The Curriculum Journal
Vol. 17, No. 3, September 2006, pp. 229–246

The impact of authentic learning on students' engagement with physics

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The changes in the statutory science curriculum specification for all students aged 14–15 in England and Wales in 2006 herald a shift in how curriculum content is organized, and the purposes for science learning. In a curriculum for scientific literacy the selection of social situations and scientific controversies determines the knowledge that is required. The goal for students' learning is to enable them to participate competently in a world permeated by science and technology. Such changes involve recognition of the situated nature of science and the situated nature of learning; hence authenticity is at the core of students' curriculum experiences. To support students as they learn about the nature of science and the communities and situations where science is created and used requires a wide range of primary and secondary sources. Energy Foresight[1] is a set of multimedia resources to support the teaching and learning of 'Radioactive materials' in the new curriculum. The article describes and discusses the main evaluation findings of the impact of the Energy Foresight resources on students' engagement and learning, noting in particular the impact of the approach to authenticity in the resources. 279 students were involved in various aspects of the national implementation of the resources. The findings showed that students enjoyed the opportunities to engage with physics in the context of relevant social and personal issues and professional practices. The impact on girls' views of the relevance and interest of physics was dramatic, as was the increase in their learning. The impact on boys, though positive, was much smaller in effect. The findings also revealed some unintended effects, particularly for some boys and for students new to the approach, as they moved from certainty about what they believed they understood about science, to more reflective awareness of the complexity of using scientific evidence to make judgements about risks and benefits.

Keywords: *Constraints and boy's learning; Cultural and personal authenticity; Enhancing girls' participation; Physics learning; Radioactivity*

Introduction

It is an international phenomenon that as students progress through schooling their interest in, and liking for, science declines (Osborne *et al.*, 2003). This decline is

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ISSN 0958-5176 (print)/ISSN 1469-3704 (online)/06/030229–18

DOI: 10.1080/09585170600909688

more rapid for physics than other science subjects, and more dramatic for girls than for boys (Hoffmann, 2002; Spall *et al.*, 2004). What research there is indicates that central to this decline are students' perceptions that the abstruse theoretical content in physics and chemistry lacks relevance to and meaning in their lives (Osborne & Collins, 2001). What is disputed is whether this decline in interest is a problem, given current economic arguments about skills shortages in science (Hayward & Wright, 2006). However, the decline has been used to challenge the national science curriculum for students aged 14–16 by those who advocate an alternative model of science education on the basis that the current curriculum up to 2005 was 'ill-suited to the needs of the majority' (Millar *et al.*, 1998, p. 19). *Beyond 2000: science education for the future* (Millar & Osborne, 1998) offered a new vision of science education that, it was argued, would halt the decline in students' interest and ensure a citizenry that was scientifically literate as opposed to scientifically alienated.

The style and extent of the content of the then current national curriculum specifications were blamed for encouraging teachers to adopt a 'transmission' mode of teaching. Teachers have commented on the lack of time available to cover all the content of the science curriculum and prepare students for their examinations at age 16 (Osborne & Collins, 2000). The need to 'rush' through the science content placed students in a passive role as receivers, rather than constructors, of knowledge. This meant that they experienced only a narrow range of pedagogic strategies, and rarely had their ideas, and even rarer, their values and concerns about science, considered. Furthermore, practical work, so valued by students (Sharp, 2004), was typically a ritualistic instruction-led exercise rather than an agentive experience of problem-solving and decision-making (Murphy & McCormick, 1997). All of these attributes were associated with students' disengagement from the subject.

A further claim was that the uniformity of the science curriculum provision for all students failed to take account of the diversity of interests and aptitudes of students aged 14–16. Thus, the decline in students' interest in science, it was argued, was a product of an undifferentiated curriculum. The solution has been a change nationally in the nature of the specified science curriculum and its assessment, which was introduced in 2006. Scientific literacy is now the statutory core science that all students must study from age 14–15 and this is assessed in a single examination, the General Certificate of Secondary Education (GCSE) Science. Students at age 15 can then either choose not to study any further science or they can continue with science via two routes. One route is through GCSE Additional Science, which is the traditional academic route that prepares students for further science study post-16. Another route is through GCSE Additional Applied Science which provides a basis for progressing to a range of post-16 technical, pre-vocational and vocational courses involving science.

The scientific literacy core requires all students to be taught: (1) a broad understanding of the main scientific explanations for making sense of the world; and (2) an understanding of the workings of science, i.e. the practices that produce scientific knowledge, the reasoning that is involved in scientific argument and the consequences when scientific knowledge is put into practice. These key scientific ideas, practices and ways of thinking are to be learned in the context of current scientific debates about social issues and dilemmas. The contexts selected had to be relevant to students either in the present or in the future. The assessment of scientific learning had to reflect these curriculum requirements. Thus, the continuous assessment element of the GCSE Science examination involves students in the collection, analysis and evaluation of scientific data, and in case-studies where they explore scientific issues of interest to them (Burden, 2003). A major shift represented by the new curriculum is in the selection and organization of content. The choice of content is driven by a different purpose from that of the previous science curriculum as the social situation and scientific controversy explored determine the content. Providing students with opportunities to pursue their own interests as they explore scientific knowledge production also introduces an element of uncertainty and diversity in the content covered.

Evidence (see Murphy & Whitelegg in this issue) from the implementation of science courses which embed canonical science knowledge in socially and culturally relevant contexts suggests that they enhance girls' access and achievement while maintaining that of the boys. Thus, the pilot of the new curriculum, the Twenty First Century Science suite of courses,[2] had the potential not only to impact on the decline in students' interest, but also to engage girls who were choosing in significant numbers not to continue with their study of physics post-16.

Energy Foresight resources

The Energy Foresight (EF) multimedia resources were independently commissioned by the North West Regional Development Agency and the British Nuclear Group to support the teaching of the Twenty First Century Science core module 'Radioactive materials'. The resources include three 20-minute television programmes made available on DVD: 'Radiation and health'; 'Power production'; and 'Radioactive waste'. The programmes are accompanied by teaching notes, student activities and a dedicated website.

Authenticity and the Energy Foresight resources

The new curriculum has no explicit theoretical rationale yet the view that students need to engage in the workings of science suggests that its rationale, and that of courses based on it such as Twenty First Century Science, is linked to international developments in science education that see mind as situated (Roth, 2001). In this view of mind, learning takes place in a participation framework as part of on-going activity in a social context (Lave & Wenger, 1991). Consequently, learning and knowledge emerge through action with others and are distributed among co-participants. Thus, knowledge is understood as an aspect of practice, discourse or activity rather than as a commodity or possession of an individual (Sfard, 1998). From this stance, to learn about science requires students to 'do' science. Therefore to learn about the workings of science, students need to participate in the practices and activities in which professional scientists engage, or an activity appropriate for them, that corresponds closely with these ways of working. This is what is referred to as culturally authentic science learning.

The new curriculum for scientific literacy recognizes that a diverse range of people create and use scientific knowledge. This alters how the nature of science is represented from a vision of uniformity and certainty enshrined in the traditional science curriculum, to one of heterogeneity and complexity. It also alters the range of problems, practices and potential solutions with which students engage. Scientific discourse, that is the forms of talk, communication and argumentation employed by scientists, is central to the practice of science. Scientific discourses are taken up in particular ways by communities of users of science, be they professional communities of practice, or lay communities concerned with the public understanding of science. A major aim of the Twenty First Century Science course is to engage students in culturally authentic learning environments where they participate in science-based discourses around social issues involving a range of communities.

The Energy Foresight resources meet the requirement of cultural authenticity in a number of ways. Learning is situated in the professional lives of those who use science, for example professionals and technicians using radiation in medicine or in power production. The science behind radioactivity is introduced and discussed in relation to professional practices, for example, in the diagnosis and treatment of cancer, and the management of nuclear waste. The 'Radiation and health' topic involves several activities where students look at the risks and benefits of using radiation and draw on a range of information sources, such as a National Radiological Protection Board patient leaflet. Students are shown in the programme a procedure where an isotope scan of the thyroid using radioactive iodine is carried out as part of the process of diagnosis. They then have to role play working in a nuclear medicine department, discussing how they would explain to a patient the benefits of having a scan in relation to the risks.

Cultural authenticity also requires students to participate in critically evaluating the knowledge claims of science. To understand the situated and contextual nature of science students need opportunities to reflect on the positive and negative aspects of science and, in so doing, to consider its fallibility. One example of how this is addressed in the EF resources is an activity where students have to consider alternative approaches to the treatment of cancer. Another example involves students in debates around power production. Students have to evaluate the ways in which scientific evidence is interpreted and used in the arguments advanced by spokes-people working in the different power production fields, and by pressure group representatives. To achieve these different forms of authenticity requires different teaching and learning strategies, in particular a much greater emphasis on research, discussion, role play, critique and debate, and these are embedded in the EF student activities.

Personal authenticity relates to learners' ability to perceive value and meaning in what they are asked to do and learn. Twenty First Century Science incorporates personal authenticity in the curriculum by using contexts for students' learning that are relevant to their current or future lives. Relevance cannot be 'given'. It has to be perceived and therefore needs to be transparent to students. This is addressed in the EF resources in different ways. In the 'Radiation and health' programme the science and the professionals are introduced in a case-study of a patient as she is diagnosed and treated for cancer. This is intended to have immediate relevance to students' lives and those of their families and friends. In 'Power production' professionals are involved in discussing different production means and their economic, environmental and social risks and benefits. In 'Radioactive waste' students are introduced to the magnitude of the waste problem, the different approaches to its management and the risks associated with these, for different levels of radioactive waste. It is anticipated that students would perceive these social issues to be relevant to their future lives.

Past research has found that, as students go through schooling, their view of radioactivity as harmful becomes an increasingly dominant one (Boyes, 1994). It is also a topic where, after teaching, students continue to hold confused ideas about key concepts (Alsop, 2001). Research shows too that students have strong feelings and beliefs about radioactivity, such that their willingness to engage with the topic might be even more problematic than other physics topics. Alsop and Watts talk about a potential goal for such a topic as achieving for students 'equilibrium between their wariness of issues and an informed view of matters' (2000, p. 138). This was in many respects what the Energy Foresight resources hoped to achieve.

The evaluation study

The trial of the Energy Foresight resources preceded the changes to the national science curriculum and coincided with the pilot of Twenty First Century Science. The trial ran from July 2004 to December 2005 (Murphy *et al.*, 2005) and began with a series of professional development days for teachers across the country. Teachers from the schools piloting Twenty First Century Science (the pilot sample) and from schools continuing with the then current curriculum specifications (non-pilot sample) were involved. The EF resources were designed to 'fit' the content and teaching approach of Twenty First Century Science, such that the degree of match between the resources and the curriculum specifications taught by teachers in 2005 varied. This had several consequences for the evaluation study. For the non-pilot teachers using the current curriculum specification the content covered in the resources spread over a number of topics. The EF resources also included content not covered in the 2005 science curriculum specifications. This meant that the non-pilot teachers typically implemented only fragments of the EF resources. More importantly, the curriculum objectives that the non-pilot teachers were guided by were in terms of physics content and not social situations and professional practices.

Data collection methods

Participation in the evaluation was voluntary. Data collection had to minimize disruption for teachers and their students. Consequently, the evaluation data were collected mainly by questionnaires. Teachers at the professional development events completed an evaluation questionnaire about their views of the professional development and the EF resources. A sample of the professional development events was observed. Of those teachers who intended to implement the EF resources in the trial period a sub-sample agreed to complete a planning questionnaire and a post-implementation questionnaire. A further subset of these teachers agreed to administer student pre- and post-implementation questionnaires. These were to ascertain the impact of the EF resources on students' understanding and attitudes. In a small number of cases teachers and their students were interviewed.

The sample

There were only a small number of teachers involved in the pilot of the new curriculum and of these 23 attended the professional development events. The majority of teachers ($N = 107$) were from non-pilot schools; 95% of teachers completed an evaluation questionnaire. Ten teachers who implemented the EF resources in the time-frame of the evaluation study completed the student data collection. Three were pilot teachers in an independent school, a girls' grammar school and a mixed comprehensive school in the north-west and south-east of England. The pilot student sample was in Year 11 (age 15–16) and in the GCSE higher groups. Two of the three teachers and six students were interviewed.

The remaining seven teachers were from non-pilot schools, one being a boys' selective state school and the remaining schools were mixed comprehensives in the north-west of England. The non-pilot student sample was predominantly from Year 11 spread across foundation level (46%) and higher level (40%).[3] Two teachers and nine students were interviewed.

For the purposes of the article the findings from the students ($N = 279$) engaged in the implementation are prioritized with brief reference to teachers' views.[4] In reporting significant changes pre- and post-implementation, because of the sample size (pilot pre- and post- $N = 53$; non-pilot pre- and post- $N = 81$), we included findings only at $p < 0.01$ or lower.

Table 1. Summary of sample characteristics

	Pilot	*Non-pilot*	*Total*
Teachers attending professional development	23	107	130
Classes providing student data	3	7	10
Students completing pre- and/or post-questionnaire	64	215	279
Students completing both pre- and post-questionnaire	53	81	134
Students interviewed	6	9	15
Teachers interviewed	2	3	5
Male:Female ratio in student samples	40:60	56:44	51:49

The findings

Teachers' views

The professional development days were very well received, with 79% of teachers rating them as very good or good, which rose to 90% for the pilot teachers. The ratings for the Energy Foresight resources were even higher, with 85% of the teachers considering them very good or good, rising to 95% for the pilot teachers. The programmes received the highest ratings of the resources, 90% of the teachers rating them very good or good compared with 75% who considered the supporting text materials to be very good or good. 'Power production' received the highest rating, followed by 'Radioactive waste' and then 'Radiation and health'. The teachers in their ratings of the programmes appeared to give value to the more traditional content as the 'Radiation and health' programme and activities were the most radically different in content and pedagogic approach.

In interview teachers who implemented the resources continued to rate the resources as excellent and considered all the programmes to be very effective in motivating students and supporting their learning. One teacher in a pilot school commented on the way that the science learning was represented in the resources, explaining that when students could relate to what they were learning it increased their understanding of physics:

> The medical stuff, there was one girl in the group whose [relation] had recently had a brain tumour treated, and she was okay with it, and that was something of a focus, so when students had first hand experience I think they got a lot out of it.

The teacher appreciated the real-life situations covered in the programmes:

> I liked where they had the actual information that was given to a patient who'd been treated with radioactive iodine. That was very relevant and really got me thinking about that particular situation. I think that's one of the strengths of these materials, where it directly relates to what you might have experienced.

The teacher described an advantage the programmes gave her as a teacher, with the students now able to see different locations relating to their science learning:

> I also feel that it was useful for them to see the different methods of power generation actually in action at the different kinds of power stations because you're always geographically limited by what you can offer.

A teacher in a non-pilot school thought that the resources being up to date added to their credibility with students:

> There was a very modern approach, whereas all the videos and DVDs we'd shown before, the medical applications were, almost as if they'd been in their infancy. These were

> obviously state of the art, it looked as though if you walked into any hospital and you go into any department where they're doing this, this is exactly what they'll be doing.

The pilot teacher recognized the shift in the learning objectives represented by Twenty First Century Science and embodied in the Energy Foresight resources.

> In terms of opening up debates about how we generate power and what we do about nuclear waste, it's not dealing with the theory, it's dealing with how we apply it, how we use it.

The non-pilot teachers tended not to be aware of the challenges to traditional scientific content that Twenty First Century Science posed, though they were concerned about the motivation for students' learning and recognized that this often came about from social situations of the type represented in the EF resources.

> they need to make that link between the political, the environmental and the science as well, if we could get that then you've got a whole live debate opening up.

These differences in learning goals and experience of the new curriculum were not insignificant and did influence both what was implemented and how it was implemented, which needs to be remembered in considering the findings reported.

Students' views—liking for science and physics

Before the implementation, 41% of pilot students compared with just over 30% of non-pilot students reported that they liked science because it was interesting. The ratings for liking physics were lower, with about a quarter of pilot students compared with a fifth of non-pilot students liking physics because it was interesting and because it helped them understand the world and themselves. There was a difference across the two samples, with the non-pilot students reporting low levels of liking for both science and physics because of the lack of relevance to their lives (see Table 2). For the pilot students the lack of relevance was more of a problem for physics than science, and it should be noted that there were more girls in the pilot sample than boys. Both samples considered that science and physics were not subjects that offered opportunities for discussion.

Table 2. Pre-implementation findings about liking for science and physics

Pre-implementation	*% Pilot students*	*% Non-pilot students*
Liked science because it was relevant to their lives	39	18
Liked physics because it was relevant to their lives	20	15
Liked science because they discussed issues	16	13
Liked physics because they discussed issues	13	7

Overall, far more boys than girls reported they liked physics, for a variety of reasons. For example, before implementation twice as many boys as girls considered physics interesting; and whereas nearly 40% of boys thought physics helped them with understanding themselves and the world, this was the case for only 16% of girls.

After the implementation the pilot girls showed a very significant shift in their liking for physics ($p < 0.000$) in terms of it now being reported to be a subject that was interesting (pre-implementation 16%; post-implementation 41%), where they discussed ideas, and which helped them to understand themselves and the world and was relevant to their lives. There were no significant shifts for the pilot boys.

> *Girl*: It wasn't just like a textbook, it showed that these things actually happened and it made it seem more real, you were able to comprehend it better and understand it more because of that. . . . It was more about the world around you, and I think that's more interesting, you know, better in terms of the future really.

For the non-pilot students, for both boys and girls, there was a significant increase in the numbers seeing physics as interesting and a subject where they discussed ideas, and which helped them to understand themselves. There was a significant shift for girls in perceiving the subject as relevant, with no change for boys.

> *Girl*: I think they were in like the medical side of it, because part of my family have used like a treatment to cure disease and all that. It helped me understand a lot more of what the family were going through, you know, like what they had to do and what happened to them. It reassured me a bit that they were getting the right treatment.

The finding that girls' perceptions of relevance and interest shifted after study of EF indicates that the focus on social issues and the problems that confront real people more closely matched girls' concerns and goals for their learning than the traditional curriculum (see Murphy & Whitelegg in this issue). Girls expressed most interest in the 'Radiation and health' programme and activities, followed by 'Radioactive waste'. They showed a low level of interest in 'Power production'. Boys' interests were first and foremost in 'Power production', they shared the same level of interest as girls in 'Radioactive waste' and a slightly lower interest in 'Radiation and health'. The interviews with girls revealed that embedding the approach in real-life situations, and allowing different perspectives to be considered, were the reasons why they valued the 'Radiation and health' programme.

> *Girl*: When you read from a book, it's hard to imagine how things are going to work. I think, the radiotherapy one, I think that helped the most because you saw how it was done and that. . . . I just liked the way they showed what they actually done, and I just think that was quite interesting, because people go through that every day.

Boys also valued being able to 'see' beyond the classroom:

> *Boy*: To see how the massive, huge, landscape that was just full of containers [nuclear waste], I liked seeing how much we use it, it put it all into perspective, and how we get to dispose of them.

The observation that boys overall found the 'Radiation and health' programme the least interesting corresponds with reported differences in girls' and boys' approaches to context. Boys are more likely than girls to ignore context or to discount it as extraneous, because it gets in the way of them seeing the science that they have to learn or the task they have to address (Boaler, 1994; Whitelegg & Edwards, 2001). The 'Radiation and health' programme was considered to be the most difficult by boys in both samples. For girls, context gives value and purpose to their learning (Murphy, 2000). 'Power production', which girls reported as least interesting, is much more traditional in its approach to the content.

The majority of boys and girls considered the programmes accessible and this was to do with the approach.

> Usually you're just like looking at question answers in a book or whatever, but with this you get to discuss what you thought, and I did think that was good.
>
> I thought it was interesting being able to find out like different people's views and sometimes it's raised issues that I hadn't really thought about before.
>
> Helped me visually to understand what they were, because it's hard to visualize it in your mind when someone's just talking, but if you see it on video it helps.

Changes in measured understanding of science ideas and concepts

The student questionnaires included a knowledge probe to see if there was a measurable impact on understanding. Before the implementation boys overall demonstrated a significantly higher level of understanding than girls. After the implementation, across both samples, there was a significant increase in students' understanding. This was more so for the pilot sample than the non-pilot sample which was anticipated because of the restricted implementation of the resources in the non-pilot schools.

After the implementation the increase in understanding for the pilot sample was largely attributable to the very significant increase in girls answering the questions correctly, with the achievement gap between the boys and girls disappearing. Average scores for the pilot sample rose from 46% to 63% ($p < 0.000$). The boys started at a higher level than the girls and changed little, from 60% to 65%. The girls started at a much lower level but changed considerably from 38% to 62% ($p < 0.000$).

For the pilot sample there was a 40% increase overall in the number of students correctly understanding radioactive decay. The proportion of girls understanding this increased from 12% to 70% while the proportion for boys increased from 48% to 62%. Boys' understanding of nuclear fission did not change, 67% getting this correct before and after their study. There was a 47% increase in the number of girls getting this correct after their study. There were small positive changes in boys' understanding of sources of background radiation and significantly larger increases for girls, with about a third more understanding that microwave ovens, cosmic rays and radon gas were sources of background radiation. Understanding of the penetration of the three different types of radiation showed a significant increase for both boys and girls, although this was most dramatic for girls. There was a 62% increase in the number of boys understanding the most damaging radiation per mm of travel and a much smaller increase in the number of girls (19%). Students' understanding of irradiation changed significantly with 33% more boys and 60% more girls understanding this after their study. The proportion of students understanding contamination increased from a very low level for boys (from 5% to 30%), and a smaller but positive increase in understanding for girls (from 28% to 47%).

The non-pilot teachers tended to emphasize power production rather than radioactivity in their implementation and this was reflected in the reduced increases in students' understanding compared with the pilot students. There were very small increases for both boys and girls in understanding of radioactive decay; inconsistent gains in understanding about background sources of radiation; and significant increases in understanding of the penetration of different types of radiation. The proportion of boys understanding this after the implementation nearly doubled (from 32% to 62%) and the proportion of girls understanding this tripled (from 16% to 50%). There was a smaller increase in understanding about beta radiation (boys from 43% to 65%; girls from 30% to 50%) and gamma radiation (boys from 56% to 78%; girls from 34% to 59%).

These findings are illuminating if linked to the increase in the proportion of girls that, after their study of EF, reported that they viewed physics as a subject that was relevant and interesting. The change in content and approach represented in the EF resources appears to have increased girls' engagement and extended the possibilities for their learning about physics. This, coupled with the approach that gives value to discussion and alternative perspectives, compounded the positive impact for girls and this is evident in the significant changes in their understanding of key concepts within the topic. It was not the case for all girls, however, and this might reflect the quality and nature of the implementation or it might say something about differences between girls yet to be researched. The approach has not had a negative impact on boys' learning, but the positive impact is very much reduced and this may relate to issues raised earlier about how the approach to the content and the pedagogical strategies used may be less familiar to boys than girls.

Changes in opinions

The pilot students experienced an implementation much more focused on the social issues and dilemmas than the non-pilot students and this had an effect on how the issues were approached and addressed. One major aim for students engaging in critical reflection about the contribution of science to social problems and issues is to enable them to develop informed opinions. To consider this, students were asked their opinions on key issues before and after the implementation. The pilot girls reported significant positive shifts in their opinions about: the benefits of using radioactivity to fight disease, and to identify medical problems; and the acceptability of people working with radioactive materials. There were negligible changes in the opinions of the non-pilot students, except for the increase in the boys' positive response to using radioactive materials to treat diseases.

In the traditional science curriculum the tendency was to consider one variable in isolation, such as sustainability, when learning about renewable energy sources. From this standpoint renewable energy sources are a good thing. The EF resources, on the other hand, require students to evaluate alternative viewpoints and weigh up the advantages and disadvantages of different forms of power production. The pilot boys were more likely to consider that renewable energy sources were unreliable after their study of EF, with 24% agreeing with this before the implementation, rising to 48% after implementation. Girls' views remained unchanged: a third agreed, a third were unsure and a third disagreed that renewable energy sources were unreliable. The impact of exploring social issues from a number of standpoints was evident in the significant decline, for the pilot sample, in their view of the desirability of investing in renewable energy resources, where boys overall became less certain. Their interviews revealed that they were now forming opinions based on a number of related variables:

> *Boy*: I don't think we could ever produce as much electricity as we do now, you know, using fossil fuels, as we would with renewable. But I think if we don't worry too much about what it'll look like, like wind power. They do take up a lot of landscape, and they don't look like the nicest things, but I think it's worth it if we people can replace that, than get caught using all this fossil fuel.

> *Girl*: I think it was good because it went through separately things like wind . . . and you were able to easily understand the pros and cons of it. Issues about, like solar power, for example, it was a really good idea but it was really expensive and, you know, gave facts and figures.

> *Girl*: It made me realize more than I used to, about some new stuff coming out, other energy instead of using fossil fuels and nuclear and stuff. It made me realize that something was actually happening.

The pilot students were well aware that fossil fuel sources were limited, and awareness of their contribution to environmental pollution increased after their study. The proportion of boys and girls agreeing that fossil fuels should not be part of future power production increased from 68% to 81% for boys, and only slightly less for girls, from 72% to 78%.

> *Boy*: Fossil fuels. I mean when it's harming us isn't it, how we're using so much, and global warming and causing the earth to overheat, which is like why we are getting all these freak weather conditions now.

When asked to consider whether they could foresee any problem with extending the use of nuclear power, the students were fairly open to the suggestion, with the proviso that the problem of dealing with nuclear waste would first need to be solved.

> Yes, because it also has an effect on the environment, like when the power station's finished with . . . and if it's like not controlled, it can kind of go wrong.

The tendency for some students to become less certain about their prior opinions is unsurprising in retrospect, as the whole approach of Energy Foresight is dilemma driven and this requires students to engage with complexity in making decisions about risks and benefits. There were changes at the individual level that indicated students' more reflective stance:

> *Girl*: I always thought it [radioactivity] was bad, but from watching the programmes and talking about it I know that it can help. I found how radioactivity can help the medical profession. I found that really interesting.
>
> *Girl*: [commenting on the use of radioactivity to treat disease] I think they'd like explore other options, like see what all the different options are and then look at the advantages and disadvantages of each of them and then decide from that.
>
> *Boy*: I think like consider how bad the problem is and whether the effects of the radiation will do more damage to them than this disease will in the end, and see that the radiation will actually give them a chance of living while the disease is going to spread and get worse.

Students appreciated the opportunities provided by the EF resources to develop their opinions:

> *Boy*: We do have discussions in class, but I think, after looking at the programme and then having a discussion you actually know a bit more about it, so you get more of an informative debate especially if you can give it more thought. You have a lot more chances to explore your own mind rather than just keeping it closed in, and you get a chance to hear other people's points as well.

Changes in students' ratings of understanding of science ideas and concepts

Any radical curriculum changes can have unintended effects in their initial implementations. Students form 'habits of mind' based on how to do science in ways that are valued in the curriculum and in its assessment. We measured changes in students' learning but were also concerned to examine students' views about what they felt they had learned. Students were asked to rate how well they understood topics covered in the EF resources, before and after the implementation. Just as students' opinions often moved from certainty to a more considered position so too, in their ratings about their understanding, there was often a decline after the implementation in how well students thought they knew a topic. This appeared to be because what they had previously understood in a simple way was now more complex. Aikenhead argued that learning was more complex when canonical knowledge is embedded in socially and culturally relevant contexts:

> The greater the social or cultural relevance associated with canonical content, the greater the student motivation to learn but the greater the complexity to learn it meaningfully. (Aikenhead, 2003, p. 53)

Overall, more boys than girls rated their initial understanding highly, and there was evidence from the knowledge probe that this had some basis in fact. However, after studying the EF resources, many realized that they had not understood issues as well as they thought, which affected the degree of change in understanding reported. We discuss a few examples of this next.

The 'Power production' programme and activities were aimed at informing students about the advantages and disadvantages of different energy sources rather than just learning about *how* they were used to produce power. The perceived complexity of the topics impacted on how well students thought they understood how electricity was produced. The proportion of the pilot sample reporting they knew this very well or well decreased for boys from 91% to 57%, with a small decrease for girls from 58% to 53% after the implementation. An improvement in learning was reported by 10% of boys and 26% of girls. After their study the number of pilot boys reporting they understood the benefits of different energy sources 'very well' decreased by half (from 38% to 19%) and more reported that they understood the topic well (43% to 57%). In contrast, only a third of the girls reported understanding the benefits of different energy sources well before their study and this increased to three-quarters (75%) after their study. Overall, 19% of boys and 65% of girls reported an improvement in their understanding of the topic.

The differences between girls and boys in the non-pilot sample were smaller than for the pilot sample. For example, for the non-pilot students the decline in reported understanding about how electricity is produced was noted for 48% of the boys and 50% of the girls. An improvement in understanding was reported by 27% of boys and 28% of girls. The decline in reported understanding was generally for those students who started the topic believing they understood it very well or well and deciding after implementation that they had a good understanding or an average level of understanding. Understanding of which energy sources were renewable was rated by 68% of boys and 43% of girls as very good or good before implementation and this declined to 32% of boys and 23% of girls after the implementation. There were significant numbers of students reporting that their understanding was less than they had expected (56% boys; 40% girls).

The findings suggest a potential effect on boys generally, and on girls new to the curriculum approach, that is unintended but perhaps unsurprising. Recognizing and understanding complexity is indeed an important aspect of learning, but students who have been encultured into a view of science that is about facts and concepts are less likely to appreciate this. It is possible that this change in learning goals may unwittingly reduce some students' sense of self-efficacy in physics and lower their self-esteem.

Changes in job awareness

Students' lack of awareness of science-related careers has been identified as one reason for the decline in their interest. It has also been noted that science teachers are less likely than other teachers to discuss the importance of science for future careers with career advisers (Munro & Elsom, 2000). The EF resources involved a wide range of professionals and this aspect of the resources was welcomed by the case-study teachers.

> I liked the link with careers, because I do think there needs to be more. You constantly get, why do I need this? I don't need this in my life, this isn't going to affect my life at all. And I think by showing them that there are careers in science it does make it more relevant.
>
> It was a great benefit to them, and I think a lot of them might actually be thinking well, maybe that might be a career for me.

It was generally the girls who reported an increased awareness of science-related jobs after studying Energy Foresight, with between a quarter and a third moving from being not aware to aware of a range of technical and professional jobs in science, engineering, medicine, power production and nuclear waste management. Although girls' awareness of science-related careers had shifted, there was little change in their personal plans:

> Not really because it's not really the sort of thing that I had in mind to do when I'm older. I want to become a music teacher. I'm going to college to study music.
>
> Well, I'm not really thinking about a career in science, so not really.

The EF resources did help some of the boys extend their career horizons:

> Definitely, yeah, and that's opened my mind to it a lot more, knowing different ways you can go about it and different thing you can get into. I've always been a lot more based around chemistry where I've done my best results in, and it's opened it a lot more to other aspects of science as well, definitely.
>
> Well, working with people, yes, and what they have to go through, maybe a GP or something, when a doctor tells the patient what can be done and helps them to understand it. You've got to tell the patient about the risks and consequences fairly, and seeing as I'm quite good at biology, it does make me think about something to do with being a GP.

The findings from the evaluation reflect what is now increasingly reported from research into gender and science, that in the short term changes to the curriculum and its assessment can have a major impact on girls' access, participation and achievement in physics, yet they do not impact on girls' view of the subject in terms of their future lives. This requires more fundamental and long-term changes (Murphy & Whitelegg, 2006).

Discussion

The particular strength of the EF resources was the approach to cultural and personal authenticity. Both teachers and students welcomed this approach and there was a significant impact on girls' participation and learning. Although the impact on boys was less positive, students made it clear how much their learning benefited from visualizing complex issues and having access to world views that made the classroom walls permeable for them. The findings about the change in girls' views, and the impact on their understanding of radioactive materials, suggest that the decline in girls' interest in physics can be significantly affected by appropriate changes in the organization and teaching of physics. As girls' views of their self-efficacy in physics can often be low relative to boys, it would be important for teachers to provide positive feedback to girls on their physics achievement so that they can come to see themselves as competent to study the subject. Not all of the contexts used in the EF resources were equally appealing to girls and boys. This suggests the need for teachers to elicit students' perceptions and feelings about the social situations in which their science learning is embedded, as part of teaching and learning.

The teacher is, as always, a crucial factor in curriculum innovation. Although the shift in girls' views of the interest and relevance of physics occurred across the samples, the most dramatic shifts were for the pilot sample. The pilot teachers' pedagogy was in line with the pedagogy implicit in Energy Foresight, and this may not be the case for other teachers. There is also need for caution about whether the impact is positive for all girls and, indeed, whether there is potential for negative impact on boys. Traditional approaches to physics have not been identified as problematic for many boys as they rely on content and contexts that boys are more likely to be familiar with than girls. Hence, increasing the range of contexts and social situations in which to learn about physics will be challenging for some boys, especially if the value of the changes is assumed and not made a matter for discussion and teaching.

Some students expressed fears about the social aspects of the topics, fears which relate to common-sense understandings about the dangers of radioactivity and which influenced their learning. Expressing such concerns is not something that is typically done in traditional science classrooms. Students need to feel that it is valid to express their emotional responses as well as their cognitive responses in a curriculum concerned with scientific literacy where ethical issues are confronted. This will be a further challenge for many teachers.

The shift in learning objectives, where students have to consider dilemmas and weigh up evidence, is another potential challenge, particularly for students who have learned how to be successful in physics. Teachers need to be aware of how the approach raises students' awareness of the complexities of issues and that for some students this means that they can become insecure about their scientific understanding, particularly some boys. Students need to feel secure in their understanding of the explanatory scientific ideas while also being aware of the situated, contingent and contextual nature of science, and the uncertainty of decision-making about future social issues. The challenge for teachers will be to achieve this while maintaining the context and social situations as the determinants of the content to be learned.

The teachers did not regard career awareness as an appropriate topic for teaching. Having cultural authenticity as a core feature of the science curriculum means that there is the potential radically to improve career awareness, by making it integral to subject learning. It has been noted that physics self-concept is a key determinant of attitudes to physics (Murphy & Whitelegg in this issue). Students' motivation to continue to study science is, therefore, as dependent on their future views of themselves in relation to the subject as their current views. The approach in the EF resources, and more widely in Twenty First Century Science, should encourage students to reflect on the social situations and purposes of different careers, and to consider the types of practices associated with them, and how they might feel about engaging in these. This may make some students rethink the future they envisage for themselves and enable all to accept or reject future possibilities from an informed position.

The evaluation of Energy Foresight has provided support for the potential positive impact of the new national science curriculum on students' engagement in physics. The findings identify a number of sources of professional development needs. In any curriculum innovation there is the potential for unintended effects. The evaluation findings indicated what some of these might be, and it will be important that these too become part of the continuing professional development for teachers of the new curriculum.

Notes

1. Produced by Software Production Enterprise (EF) Limited.
2. Twenty First Century Science is developed jointly by the Nuffield Curriculum Centre and the Science Education Group at the University of York.
3. The higher level covers grades A*–D (an E grade can be assigned but rarely is); and the foundation level covers all the grades up to grade C.
4. See the full report (Murphy *et al.*, 2005) for the detailed teacher feeback.

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