions on subject choice at the point of choice. Their study found that when the negative aspects of a course of action were emphasized, people preferred to risk the choice that leads to the definite avoidance of *loss* rather than risk an opportunity that may have *no loss* whatsoever. Thus, school students confronted with a choice that is high risk, although potentially with high financial gain (i.e. doing science with its concomitant risk of failure) and one of lower risk (i.e. the greater certainty of success with arts-based courses), will choose the low-risk option even though the financial rewards may be less.

Such findings led Simpson and Oliver (1990) to conclude that attempts to persuade students to pursue science would be more successful if they sought to emphasize *lost* career and educational opportunities rather than emphasizing the benefits of careers in science. Hence, rather than selling the positive aspects of being, for instance, an engineer or research scientist, teachers should emphasize the certain loss – that without science qualifications the student can never be a doctor, an engineer, etc.

Enhanced subject choice

One clear feature of the post-16 curriculum for students, at least in the UK, is the growth in a much wider range of subject choice in the past decade. Psychology, economics, business studies, sociology, theatre studies, and sports studies are a few of the new and growing number of A-levels that are on offer. Some of these contain aspects of science within them. No research has identified what effect the increasing range of choice has had on individual student choice. In part, such research is difficult to do because of the difficulty of gathering meaningful data retrospectively. However, it clearly is a factor identified by Smithers and Robinson (1988) and Tarsh (1994) for the demise of students studying only mathematics and sciences. Within the English system, students' choices from this range were, until recently, limited to three subjects. Students' attempts to achieve a balanced selection from the wide range of choice may well account for the growth of mixed A-levels and the drift away from science

Attitude and achievement

The relationship between these two variables is a key issue for consideration permeating much of the literature. For much of the generalized concern and interest in attitudes towards school science is based on a somewhat simplistic notion that 'the best milk comes from contented cows' (Fraser 1982). However, Gardner's review of the research evidence offered little support for any strong relationship between attitude and achievement. Writing somewhat later, Schibeci (1984) draws

a stronger link between the two, quoting studies that show a correlation of 0.3–0.5. However, he also cites studies that show no relationship. The current position is best articulated by Shrigley (1990), who argues that attitude and ability scores can be expected to correlate moderately. Likewise, the measures used in the TIMSS study, albeit somewhat unsophisticated, have found a consistent relationship between attitude and achievement (Beaton *et al.* 1996). Weinburgh's (1995) meta-analysis of the research suggests that there is only a moderate correlation between attitude towards science and achievement, although this correlation is stronger for high and low ability girls indicating that, for these groups, 'doing well' in science is closely linked with 'liking science'. Similar findings have appeared in the major study conducted by Simpson and Oliver (1990), by Jovanic and King (1998) and by Osborne and Collins (2000).

The exception to these findings is the research of Oliver and Simpson (1988). These authors would argue that their longitudinal study shows a strong relationship between the three affective variables – attitude towards science, motivation to achieve and the self-concept that the individual has of their own ability – and their achievement in science. In part, this may be explained by their attempt to measure motivation to achieve that may be a more significant factor than attitude toward science in determining achievement. In this context, it is interesting to note the general finding that girls are always more motivated to achieve than boys. This finding might then explain why English and Welsh national science examination results demonstrate that, although boys are more positively inclined toward science as more of them choose to study it and are keener to pursue the subject post-16, their achievements relative to girls are inferior.

Within all of the literature, there is some disagreement about the nature of the causal link and whether it is attitude or achievement that is the dependent variable. The essential premise permeating much of the research is that attitude precedes behaviour. Somewhat in contrast, the work Millar and Tesser (1986, 1989) would suggest that the affective and cognitive components of individuals are often independent of each other. Perhaps the only tenable position is that the two are inescapably linked in a complex interaction. Research clearly shows that early childhood experiences serve as a major influence on academic interest. Feelings of enjoyment and interest in science combined with success in junior science courses are likely to lead to a positive commitment toward science that is enduring. Nevertheless, this is only a partial picture and children can achieve highly in science without holding a positive attitude towards it.

Cultural attitudes towards the study of science

This aspect of students' attitudes to science has rarely been investigated but has become more prominent recently from data collected on admissions to universities and teacher training analysed by Taylor (1993) and Modood (1993). These show that, compared with their white peers, Asian students have a clear preference to study for degrees in medicine-related studies, engineering or mathematics. Moreover, a disproportionately low percentage apply to become teachers. In contrast, Afro-Caribbean students seem to shy away from science preferring to pursue degrees in the social sciences. More recent American research with over 1000 students in Grade 3, Grade 6, Grade 8 and Grade 10 also shows a similar picture, indicating that ethnic origin is significantly associated with attitudes

towards science and a career in science (Greenfield, 1995). Caucasians were found to have the most positive attitudes towards science and Japanese-Americans were most positively inclined towards scientific careers. In this research, the influence of ethnic origin was found to be more significant than gender.

Woodrow (1996) explores the reasons for these findings in some depth, arguing that research on pupil life stories shows that Asian parents have a particularly important affect on student career choice. Within Asian families, career decisions will generally tend to favour longer term advantages compared with the more individualistic and immediately attractive choices made by students within contemporary Caucasian cultures in which personal enjoyment and/or perceived ability may play a more significant element. Moreover, within mainstream English society, the valuing of professions above trade is deep seated, reinforced by the financial disparities between arts-related careers and the sciences, and a nineteenth-century disdain for anything that is not rooted in the classics or Christianity (Barnett 2001). Some antipathy to science is shown by one of Breakwell and Beardsell's (1992) findings that a negative attitude to science is correlated with pupils coming from middle-class families. However, if science-based careers are less economically profitable, why are they the predominant choice with the Asian community? As Woodrow points out, all the research has done so far is show that different groups hold different perspectives on the value of science-based careers and possibly science itself. Moreover, as Lemke (2001) cogently argues from a socio-cultural perspective, contemporary science is a product of European cultures, and a middle-class subculture at that. For those who lie outside the orbit of such cultures by virtue of their ethnic origin or social status, the nature of what counts as knowledge and what counts as explanation may be startlingly different. Changing students' minds, therefore, requires more than their assent to the bare facts, logical structure and epistemology of Western science. For it demands, in addition, a felt commitment, a bond with a community and a change in identity that, some would argue, is equivalent to a cultural border crossing (Aikenhead 1995). The implication drawn by Lemke is that it is no longer tenable to imagine that engaging with science is an equivalent process for all demanding only logical thought and application, and that, rather, cultural and class difference may be a significant aspect of many pupils' attitudes towards science.

Conclusions

This paper has sought to provide a review of the many facets of research on students' attitudes to science. The increasing attention to the topic is driven by a recognition that all is not well with school science and far too many pupils are alienated by a discipline that has increasing significance in contemporary life, both at a personal and a societal level. While the body of research conducted has been good at identifying a problem, it has had little to say definitively about how the problem might be remediated. Our view is that science educators have much to learn from the growing body of literature on the study of motivation (Bergin 1999; Dweck 1986; Dweck and Leggett 1988; Hidi 2000; Paris 1998). The common feature of much of this work is a recognition of a distinction between individual and intrinsic interest, and situational and extrinsic interest. The latter is stimulated by contextual factors such as good teaching that stimulate interest and engagement. Hidi in particular has argued that the role of situational interest is highly significant in classrooms or subjects where

children are disinterested in the subject at hand or are academically unmotivated. Paris argues that the essential ingredients of motivation are opportunities to choose, challenge, control over the pace and nature of learning, and collaboration. Likewise, Wallace's (1996) detailed research on the views of pupils about learning and its implications led her to conclude that engagement was raised by opportunities for pupils to take control of their learning and greater pupil autonomy. Further support to this is lent by our work (Osborne and Collins 2000) that found pupils desired more opportunities in science for practical work, extended investigations and opportunities for discussion – all of which provide an enhanced role for personal autonomy. School science, as currently taught and constituted, and because of its power and the consensus that science commands, offers 'little space for the pupil as an autonomous intellectual agent' (Donnelly 2001). The essential irony of a discipline that offers intellectual liberation from the shackles of received wisdom is that the education it offers is authoritarian, dogmatic and non-reflexive – an aspect captured by Claude Bernard, the famous nineteenth-century scientist in his statement that science is a 'superb and dazzling hall, but one which may be reached only by passing through a long and ghastly kitchen'.

While it would be difficult to transform the nature of science offered in most curricula, at least in the short term, such work does suggest that a better understanding of the attributes of science classroom activities that enhance 'task value' might make a significant contribution to how the quality of students' experience might be improved. Eccles and Wigfield (1995) describe 'task value' as the degree to which an individual believes that a particular task is able to fulfill personal needs or goals and it consists of three components: *interest*, or the enjoyment that a student derives from engaging in a task; *importance*, or the degree to which a student believes it is important to do well on a task; and *utility*, or the degree to which an individual thinks a task is useful in reaching some future goal. If, as Eccles (1987) has argued, 'task value' beliefs are central to explaining the nature of students' attitudes to science, then it would suggest that identifying those tasks which are viewed positively, the reasons why, and their differentiation by such factors as gender, social class and ethnicity should be a central concern for research in this domain if we are to offer prescriptive solutions and advice to science teachers on how to improve the quality of the classroom experience. It is somewhat surprising that so little work has been done in the context of science classrooms to identify what are the nature and style of teaching and activities that engage students. For lest it be forgotten, attitudes are enduring while knowledge often has an ephemeral quality. The price of ignoring this simple fact and its implications is the potential alienation of our youth and/or a flight from science – a phenomenon that many countries are now experiencing. There can, therefore, hardly be a more urgent agenda for research.

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