
18 **Biotechnology and Genetic Engineering: Student Knowledge and Attitudes: Implications for Teaching Controversial Issues and the Public Understanding of Science**

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Abstract

Knowledge and attitudes towards biotechnology and genetic engineering have been investigated in a questionnaire study of 188 14–15-year-old students (112 males, seventy-six females) drawn from six schools in England.

One-third of the sample, and more males than females, did not know what biotechnology or genetic engineering was, and nearly half the sample could not give examples of biotechnology or genetic engineering. Internal consistency of response to attitude questions was high. Attitudes of students were context-dependent: there was broad approval of genetic engineering applied to microbes and plants but not of genetic engineering applied to animals; females were particularly unsupportive of genetic engineering applied to farm animals.

Teaching about genetic engineering increased student knowledge levels and reduced uncertainty of attitudes leading to increased approval of genetic engineering in all contexts surveyed.

This paper concludes with a consideration of the implications of these findings for the teaching and learning of controversial science–society issues and for a curriculum which addresses the public understanding of science.

Introduction¹

Durant (1990) has summarized the rationale for concern about the public understanding of science into three categories; cultural, practical and political. The first concerns the need for people to be informed about what are probably the most important achievements of our time, that is science as part of our heritage. The second concerns the need to understand how some of the everyday science-based technologies work at the functional level. The political rationale is about democracy in action. Effective citizen participation depends upon access to particular knowledges such that policy issues may be subjected to critical scrutiny. It is in this respect that the importance of disseminating scientific and technological information is accentuated. (Dickens, 1992; Science Museum, 1994; Ziman, 1980). The significance of the public understanding of science and the related public attitudes

is demonstrated by the activities of science/technology-based commercial concerns, The Royal Society and various social action groups (e.g., animal rights, conservationists etc.) (Irwin, 1995; Roberts, 1988; Turney, 1994). In general, these activities aim to close the gap between scientists and general public. They include the staging of special events, innovative ways of presenting science to the public through day conferences, exhibitions, etc. or concentrate upon developing scientists' communication skills.

Formal education offers unique opportunities for the improvement of the public understanding of science. Not only can it provide access to the majority of the future population, it has an explicit function to develop pupils' scientific understanding in preparation for adult life (Husen, 1991; Jenkins, 1990). It is also the main arena in which non-scientists learn about science (Cross and Price, 1991; Dixon, 1989). This potential within schools has been capitalized by various anti-science pressure groups. Schools and students are the principal targets for publicity and promotion of their views (Parliamentary Office of Science and Technology, 1992). Despite this, the significance of particular school experiences for the development of conceptual understanding of, and attitudes towards, science-society issues has only rarely been empirically investigated. (Lock and Miles, 1993; Lock, Miles and Hughes, 1995.)

The place in formal education of biotechnology, and in particular genetic engineering, has been reinforced in syllabuses offered to 14–15-year-old students by the prominent position afforded to such work by the Science National Curriculum in England (Department for Education and Science (DES), 1991). However, inclusion in the National Curriculum is not the only rationale for studying such a topic in schools. For most people the period of formal education is the major lifetime opportunity for understanding the science that will impact on their lives and lifestyle. Adults are expected to play a full and responsible role in society which includes applying the knowledge, understanding and attitudes gained from their study of science to their everyday life. Biotechnology and genetic engineering are aspects of science content rich with opportunities for work of this kind.

Method

This study was carried out using 188 students (112 males, seventy-six females) drawn from six schools in central England. The schools involved included independent and maintained, selective and comprehensive, single sex and coeducational. They had urban, suburban and more rural catchment areas and contained students from a wide range of religious and cultural backgrounds. Students were involved over a period of at least two double lessons. Although this was an opportunity sample and not one selected at random to be representative of 14–15-year-old students in general, it was a carefully constructed group of schools and classes, and there was no reason to suspect any specific bias in the sample.

The study involved three elements:

- 1 a questionnaire that measured knowledge and attitude (15/20 minutes);
- 2 teaching materials/activities (90/120 minutes); and
- 3 questionnaire (15 minutes).

The first questionnaire was developed to measure the level of knowledge and type of attitudes that students held about biotechnology and genetic engineering before any teaching on the topic. It used open-ended questions to assess knowledge and a Likert-type scale to measure attitude. It was administered by the teachers involved in the study during science lessons at the schools in the survey.

Activities in the lessons were student-centred and involved comprehension exercises and small group discussion of ethical and moral issues involved in genetically engineering bacteria, tomatoes and sheep.

The second questionnaire was administered at the end of the second/third lesson devoted to the study. It replicated the knowledge questions involved in the first questionnaire and a selection of the attitude scale items as well as including open questions that explored what students thought about the materials and the work they had studied.

The questionnaires had been subjected to small-scale trials prior to the study and validation by administering in one-to-one situations with students as semi-structured interviews.

Earlier papers have reported on student knowledge and attitude (Lock and Miles, 1993) and on the influences of teaching upon them (Lock *et al.*, 1995). Here a brief synopsis of the earlier findings is presented to set the context for the bulk of this paper which focuses on the implications of the findings for teaching controversial science and society issues.

Results

Student Knowledge

Responses were categorized and then collated for gender and the whole sample from questionnaires administered *before* (B) the teaching materials and activities were introduced and *after* (A) the exercise was completed. Results are presented in Tables 18.1 and 18.2. Both tables show a low 'no response' rate, possibly indicating a high level of student interest and involvement in the study. The rate of 'no response' to examples of genetic engineering (Table 18.2) was higher than for the other question, possibly because this included candidates who knew no examples but did not respond rather than stating 'don't know'. This view is substantiated by the drop in 'no response' to this question after the exercise, whereas in Table 18.1 there is an increase in such responses. This latter pattern is expected from some adolescents in a study of this kind where a near-identical questionnaire is administered twice with only a short time interval.

About 50 per cent of the sample did not understand what genetic engineering meant prior to the teaching. The exercise has increased understanding of the term.

Table 18.1: What does genetic engineering mean?: Pupil knowledge before and after related teaching (Multiple responses recorded)

Response	Before Males (n = 112)	After Males (n = 108)	Before Females (n = 76)	After Females (n = 71)	Before All (n = 188)	After All (n = 179)
No Response	5	9	9	4	14	13
Don't know	33	5	17	7	50	12
Manipulate/change/alter genes	32	47	20	20	52	67
Manipulate/change/alter organisms	24	37	18	11	42	48
Reference to DNA or gene	19	21	17	13	36	34
Transfer genes	7	10	2	9	9	19
Genes from one organism to another	1	2	5	0	6	2
Select characteristics	1	4	2	10	3	14
Make genes	2	3	3	0	5	3
Cure diseases	1	1	0	2	1	3
Precise form of selective breeding	0	13	0	19	0	32
Cells from one organism to another	0	4	0	0	0	4
Reference to genetic fault	0	1	0	2	0	3
Reference to specific product	0	4	0	1	0	5
Other	0	7	0	6	0	13

Source: Lock *et al.*, 1995

More students understood that the process involves manipulating, changing and/or altering genes and/or organisms. Others preferred a less specific definition that saw it as a precise form of selective breeding or as selecting characteristics. There were about 20 per cent of the sample who referred to DNA or genes but who did not show an understanding of how they were involved in genetic engineering. The percentage of such students was the same both before and after the lessons. After teaching, about 10 per cent saw the process as involving transfer of genes, but few

Table 18.2: Pupil knowledge of examples of genetic engineering before and after related teaching (Multiple responses recorded)

Examples	Before Males (n = 112)	After Males (n = 108)	Before Females (n = 76)	After Females (n = 71)	Before All (n = 188)	After All (n = 179)
No response	13	12	13	9	26	21
Don't know	42	2	30	4	72	6
Humulin	16	3	15	6	31	9
Cystic fibrosis	10	2	3	1	13	3
Genetic fingerprinting	0	0	7	4	7	4
Improve cereals	4	4	0	8	4	12
Cross breeding	5	1	2	2	7	3
Prevent diseases	3	2	0	2	3	4
Improve food taste	1	6	1	3	2	9
Improve food quality	1	2	1	2	2	4
Genetic implants	1	0	2	1	3	1
Develop flower colour	3	0	1	0	4	0
Pharmaceuticals from sheep milk	0	24	0	11	0	35
Reduce tomato spoilage	0	50	0	16	0	66
Authentic human milk from cows	0	6	0	6	0	12
Tomato shape	0	0	0	2	0	2
Improve yield	0	3	0	1	0	4
Increase plant variety	0	3	0	6	0	9
Other (not genetic engineering)	12	13	4	10	16	23

Source: Lock *et al.*, 1995

made the specific point that the transfer of genes is from one organism to another. Some misconceptions occur as the result of teaching with, for example, the belief that whole cells are transferred from one organism to another.

Table 18.2 shows that the teaching reduced the size of the 'don't know' response considerably. It appears that knowledge of examples of genetic engineering was enhanced more successfully than knowledge of the definition. As with

Table 18.3: Reliability of student response (Percentages to nearest whole number)

Statements	M F T			M F T			M F T			M F T			M F T		
	I strongly agree			I agree			I'm not sure			I disagree			I strongly disagree		
*8. Altering the genes in fruit to improve their taste is not acceptable to me.	3	7	4	15	24	19	11	13	12	52	55	53	19	1	12
*28. Altering the genes in fruit to improve their taste is not acceptable to me.	2	8	4	15	17	16	8	22	14	52	49	51	23	3	15

* Numbers show positions of statements in the questionnaire

Key: M = males, F = females, T = total sample

Source: Lock *et al.*, 1995

Table 18.1, there are data that suggest students learn incorrect information. For example, in Table 18.2 an increase in examples which are not genetic engineering is shown.

Overall, the increase in student knowledge of examples of genetic engineering was pleasing.

Student Attitudes

Attitude measurement is fraught with a number of difficulties, not least their ephemeral and vacillating nature, sometimes even within the timespan taken to complete a questionnaire. With this in mind, the first questionnaire had a statement repeated in exactly the same format within its structure (statements 8 and 28). The results from these questions are given in Table 18.3 and show the high level of consistency of response achieved.

There are a range of factors that could influence pupil attitudes in an exercise such as this. It is tempting to ascribe changes in attitude, if any, solely to the work involved in this study. This will be a factor, and a major one at that, but it will not be the only factor involved; other factors may emanate from outside the science laboratory.

The attitude statements used before the teaching and learning activity showed broad approval for genetic engineering applied to microbes and plants but more disagreement with applying the process to animals (Table 18.4). Females were particularly unsupporting of genetic engineering in animals.

The major change that is noted between the two questionnaires is in the reduction of the 'I'm not sure' responses. Such a pattern was seen in response to ten of the thirteen statements (Lock *et al.*, 1995). Two of the statements where such a decrease was not observed related to genetic engineering of animals.

A reduction in the uncertain response is heartening as it suggests that teaching and learning about controversial issues can help students to clarify their position.

Table 18.4: Attitudes to genetic engineering (Percentages to nearest whole number)

(a) Microbes															
Statements	M F T			M F T			M F T			M F T			M F T		
	I strongly agree			I agree			I'm not sure			I disagree			I strongly disagree		
*19. Microbes should be genetically engineered to make them more efficient at decomposing human sewage.	23	20	22	59	58	59	14	20	17	2	1	2	2	0	1
(b) Plants															
*9. Altering the genes of plants so that they will grow better in salty soils is acceptable to me.	22	5	15	61	61	61	9	21	14	7	11	9	1	1	1
*18. We should not alter the genes in plants to get them to make more oils useful in manufacturing.	5	1	3	19	25	21	17	16	17	47	55	51	13	1	8
(c) Animals															
*2. Changing the genetic make up of farm animals should be banned by law.	21	26	23	26	34	29	31	28	30	16	12	14	6	0	4
*13. Inserting genes from human cells into the fertilized eggs of sheep is acceptable to me.	3	0	2	7	0	4	21	18	20	31	46	37	38	34	36

* Numbers show position of statements in the questionnaire

Key: M = males, F = females, T = total sample

Source: Modified from Lock and Miles, 1993

However, reduction in the level of uncertain response is not the only indicator that attitudes had changed over the period of study.

There was also a reduction in the level of disagreement with genetically engineered changes in over half of the statements (Lock *et al.*, op. cit.). Such a finding suggests that most of those who changed their responses from 'I'm not sure' moved to a position where they supported genetic engineering.

Table 18.5 shows that more females than males disapproved of genetic engineering, particularly in contexts where animals are involved but levels of disapproval between the genders differ little with respect to manipulation of microbes. Table 18.5 further shows that a majority approved of genetic engineering in animals where drug production was involved for the treatment of human or animal conditions.

Table 18.6 highlights the influence that teaching activity or style may have on student attitudes. In one school (Y) the majority of students disagreed with the statement that changing the genetic make up of farm animals should be banned by

Table 18.5: Attitudes to genetic engineering for pharmaceutical and veterinary products before and after related teaching (Percentages to nearest whole number)

Attitude to Genetic Engineering for Human Medicines

(a) Microbes

		M	F	T	M	F	T	M	F	T	M	F	T	M	F	T
Statements Before/After Teaching		I strongly agree			I agree			I'm not sure			I disagree			I strongly disagree		
*14. I am against changing the genes of microbes so that they make medicines for humans.	Before	2	0	1	7	7	7	10	26	17	54	49	52	28	17	23
*6.	After	2	1	1	7	6	7	10	16	12	50	59	54	31	18	26

(b) of Animals

*20. Genetically engineering cows to produce life saving drugs for humans is not acceptable to me.	Before	6	5	5	19	24	21	18	22	20	39	37	38	19	9	15
*10.	After	3	4	3	9	17	13	16	21	18	49	44	46	23	14	20
*23. Using genetically engineered sheep to produce medicines for humans is a good idea.	Before	13	7	11	39	32	36	19	29	23	22	25	23	7	7	7
*12.	After	15	10	13	45	49	47	16	21	18	19	16	18	5	4	4

Attitude to Genetically Engineering Animals for Veterinary Products

*18. Changing the genes of animals to produce vaccines to treat animal diseases is not acceptable to me.	Before	4	1	3	18	17	18	16	29	21	44	43	44	18	8	14
*9.	After	4	3	3	16	18	17	18	27	22	44	45	45	8	7	13

* Numbers show positions of statements in the questionnaires

Key: M = males, F = females, T = total sample

Source: Modified from Lock *et al.*, 1995

Table 18.6: Differences in attitude between students in two schools after teaching activity

	I strongly agree	I agree	I'm not sure	I disagree	I strongly disagree
School X (n = 46)	6	9	11	15	5
School Y (n = 50)	4	21	12	13	0

Source: Lock *et al.*, 1995

law, a position that reflected the combined views of the whole sample. In contrast, students in school X had a wider spread of views with more, in real and proportionate terms, in disagreement. This difference between schools cannot be explained in terms of gender differences between the groups and is more likely to be influenced by factors associated with the teaching and learning styles to which pupils were exposed.

Implications

The findings presented in preceding sections raise implications for the approaches used in teaching and learning about controversial science–society issues and for the curriculum. Each of these issues will be addressed in turn.

Teaching and Learning about Science: Society Issues

Firstly, it is important to include controversial science–society issues as an integral part of work schemes; not as an 'add on' at the end of a unit, nor as an extra for homework or as the final element of extension material for fast workers, but as a central theme covered by *all* students. Having included such work, it is vital that the specific contribution that science makes to work with these issues is a key element of the teaching and learning strategies used; for it is not only science teachers who include topics like genetic engineering in their work schemes. In essence this means adopting a 'scientific' approach, one where students are asked to distinguish between fact and opinion and to determine if data support the interpretation that is presented. Students should be encouraged to show scientific attitudes such as curiosity, open mindedness and respect for evidence. They should be willing to tolerate uncertainty. Above all, it is knowledge rather than hearsay upon which sound opinion is based. Student views should respect and not contradict or conflict with the evidence. This places the onus on teachers to provide the accurate data and information that might underpin student opinion.

Having included controversial issues in a work scheme, the next priority is to ensure that a balanced approach is provided in dealing with such issues. This means that students should be exposed to a range of views and value positions, not just indoctrinated with the view held by the teacher.

Teachers could present a range of possible views without indicating which they personally support, or alternatively, resource material representing a wide range of different view points could be presented to students (for further details on teaching strategies see, for example, Bridges, 1986). However balanced a teacher attempts to be, there will almost certainly be some influence on students' views, but if there has been an even-handed lesson, conducted in a scientific manner, then students will have a model of how to approach similar controversial issues in contexts outside the school environment. Having been exposed to a range of view-points, students should be encouraged to discuss their views with their peers. Through such discussion students should be encouraged to make up their own minds about an issue. The significant elements here are that students come to their views through a critical evaluation of the evidence which should be seen to support rather than contradict their opinion. The nature of the student opinion should not be important, but the fact that it has been gained through critical reflection and respect for evidence is important.

A further teaching approach is to ask students to justify and defend their position to their peers. In such activities students may reveal inconsistencies in their views and attitudes. Drawing apparent inconsistencies in attitudes to students' attention and seeking explanations can be a powerful classroom strategy to generate debate, discussion and further clarification and justification of attitudes. The materials, used by all students involved in this study, described the production of pharmaceuticals in sheep milk through insertion of human genes into fertilized sheep eggs. While the majority of students approved of using genetically engineered sheep to produce human medicines, they disapproved of the insertion of human genes into fertilized sheep eggs which makes this possible. Facing students with dilemmas such as this leaves them to question and clarify their position. At what point, if at all, does it become acceptable to insert genes into sheep? For what purpose would this process be acceptable/not acceptable?

It is important to include the teaching of controversial science-society issues in order to develop student understanding of science, scientists and the dilemmas faced by scientists through their professional activities. There may be some teachers who consider teaching about controversial issues to be the preserve of English or Religious Education teachers and those concerned with personal and social education. In my opinion this is a mistaken view. It is vital that such issues are covered in cross-curricular contexts, as in this way the distinctive contribution that science and scientists make becomes evident. The way that science interacts with daily life is made explicit and applied issues such as those relating to food production and food labelling can be drawn to the attention of future citizens in an objective and unsentimental manner. Equally, it is vital that we illustrate that the moral high ground is not the exclusive preserve of the non-scientists. In such ways teachers can make a major contribution to the public perception of science and scientists. By exposing students to the kind of moral and ethical issues that face scientists working in the field of genetic engineering they may come to challenge the media stereotyped view of a scientist as a hard, uncaring and unsympathetic individual.

Curriculum

The first implication for the curriculum is that of including the content relating to controversial science-society issues in a prominent enough position. While there have been many attempts to marginalize and exclude such content, the current discussion will focus on two of the more recent examples.

In 1983 discussions were well underway about the development of an examination that combined the, then largely separate, General Certificate of Education Ordinary Level (GCE) from the less highly rated Certificate of Secondary Education (CSE). Physics was one of the first new syllabuses to be submitted to, and considered by, the then Secretary of State for Education, Sir Keith Joseph. The proposals, which came from Her Majesty's Inspectorate and a host of professional associations, industrialists and curriculum development bodies, argued that the syllabus should emphasize the wider social and economic implications of the subject. The rejection of the proposals by Sir Keith led the editor of the Times Educational Supplement (TES) to comment (TES, 1983):

Where Sir Keith has gone farther out on a limb is in his total rejection of anything which suggests that the study of physics should include any consideration of the social and economic issues which arise from the application of scientific knowledge. Thus, while he insists that pupils must learn about the technological applications, he believes they must be rigorously steered away from the interesting questions of value, morality and expediency, of which (it is to be hoped) scientists have become increasingly aware. Although social and applied issues were included in the syllabuses for the new GCSE courses, the examinations assessed only fact and not views and opinions.

A further bid for status for social and ethical issues in science was made in one of the early drafts of a science national curriculum (DES, 1988). In the proposed attainment target 21, Science in Action, it was suggested that

Pupils should develop a critical awareness of the ways that science is applied in their own lives and in industry and society, of its personal, social and economic implications, benefits and drawbacks.

By proposing to devote a complete attainment target to such issues a clear signal could be given to students and teachers about the status of such work. However, by the time a statutory version of the curriculum had been produced, not only had the attainment target been deleted, but references to ethical issues were confined to the statements of attainment and the Programme of Study. The position with respect to genetic engineering is shown in the following extract from the Key Stage 4 (14-16-year-olds) Programme of Study (DES, 1991).

Using sources which give a range of perspectives, they (pupils) should have the opportunity to consider the basic principles of genetic engineering, for

example, in relation to drug and hormone production, as well as being aware of any ethical considerations that such production involves.

Not only were the social, moral and ethical issues marginalized in terms of their status within the National Curriculum, but they were often included in a position which suggested that study of such issues was only appropriate for the most able students. The statement of attainment related to the part of the Programme of Study quoted above was located at level 10 and hence deemed only suitable for students who would attain the highest standards; only a tiny proportion of the grade A candidates. It is hardly surprising, therefore, that in many schools study related to this specific statement of attainment was not included.

In an interesting way the same statement of attainment illustrates the further progressive marginalization of ethical issues. In the equivalent component of the revised National Curriculum (DFE, 1995) it reads

Pupils should be taught the basic principles of cloning, selective breeding and genetic engineering.

The consideration of ethical issues has gone! It may be that some of the concepts involved in the understanding of genetic engineering are only accessible to the most able 16-year-old, but this does not mean that others should be excluded from considering the moral and ethical issues arising from such work. That social and ethical issues are not the preserve of able students was illustrated by the interest and understanding reported by students of all abilities involved in this study (Table 18.7).

Table 18.7: The level of student interest and understanding in work on genetic engineering

Was the work interesting?		
YES		58%
SOME OF IT		25%
NO		16%
Did you understand the work?		
YES		51%
SOME OF IT		42%
NO		6%

Notes: (n = 179)

The National Curriculum appears to have taken an entrenched view of science locked in the tradition of abstract concepts and rote-learning. There is something at odds with a compulsory curriculum that makes students do more work of the type that they opted to avoid when this was possible.

Figure 18.1 shows the contrast between the science that students meet in school and that in the world outside it. It compares the list of topics, representing a term's work, taken from the exercise book of a 15-year-old student working

School Science topics January to March 1995 Year 10, 14/15-year-olds

In this ten week period there were eleven topics studied.

These were:

- Gases
- Why are solids solid?
- Gas Laws
- Structure of atoms
- Differences between elements
- Periodic table
- Separating techniques
- Emulsions and foams
- Radioactivity
- Making materials stronger
- Oxidation

Terrestrial Television — science topics March 27th — April 1st 1995

In this one week period there were twenty-five programmes on factual science, i.e., excluding drama involving hospitals.

Including:

- The information war on international battlefields
- Urban foxes
- The third sex
- Greyhound euthanasia
- Sex, slugs and the speed of light
- Vets talking with distressed owners of dying pets
- Organic meat — are customers paying over the odds?
- Chemical warfare
- Extracting DNA from Pharaohs
- Eco-terrorism
- Control of Nuclear Weapons

Figure 18.1: Science subjects from school science and terrestrial television

towards a double award science examination with the evening output, in a single week, of the four terrestrial television channels.

There is a clear mismatch between the world of science portrayed in school and the science that students may meet in their leisure time. As science teachers we should be concerned at this gulf and should spend some time offered by the current five-year period of curriculum stability in redressing such an imbalance in the curriculum as preparation for students of the next millennium.

The case for including more work with a social, moral and ethical base is strong. Such a curriculum change would be popular, particularly with female students, and could lead to more positive views of science. Not only could this contribute to increased numbers studying science beyond the compulsory years of schooling, but also it could do much to develop and enhance the public understanding and perception of science and scientists.

It is not too dramatic to stress the importance of including work on controversial science-society topics in the curriculum for all 11-16-year-olds. An informed population with an objective view of science and scientists based on experience, knowledge and understanding is a prerequisite for progress in the twenty-first century.

Note

- 1 My thanks to Mairéad Dunne and Allan Soares who contributed to the introduction.

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