Understanding Of Basic Genetics And DNA Technology

Young People's Understanding
Of, And Attitudes To, 'The New
Genetics'
Working Paper 2

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Working Paper 2
Understanding of basic genetics and DNA technology
A: The written probes

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Abstract
In this paper, we report findings from a survey of almost 500 students aged 14 - 16. Their knowledge and understanding of basic genetics and DNA technologies was elicited through written questions requiring individual written responses. While most of these students showed a good general understanding that genes determine characteristics and are involved in inheritance, very few had any awareness of the mechanisms which make this possible. In addition, few knew or understood the basic genetic concepts which they would need in order to understand these mechanisms. Despite massive coverage in the media during the data collection period of this study there was only limited awareness or understanding of DNA technologies. A summary of the detailed findings is presented and the implications for teaching genetics are discussed.

1 Introduction

The work reported in this paper is part of a much larger research project on '*Young People's Understanding of, and Attitudes to, The New Genetics*'. The overall aim of this project was to produce baseline data on the understanding of genetics, awareness of DNA technology and attitudes towards DNA technology which young people have at the end of their compulsory science education.

DNA technology is developing at a rapid pace. DNA data bases have been set up, DNA fingerprinting is a routine forensic tool, screening for genetic disease is becoming commonplace and genetically modified food is now on sale. Each of these uses of DNA technology raise important social and ethical issues, for the individual as well as for society. We were interested in the extent to which the National Curriculum prepares young people in England and Wales for the dilemmas and decisions which they will be faced with as a result of these developments. Our focus was therefore on the students' understanding of general principles - that all living things contain genetic information, for example - rather than the detailed recall of content which might be required for exams. We were also interested in the extent to which students could come to a reasoned opinion about specific uses of DNA technology (through identification, discussion and evaluation of relevant issues), and in the scientific knowledge which they might need to draw on in order to do this.

More than 700 young people aged 14 - 16 took part in the whole study, which was based on four main research questions :-

1. What knowledge and understanding of genetics do young people have at the end of their compulsory science education?

2. What knowledge and understanding of new gene technologies do these same young people have?

3. What issues do they perceive as being raised by the application of new gene technologies in particular contexts?

4. What opinions and attitudes do these young people form concerning the application of these technologies?

Research questions 1 and 2 relate to students' knowledge and understanding of genetics and gene technology. This was investigated through a written survey of almost 500 young people and through a series of audio taped group discussions involving 36 young people. Findings from this research are reported in three working papers. This paper (Working Paper 2) reports survey findings on students' knowledge and understanding of basic genetics and DNA technology. The second paper (Lewis *et al*, Working Paper 4, in preparation) reports findings, from the same survey, on students' understanding of gene action within the cell. The third paper (Wood-Robinson *et al*, Working Paper 3, (in preparation) reports on findings from the audio taped discussion task.

Research questions 3 and 4 relate to students' awareness of issues raised by DNA technology and its applications, and their opinions and attitudes towards these issues. These were investigated through a second set of written probes and through two different audio taped group discussion tasks, led by an interviewer. Findings from the written probes will be reported in Working Papers 6 and 8 (in preparation). Findings from the audio taped discussion tasks are reported in Working Paper 5 (Leach *et al*, 1996) and Working Paper 7 (in preparation).

All of the written probes which were produced for this project - each one accompanied by a commentary on its use within this research project, a brief summary of the findings and suggestions for its use within the classroom - are published as a separate photo-copy free booklet (Lewis *et al*, 1997).

Those aspects of genetics which are taught in government-maintained secondary schools in England and Wales are defined by the National Curriculum. For the students involved in this study the version of Science in the National Curriculum which they had experienced was that published by the Department of Education and Science (DES 1991). Unless otherwise stated, all references to the National Curriculum within this paper relate to the

1991 National Curriculum for Science, Key Stages 3 and 4, Attainment Target 2 : Life and Living Processes.
A new version of the National Curriculum has since been introduced (DfE 1995). Details of the design and methodology for the whole study, together with a discussion of the issues raised by the development of a science curriculum designed to increase scientific literacy within the general population and a discussion of genetics within the National Curriculum, are presented in Working Paper 1 (Wood-Robinson *et al*, 1996).

This paper (Working Paper 2) focuses on young people's knowledge and understanding of basic genetics and DNA technology. All the data presented in this paper were collected through a series of written questions to which students gave individual written responses. Almost 500 young people from across the ability range were surveyed for this part of the project. The majority of the sample had been taught genetics at Key Stage 4.

2 Previous research on knowledge and understanding of genetics and new genetic technologies

2.1 Introduction

Research into young people's knowledge and understanding of this field has been on-going for two decades. Indeed, apart from work on classification and plant nutrition, it is the area of biology which has been most researched (see Carmichael *et al*, 1990).

Much of the work in this field has been concerned with young people's understanding of inheritance rather than genetics. By **inheritance** we mean the acquisition of characteristics by an individual through the transfer of material from that individual's parent(s). **Genetics** is not only the study of patterns of inheritance, but it is also concerned with mechanisms, such as how characteristics are passed on and how genes express themselves. Nevertheless it is important to review this work as it reveals students' understanding of aspects of the phenomena under investigation in this study as well as, in some cases, providing insights into their understandings of the mechanisms of inheritance which have been probed in a wider context without prompts which are specifically genetic in their nature.

We therefore outline briefly below some of the key findings from this work. More detailed reviews can be found elsewhere (see Wood-Robinson, 1994 and 1995).

2.2 Studies involving students of school age

One of the earliest studies in the field was that of Deadman and Kelly (1978) who found that students aged 11-16 acknowledged the existence of variation within a species, but failed to understand its origins in terms of the re-assortment of genes or chromosomes and through mutation. These findings were confirmed by Brumby (1979) working with university students. A number of studies have demonstrated the widespread belief, even among quite young children, that some characteristics present in individuals are derived from their parents. (See for example, Kargbo *et al* 1980, and Engel Clough and Wood-Robinson, 1985). All of these studies, with the exception of Brumby's, which employed pencil and paper responses to questions, involved structured interviews with individual students.

There appear to be interesting differences in the ways in which some young people view intra-specific variation and inheritance in plants compared with animals. Thus 17% of Engel Clough and Wood-Robinson's sample of 80 students aged 12-16 believed that intra-specific variation did not exist among plants.

Several studies have highlighted the belief that parents contribute unequally to the characteristics of their offspring (see Kargbo *et al*, 1980, and Engel

Clough and Wood-Robinson, 1985, for instance). Many young people believe that the mother makes a greater contribution than does the father, or some believe the mother makes the only contribution, to the inherited characteristics of her offspring. In other cases there is a belief in an association of a characteristic between a child and the parent of the same gender.

Kargbo *et al* (1980) found a widespread belief in the inheritance of acquired characteristics among younger students (aged 7-13) and this was confirmed by Engel Clough and Wood-Robinson (1985) with somewhat older students aged 12-16. The existence of such beliefs has been confirmed across a number of different mammals and involving a range of characteristics. This is perhaps not surprising in the light of Albaladejo and Lucas (1988) observation, based on their study of Catalan students aged 14-18, that many were unable to distinguish between a somatic change in an individual which has no impact on its germ cells, and a change which alters the germ cells and can therefore be inherited.

In one of the only studies of students' knowledge and understanding of new gene technologies, Lock and Miles (1993) found that about half their sample of 15-16 year olds (n=188) understood that genetic engineering involved changing or manipulating genes, but about a third had no understanding of the technology whatever. This study involved open questions in which the students were asked to explain the meaning of the terms 'biotechnology' and 'genetic engineering' and to give examples in each case. About half their sample were unable to give any examples of genetic engineering.

Thus the principal findings from this research into students' knowledge and understanding are:

- Variation in mammals is frequently associated with parentage, though an understanding of the mechanisms which result in the similarity between parents and their offspring is often absent.

- Parents are seen as making unequal contributions to the characteristics of their offspring with the parent of the same gender as a child being viewed as having a greater influence on their features.

- Characteristics acquired during an individual's lifetime are often thought to be inherited, though many believe that this will only take place after many generations and with frequent reinforcement of the acquired feature.

- Knowledge and understanding of new gene technologies is poor, while attitudes to recombinant DNA technology are highly dependent on the context of the application.

- Plants are often viewed as being markedly different from humans and other mammals as far as variation and inheritance are concerned with plant variation being seen as due only to environmental causes. Many students do not accept that plants reproduce sexually.

Some of these areas of knowledge and understanding were further explored in the research reported in this paper, though our focus was the structures and mechanisms involved rather than simply a belief in the existence of a particular phenomenon.

Several researchers have commented on the language problems associated with the teaching and learning of genetics. Pearson and Hughes (1988a and 1988b) in analysing textbooks used by students in the 16-19 year old age range in the UK noted widespread misuse of terminology. Longden (1982) also identifies language as being a major cause of difficulty encountered by his sample of 17-18 year old students. With such problems in mind Radford and Baumberg (1987) have drawn up a glossary of genetic terms useful to teachers and students.

2.3 Studies involving adults

In recent years concern about the general public's understanding of, and attitudes to, a number of aspects of genetics have led to several studies in the area. Ponder *et al* (1996) interviewed a number of students (n=58) in a college of further education - hence after the completion of their 11 years of compulsory schooling. They were asked about their likelihood of suffering from three conditions (diabetes, heart disease, and cancer) and the reasons for their responses. Any reference to inheritance or family history were then followed up. Genetic terms, such as 'gene' and 'chromosome' were not used by the interviewers unless used first by the interviewees. The interviewers also refrained from any reference to inheritance as such or to the concept of 'risk'. Details of family health history were also followed up and recorded by the annotation of family trees. The parents of the students were then also interviewed along similar lines. In general, family history and the environment were perceived as increasing the likelihood of the subjects suffering from heart disease and cancer, whereas personal action and behaviour were more often perceived as decreasing susceptibility rather than increasing it. This applied to all three conditions investigated, though family history and personal action were viewed as being less influential in the case of diabetes.

Snowden and Green (1996) investigated the understanding of inheritance patterns of recessively inherited disorders demonstrated by parents who were carriers of the allele for that disorder. They found that almost all the parents were able to determine correctly the chance of their having an affected child. However, only about one third of them were able to determine the probabilities of the other two possible outcomes (i.e. that the child would be a carrier, or that the child would be completely free of the allele). This suggests that the majority of the parents had little grasp of Mendelian inheritance or understanding of the mechanisms involved.

Richards and Ponder (1996) investigated the perceived genetic relationship between family members. Their sample, which consisted of 177 adult women and 73 first year university social science students, were asked as part of pencil and paper questionnaires "what proportion of genes does someone, on average, share with their father, sister, child, uncle and grandmother?" They were given a range of possible responses (none, 5%, 15%, 25%, 50%, 75%, 100%, or don't know). It is noteworthy that their questionnaire referred to **genes** shared between relatives, whereas in reality they were presumably referring to shared **alleles**. However, as indicated elsewhere in this paper, the term allele is less familiar to most people and we must assume that the incorrect 'gene' was preferred on grounds of familiarity. The majority of both groups of respondents selected the correct response for father and child, but only a minority selected the correct response for uncle and sister. Most underestimated the proportion of shared genes between these relatives, but there was also a large proportion selecting the 'don't know' option. The situation in relation to responses to the grandmother question was less clear cut, but again there was significant tendency to underestimate the proportion of shared genes.

Michie *et al* (1995) involved Gallup in an attitudinal investigation of a sample of adults aged 18-45 (n=973). However, this work, which focused on attitudes to pre-natal and adult screening, made no attempt to determine the participants' knowledge and understanding of the genetics related to the areas being probed.

3 Design, methodology and administration of the written probes

3.1 Design of the written probes

In order to design written research probes which could be used to investigate our first two research questions:-

- What knowledge and understanding of genetics do young people have at the end of their compulsory science education?
- What knowledge and understanding of new genetic technologies do these same young people have?

we made a conceptual analysis of the two areas we wished to cover (see Appendix 1). In making this analysis we took into account both the requirements of the 1991 National Curriculum for Science at Key Stages 3 and 4 and also the background knowledge and understanding of genetics which an individual might need in order to develop a basic understanding of DNA technologies and the issues to which the use of these technologies could give rise. For a more detailed discussion of the conceptual analysis see Working Paper 1 (Wood-Robinson *et al*, 1996).

Students' knowledge and understanding of these key concepts were initially investigated using free response questions and small discussion groups. On the basis of this preliminary work a number of written research probes were produced, designed to cover as many of the conceptual areas as possible. These probes were piloted with almost 100 students of all abilities and evaluated for effectiveness, comprehension and timing. Finally, a revised set of 8 written probes - *Size Sequence, Living Things, Biological Terms, The New Genetics, Cells, Cell Division, Reproduction* and *Information Transfer* - were produced for the main study. Each of these probes were made up of two or more sections and each section often contained several related questions. The areas of our conceptual analysis covered by these eight probes are shown in Table 3.1. Many of these conceptual areas are covered by more than one probe, allowing us to assess the consistency of our findings across different contexts.

Only two of the conceptual areas which we listed are not covered in any way by these eight probes. Area *B2a* relates to possibilities and limitations in the application of DNA technology and is covered by a series of *'stop press'* probes which will be discussed in a future working paper. Area *A5(ii)c* was not covered at all within this project. This area relates to the effect of selective pressures on gene frequencies and the gene pool - or more correctly, allele frequencies and the allele pool! When draft probes covering this area were trialled, students showed little awareness or understanding of it and gave very few meaningful responses. As the time available for collecting data from any individual was limited, we concentrated on those areas most likely to provide meaningful data and excluded this area from the probes.

Areas *A4c*, *A5(iii)b* and *A5(iii)c* all relate to different aspects of the genetic code. These different areas were not explicitly or individually probed but students were asked, as part of *'The New Genetics'* probe, to say whether or not they had heard of the genetic code and to explain what was meant by 'the genetic code'. Any understanding of these three conceptual areas would be reflected in the student's response to this question.

Findings from the first four of these probes - *Size Sequence, Living Things, Biological Terms* and *The New Genetics* - are reported in this working paper. Findings from the other four probes - *Cells, Cell Division, Reproduction* and *Information Transfer* - will be reported in Working Paper 4 (Lewis *et al*, in preparation).

Table 3.1 - Conceptual areas covered by the written probes

Conceptual Area	Specific Topic (see Appendix 1 for moredetails)	● Probes reported in this Working Paper ❍ Probes reported in Working Paper 4
A: Genetics	A1a - basic genetics	● ●
A1. Terminology	A1b - range of organisms	●
A2. Location,	A2a - genes/organisms	● ❍
Relationship	A2b - genes/cells	● ● ❍
between structures	A2c - range	● ● ●
	A2d - site of mitosis	❍ ❍
	A2e - site of meiosis	❍
A3. Gene function	A3a - protein synthesis	● ●
	A3b - replication	● ❍ ❍
A4. Mechanisms and	A4a - alleles	●
factors influencing	A4b - environment	❍
gene expression	A4c - universal code	●
	A4d - mitotic cell division	❍ ❍ ❍
	A4e - meiotic cell division	❍ ❍
	A4f - fertilisation	❍
A5. Similarities and differences between cells	**i) within organism** A5ia - somatic cells	❍ ❍
	A5ib - gene switches	❍
	A5ic - germ cells	❍ ❍
	ii) within species A5iia - variation, germ cell	❍ ❍
	A5iib - variation, alleles	❍
	A5iic - variation, population	
	iii) between species A5iiia - genetic information	●
	A5iiib - nucleic acids	●
	A5iiic - protein synthesis	●
	A5iiid - replication	❍
B: DNA technology	B1a - terminology	●
B1. Techniques	B1b - understanding	●
B2. Applications	B2a - real or potential	

Written questions requiring a written response were used in this part of the study as it allowed us to gather a large amount of data in a limited time. The main disadvantage in using pencil and paper probes, especially when our main interest was in conceptual understanding rather than content knowledge, was in the potential for misunderstanding. Not only were the students' responses open to misinterpretation by the researchers, there was also the potential for the researchers' questions to be misinterpreted by the students (see section 7.1.3). Preliminary work and piloting help to reduce this potential for misunderstandings but cannot overcome it.

Within the written probes, both fixed response and free response questions were used. Fixed-response questions can be answered relatively quickly and yield a large amount of data in a form which is easy to code and analyse. The disadvantage of this approach is that students must choose from a limited set of predetermined responses which may not reflect their own ideas very accurately. They do not have the opportunity to express their own ideas in their own words. This type of question gives limited insight into students' underlying reasoning or conceptual understanding. Free-response questions allow students to respond in their own way and in their own words, providing the researcher with a better insight into the students' underlying reasoning or conceptual understanding. However, free response questions take students longer to answer and the coding and analysis of responses is very time consuming. Whether fixed or free response questions are used, there is always a problem of misinterpretation. Because of this, some audiotaped small group interviews were also carried out. The findings from these small group interviews are reported in Working Paper 3 (Wood-Robinson *et al*, in preparation).

3.2 Administration

All eight *knowledge and understanding* written probes were presented as a single pack of questions which was administered to whole classes at one time. Because we wanted to collect data on the knowledge and understanding of individuals, students were asked to work on their own, without discussion with other members of the class. To encourage this, three different versions of the pack were produced. Each contained the same probes but in three different sequences, although all three versions began with *'Size Sequence'*. All three versions were administered within any one class with neighbouring students having different versions. As a result, individuals usually found that at any given time they were working on a different question from their neighbours. In addition this ensured that all probes were answered within each class, even if time was limited and individual students were unable to answer the whole pack. A further benefit of using three versions was that the same probes were not always answered last, when students might be bored or tired.

3.3 Sampling

The twelve schools from which data were collected for the main study were all co-educational comprehensive schools under local authority control. They were drawn from the West Yorkshire region of England and covered a range of rural, urban and suburban catchment areas. 8 schools participated in this part of the project concerned with knowledge and understanding of genetics and DNA technologies. Within each of these schools the sample was drawn from across the ability range, with teachers selecting three classes - upper ability, middle ability and lower ability - to complete the probes. Altogether responses from 482 students in 24 classes were collected (see Table 3.2).

Our intention had been to work with a representative sample of the school population who had all completed the genetics component of their science education. In practice this proved difficult. Genetics is perceived to be difficult by some teachers and there is a tendency to leave this component of the syllabus until the end. In many schools there is little time between completion of the genetics component and commencement of GCSE exams, and researchers are not always welcome such a short time before public examinations. As a result it was impossible to collect an ideal sample in which all students had followed the genetics components of the National Curriculum programme of study. Although 28% of our sample had not yet been taught genetics during Key Stage 4, some of the more able of these students had been taught genetics to a higher level during Key Stage 3 than some of the less able students had achieved by the end of their Key Stage 4 studies.

The levels of achievement within these schools, as measured by the percentage of A - C passes in GCSE sciences in the preceding year, ranged from 58% to 11.8%.

Using the DES Ethnic Monitoring Survey schools indicated their ethnic mix. Between 1% and 16% of the intake in these schools were from minority groups. These included students of Indian, Pakistani, Bangladeshi, Afrocaribbean and Chinese origin.

Table 3.2 - Survey sample, the *knowledge and understanding* pack

		Number of students per class			
School	**Year**	**Upper ability**	**Middle ability**	**Lower ability**	**Total**
1	11	16	15	14	45
3	11	29	22	11	62
7	11	15	18	11	44
8	11	26	25	24	75
9	11	29	24	22	75
10	11	23	13	12	48
12	11	31	24	12	67
13	10	26	21	19	66
	Total	195	162	125	482

Of these 482 students -

- 416 (86.3%) were in Year 11 and aged 15 - 16,
  66 (13.7%) were in Year 10 and aged 14 - 15,

- 229 (47.5%) were female,
  253 (52.5%) were male,

- 351 (72%) had been taught most of the genetics specified in Key Stage 4,
  131 (28%) had been taught either very little or none of the genetics specified in Key Stage 4 at the time of the survey.

3.4 Coding and analysis

Each fixed response question was scored according to the alternative ticked, with each alternative being given a code. The frequency with which each code was used was then determined.

Because our main interest was in the ideas and understandings which students held rather than in the students' factual recall we adopted an ideographic approach to coding the semi-structured and free response questions. Instead of developing a coding scheme based on the scientific explanation we developed a coding scheme based on the students' own responses. As the coding of a question progressed these schemes developed, through an iterative process of reconsideration and discussion, so that all types of response could be categorised. The coding schemes therefore represent the types of reasoning present within the population and as such, in addition to providing a means of analysing the data, they are an important research finding in themselves.

3.5 Reporting the data

Not all students attempted to answer all the questions. In any one case it was not possible to know for sure if this was because the student couldn't answer the question, because the student didn't have enough time to answer the question or because of some other reason. As a result it was sometimes difficult to report key findings as a percentage of the total population (i.e. as a percentage of those asked the question). To overcome this, and to provide some consistency in reporting the data, the following criteria were used. If a student had attempted to answer some questions within a section of a probe (for example any of the four questions within the section on 'genes' in the *'Biological Terms'* probe, see Appendix 5a) but had not answered all the questions within that section then it was assumed that the student had read the questions but had been unable to answer some of them i.e. it was assumed that the student *had been asked* the questions. If a student did not respond to any of the questions within one section of a probe then it was assumed that the student had not had time to read and respond to that section i.e. it was assumed that the student *had not been asked* the questions.

Depending on the use that is being made of numerical data, they are presented either:
- as numbers,
- as a percentage of the total number of students responding to a specific question (i.e. as a percentage of those who attempted to *answer* the question),
- as a percentage of those who attempted that part of the probe (in effect, those who were *asked* the question),
- as a percentage of those who attempted some part of the whole probe.

Percentages are recorded as decimal numbers in the appendices but within the text they are rounded up or down to the nearest whole number for easier reading.

In presenting the data, ideas commonly held within the sample population are reported on. Ideas held by only one or two individuals are not. In most analyses there were also a small residue of unclassifiable responses - those which were ambiguous, incomprehensible or unreadable. In many cases the coding is not exclusive (one person may have expressed more than one of the listed views) therefore totals may add up to more than 100% at times.

Although data were collected at the individual level, they were analysed and reported at the population level. However, individual responses are sometimes used by way of illustration.

4 The *Size Sequence* probe

4.1 The probe

4.1.1 Design of the probe

This probe (see Appendix 3a) was designed to: -

1. determine whether students were familiar with some basic biological structures related to genetics;
2. ascertain what understanding they had of the relationship between these structures.

It covers the following conceptual areas:-
A1a: terms relating to basic genetics and
A2a-c: location of genes and relationship between structures within an organism
(see Appendices 1 and 2).

Students were asked to say which of the following six terms they had heard of - *cell, chromosome, gene, DNA, organism and nucleus.* With the exception of *nucleus* all of these are explicitly mentioned in the 1991 National Curriculum at KS4, although *chromosomes* are only mentioned in the examples rather than in the Programme of Study or the Statements of Attainment. The inclusion of the nucleus is *implied* in the Programme of Study, where it states that:-

> *'pupils should explore and investigate how flowering plants and mammals are normally organised at cellular and macroscopic levels'.*

Students were then asked to sequence those items which they had heard of in order of size. Recognition of the relationship between these structures is not something explicitly referred to in the 1991 National Curriculum, but none the less is highly relevant to a basic understanding of genetics. In addition, it is difficult to see what understanding students could have of the basic principles of genetic engineering if they are unaware of the relationship between these structures. Understanding these basic principles was a requirement of the 1991 National Curriculum at KS4, both within the Programme of Study and the Statements of Attainment (Level 10).

Students' awareness of the relative size and scale of these structures is also likely to influence their attitude towards the use of genetic engineering. During preliminary work in schools it was clear that the image of genetic engineering held by a number of students was of something equivalent to invasive surgery - large pieces of an animal being removed and transferred elsewhere! Not surprisingly, such students tended to disapprove of genetic engineering, considering it to be unfair on animals.

4.1.2 Critique of the probe

Some difficulties were encountered in designing this probe. We wanted to probe students' understanding of the relationship between these six different structures. Asking students to arrange the structures in sequence by order of size might appear a very simplistic way of approaching this, but it has the advantage of being a relatively unambiguous instruction. Although 'size' is open to interpretation (this is discussed in more detail below) these alternative interpretations did in part reflect students ideas about the nature of the relationship between the different structures. We also anticipated some students having difficulty with the word *organism*. However, we were interested in their understanding of the general nature of the relationship between these structures, as applied to any eukaryotic organism, and so we were reluctant to substitute a specific plant or animal.

4.2 Analysis of the data

Our sample size for this probe was 482 (100% of those taking part). For a breakdown of the exact numbers responding to each question see Appendix 3(b).

4.2.1 The terms

Students were asked to tick the terms which they had heard of. The results are shown in Table 4.1.

Table 4.1 - Which of the following terms had students heard of?

	yes	no
cell	99.8% (481)	0.2% (1)
chromosome	95.6% (461)	4.4% (21)
gene	99.0% (477)	1.0% (5)
DNA	90.7% (437)	9.3% (45)
organism	98.3% (474)	1.7% (8)
nucleus	99.0% (477)	1.0% (5)

4.2.2 The sequence

Those responses which were ambiguous e.g. suggesting more than one sequence, were considered invalid for the purpose of this analysis and excluded. Incomplete sequences were also excluded as it was not possible to analyse them further without making assumptions which the data could not support. Only those responses which sequenced all six items unambiguously were used in the analysis below. Together, these 400 responses suggested 164 different sequences for the six items. These clearly needed to be grouped in some way in order to have any meaning.

One scientifically acceptable way of sequencing these structures by size would be *organism, cell, nucleus, chromosome, DNA, gene*. The implication here is that a gene is a section of DNA and is therefore placed after it in the sequence. An equally valid interpretation, related to structure and function, is that a gene is made up of DNA, hence the sequence *organism, cell, nucleus, chromosome, gene, DNA*. However, if the total length of 'unpacked' DNA is taken into account, a third sequence might be *organism, cell, nucleus, DNA, chromosome, gene*. Because all three responses are consistent with a scientific view of the relationship between these structures we grouped them together. However, it should be kept in mind that they might also have arisen from guesswork or a random assortment of the terms! The findings are summarised in Table 4.2. Full details can be found in Appendix 3(c).

234 students (58.5% of the analysis group) began their sequence '*organism, cell...*'. Of these:-

- 70 (17.5% of the analysis group) thought that '*chromosome*' was bigger than '*nucleus*';
- 75 (19%) thought that '*gene*' was bigger than '*nucleus*';
- 101 (25%) thought that '*gene*' was bigger than '*chromosome*'.

140 students (35% of the analysis group) began with the sequence '*organism, cell, nucleus....*'. Of these, 85 (21% of the analysis group) produced a scientifically valid sequence, as described above.

87 students (22% of the analysis group) did **not** begin the sequence with '*organism.*'

Table 4.2 - Summary of findings from the *Size Sequence* probe
(not all of these categories are mutually exclusive)

Type of response	Number of responses
1. Began the sequence - *organism, cell...*	234 (58.7%)
a. and considered '*chromosome*' to be bigger than '*nucleus*'	70 (17.5%)
b. and considered '*gene*' to be bigger than '*nucleus*'	75 (18.8%)
c. and considered '*gene*' to be bigger than '*chromosome*'	101 (25.3%)
2. Began the sequence - *organism, cell, nucleus...*	140 (35.0%)
a. and gave a scientifically valid sequence ending:- *chromosome, DNA, gene* or *DNA, chromosome, gene* or *chromosome, gene, DNA*	85 (21.3%)
3. Did not begin the sequence with '*organism*'	87 (21.7%)

4.3 Discussion of results

4.3.1 The terms

Most students (more than 98%) said that they had heard of *cell, gene, organism* and *nucleus*. There was slightly less confidence about *chromosome* and *DNA*. 1 in 20 did not appear to have heard of *chromosome* and 1 in 10 did not appear to have heard of *DNA*. 89% of all students said that they had heard of all six terms. It should be noted that responses to this question only tell us which terms students say they have heard of. It does not reveal their understanding of the terms.

4.3.2 The sequence

While problems in sequencing '*chromosome, gene, DNA*' were anticipated (as described in Section 4.2.2) only about one third of responses began their sequence '*organism, cell, nucleus*' - a seemingly straightforward size sequence. One reason for this might be students' perception of chromosomes. Chromosomes are only visible during cell division, when the nucleus has broken down. At this stage they might easily appear to be larger than the original nucleus. While students who thought a chromosome was larger than a nucleus clearly don't have a full understanding of the relationship between the structures, they may have an awareness of the relationship during cell division.

One quarter of all students said that *'gene'* was bigger than *'chromosome'*, suggesting a major confusion about the relationship between genes and chromosomes. This confusion was also evident in findings from *'Living Things'* (see section 5.3) and *'Biological Terms'* (see sections 6.2.2, 6.2.3 and 6.3).

The 1 in 5 students who failed to put '*organism*' first appear to have little understanding of the relationship between structures, although in some cases it may also reflect their lack of understanding of the term *'organism'* or perhaps a confusion between 'organism' and 'organelle'.

1 in 5 students did appear to have a scientifically valid view of the relationship between these structures as defined in Section 4.2.2 but this number is likely to include some who guessed.

5 The *Living Things* probe

5.1 The probe

5.1.1 Design of the probe

This probe (see Appendix 4a) was designed to investigate the following areas:-

1. students' awareness of the range of living things;
2. students' awareness of the cellular nature of living things - that most living things are made up of cells; that all but the smallest are made up of many cells;
3. students' awareness of the relationship between chromosomes and genetic information - that chromosomes always contain genetic information; that genetic information is not always held in chromosomes;
4. students' awareness that all living things contain genetic information.

It covers the following conceptual areas:-
A1b: knowledge of terminology for a range of organisms,
A2c: understanding of the relationship between structures and
A5(iii)a: awareness that all organisms contain genetic information
(see Appendices 1 and 2).

By investigating these areas it was possible to make inferences about students' understanding of the relationship between organism, cell, chromosome and genetic information and their understanding of the similarities and differences of this relationship in different living things.

Students' awareness of these points have important implications, not just for their understanding of DNA technologies but also for their attitudes towards the various applications of the technology. Without an understanding that all organisms contain genetic information it is difficult to see how students could make sense of the basic principles of genetic engineering - that a gene can be taken or copied from one organism and transferred to another, not necessarily of the same species. Without a concept of the cell in relation to the whole organism it is easy to see how students can be confused about the relative scale of genetic engineering. As mentioned in section 4.1.1, preliminary findings showed that a number of students had little idea of the relative scale of different structures and therefore pictured genetic engineering as being on a similar scale to major surgery. As a consequence they were concerned that if animals were used it would cause them physical pain.

5.1.2 Structure of the probe

Students were asked a series of fixed response questions about 7 different groups of organisms :-
trees, mammals, ferns, viruses, fungi, bacteria and *insects*.

The questions were :-
a) Have you heard of these organisms?

b) How many cells do you think each organism is made up of?
c) Does it contain chromosomes?
d) Does it contain genetic information?

All the questions followed a similar format (see Figure 5.1). The complete probe is shown in Appendix 4a.

Figure 5.1 - Format of the *Living Things* probe

b) How many cells do you think each organism is made up of?

For each organism please tick only ONE box.

	none	one	many	don't know
a tree	☐	☐	☐	☐
a mammal	☐	☐	☐	☐
a fern	☐	☐	☐	☐
a virus	☐	☐	☐	☐
a fungus	☐	☐	☐	☐
a bacterium	☐	☐	☐	☐
an insect	☐	☐	☐	☐

5.1.3 Critique of the probe

The types of organism were chosen to reflect the range of living things. Both eukaryotic organisms (trees, mammals, ferns, fungi and insects), prokaryotic organisms (bacteria) and viruses were included. While all living things contain genetic information it is organised differently in these different types of organism. In addition, eukaryotes tend to be multicellular, prokaryotes tend to be unicellular and viruses have no cell structure. These differences have implications for the usefulness of these different types of organism in gene technology and the ways in which their genetic material can be manipulated.

Preliminary work suggested that some students would be unfamiliar with the singular form of some of the names e.g. bacterium. This was overcome by using the plural form in the first question.

This probe was called *Living Things*. The title told students that it was asking them about living things and the text stated that the categories were all organisms. With this design we didn't feel it was necessary to confirm that students knew that each of these organisms *was* living. In view of our findings (section 5.2.4), perhaps we should have.

5.2 Analysis of the data

Our sample size for this probe was 482 (100% of those taking part). For a breakdown of the exact numbers responding to each question see Appendix 4b.

5.2.1 'Have you heard of the following organisms?'

There were 474 responses to this question, but not all of them were complete. The frequency of each response is shown in Table 5.1. The percentage refers to those answering that part of the question.

Table 5.1 - The frequency of responses to *'Have you heard of..?'*

	yes	no
trees (n = 474)	464 (98%)	10 (2%)
mammals (n = 474)	464 (98%)	10 (2%)
ferns (n = 467)	404 (86.5%)	63 (13.5%)
viruses (n = 468)	434 (93%)	34 (7%)
fungi (n = 472)	460 (97%)	12 (3%)
bacteria (n = 474)	468 (99%)	6 (1%)
insects (n = 474)	467 (98.5%)	7 (1.5%)

The two groups of organisms with which students were least familiar were ferns (13.5% of those answering stated that they had not heard of ferns and 7 students chose not to respond to this item) and viruses (7% of those answering stated that they had not heard of viruses and 6 students chose not to respond to this item). At least 97% of the students had heard of all the other types of organism. Although 99% of respondents said that they had heard of bacteria only 98% said that they had heard of trees. It seems unlikely that more students would have heard of bacteria than had heard of trees and the suspicion must be that some students felt that the question on trees was beneath them and responded accordingly. The question on mammals might also fall into this category. Again, 2% said that they had not heard of them. However, in this case half of those who hadn't heard of mammals were in the lower ability sets and none were in the upper ability sets. In the case of trees, the majority of negative responses were found in the middle ability sets, with one in an upper ability set.

Perhaps not surprisingly in view of the above findings, there appeared to be no relationship between whether or not a student said they had heard of an organism in this section and whether or not they answered subsequent questions about that same organism.

5.2.2 'How many cells is each organism made up of?'

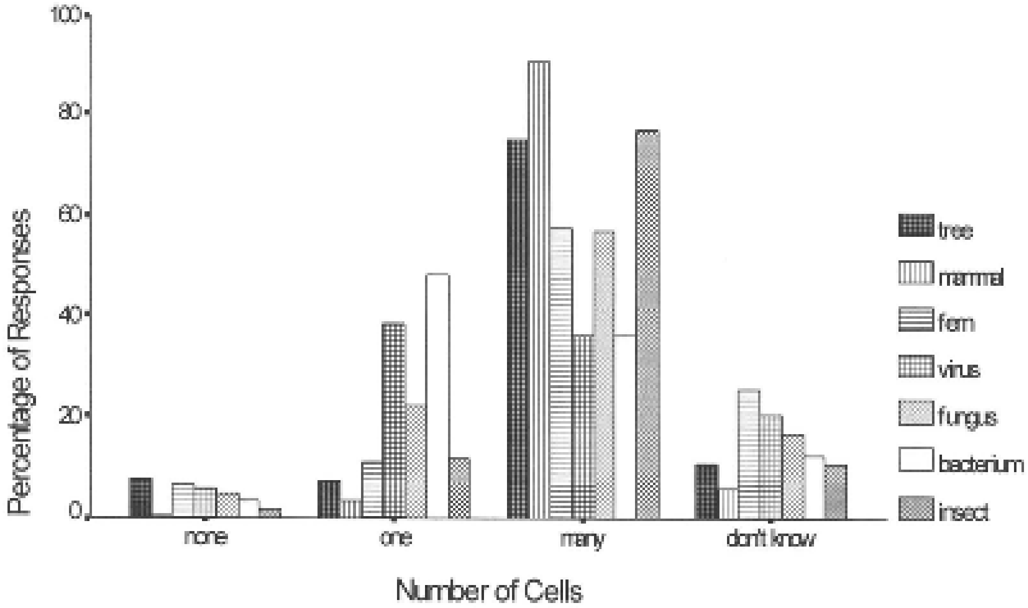
There were 473 responses to this question, but not all of them were complete. The frequency of each response is shown in Table 5.2. The percentages refer to those answering that part of the question.

Table 5.2 - *'How many cells do they contain?'*

	none	one	many	don't know
trees (n =472)	36 (7.6%)	34 (7.2%)	353 (74.8%)	49 (10.4%)
mammals (n = 473)	2 (0.4%)	17 (3.6%)	426 (90.1%)	28 (5.9%)
ferns (n = 466)	31 (6.7%)	51 (10.9%)	267 (57.3%)	117 (25.1%)
viruses (n = 472)	27 (5.7%)	180 (38.1%)	170 (36.0%)	95 (20.1%)
fungi (n = 470)	23 (4.9%)	103 (21.9%)	266 (56.6%)	78 (16.6%)
bacteria (n = 472)	17 (3.6%)	227 (48.1%)	170 (36.0%)	58 (12.3%)
insects (n = 473)	8 (1.7%)	54 (11.4%)	361 (76.3%)	50 (10.6%)

The distribution of responses is shown in Figure 5.2 below.

Figure 5.2 - *'How many cells...?*



In general, students were more aware of the cellular nature of animals than of plants. 4 out of 5 students said that mammals were made up of many cells but only 3 out of 4 thought the same was true for trees. Conversely 7% thought that trees were made up of only one cell, but only 3% thought the same was true for mammals. 8% thought that trees contained no cells at all. When the responses to ferns, fungi and insects are considered, this conceptual difference in their perception of animals compared with other eukaryotic organisms appears to be consistent.

Students seemed to have a better understanding of the cellular nature of bacteria than they did of trees. Almost one half of all responses for bacteria said that they had only one cell. This compared with just over one third who said that bacteria had many cells. There was also some awareness of differences between bacteria and viruses. While similar numbers of students thought that viruses had many cells, slightly more thought that they had no cells (6% compared with 4% for bacteria).

5.2.3 'Do they contain chromosomes?'

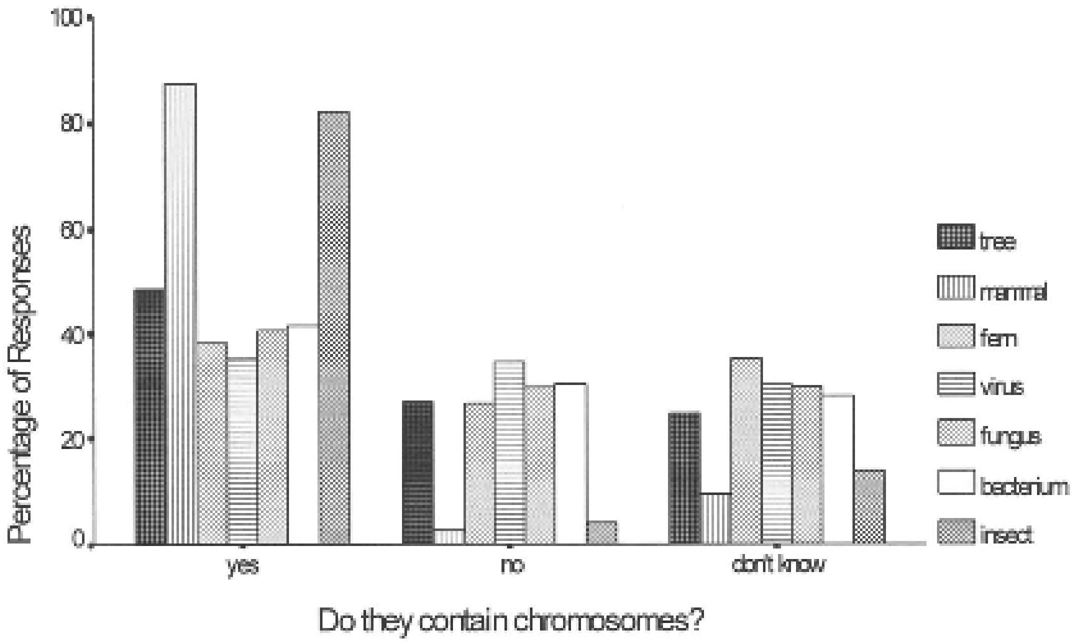
There were 474 responses to this question, but not all of them were complete. The frequency of each response is shown in Table 5.3. The percentages refer to those answering that part of the question.

Table 5.3 - *'Do they contain chromosomes?'*

	yes	no	don't know
trees (n = 470)	228 (48.5%)	126 (26.8%)	116 (24.7%)
mammals (n = 472)	413 (87.5%)	14 (3.0%)	45 (9.5%)
ferns (n = 471)	192 (40.8%)	139 (29.5%)	140 (29.7%)
viruses (n =470)	166 (35.3%)	162 (34.5%)	142 (30.2%)
fungi (n = 471)	192 (40.8%)	139 (29.5%)	140 (29.7%)
bacteria (n = 470)	195 (41.5%)	143 (30.4%)	132 (28.1%)
insects (n =474)	389 (82.1%)	20 (4.2%)	65 (13.7%)

The distribution of these responses is shown in Figure 5.3 below.

Graph 5.3 - *'Do they contain chromosomes?'*



The conceptual difference in students perception of animals compared with other eukaryotic organisms was also apparent in their responses to this question. 9 out of 10 students thought that mammals contained chromosomes, but less than half the sample thought that trees did. Again, this perception was consistent when other eukaryotic organisms were considered. More than 3 in 5 students said that insects had chromosomes, compared with 2 in 5 for ferns or fungi.

Viruses were thought to be slightly less likely than bacteria to contain chromosomes (35% compared with 41%).

In general, levels of uncertainty were high for this question. Almost one quarter of the students didn't know whether or not trees had chromosomes, and this proportion rose to nearly two fifths for ferns, fungi, bacteria and viruses.

5.2.4 'Does it contain genetic information?'

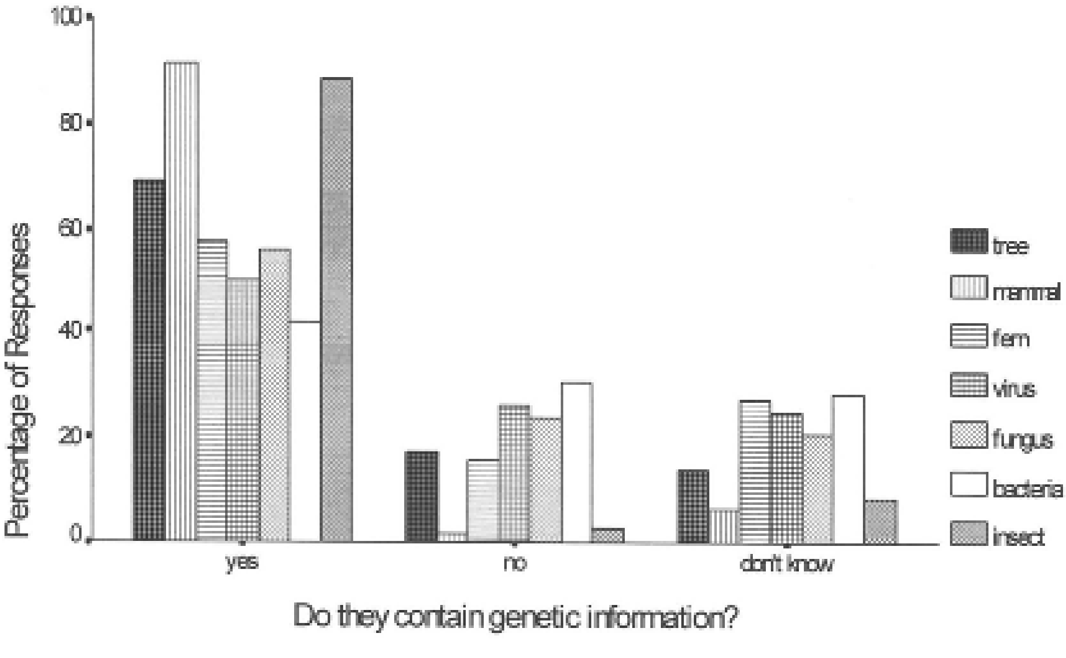
There were 472 responses to this question, but not all of them were complete. The frequency of each response is shown in Table 5.4. The percentage refers to those answering that part of the question.

Table 5.4 - *'Do they contain genetic information?'*

	yes	no	don't know
trees (n = 472)	326 (69.1%)	81 (17.2%)	65 (13.8%)
mammals (n = 452)	414 (91.6%)	8 (1.8%)	30 (6.6%)
ferns (n = 470)	271 (57.7%)	73 (15.5%)	126 (26.8%)
viruses (n = 470)	233 (49.6%)	122 (26.0%0	115 (24.5%)
fungi (n = 472)	264 (55.9%)	111 (23.5%)	97 (20.6%)
bacteria (n = 471)	260 (55.2%)	110 (23.4%)	101 (21.4%)
insects (n = 472)	418 (88.6%)	14 (3.0%)	40 (8.5%)

The distribution of these responses is shown in Figure 5.4 below.

Figure 5.4 - *'Do they contain genetic information?'*



The perceived differences between animals and other eukaryotes were still apparent in the responses to this question. 9 out of 10 students thought that animals (mammals and insects) contained genetic information compared with 1 in 7 for trees and just over half for ferns and fungi.

Slightly fewer students believed that viruses contained genetic information than did bacteria.

For any one type of organism, between 8% and 50% of these students either did not know if the organism contained genetic information or believed that it did not. Assuming that they accepted that all these organisms were living, this implies that one half of these students were not aware that *all* living things contain genetic information. In which case, what ideas do they have about the nature of genetic information? What do they think it does? What do they think it is for? Students' understanding of the nature of genetic information was also explored with the *'Biological Terms'* probe. Findings from this are reported in Section 6.2.7.

5.3 Discussion

The percentage of students who thought each organism contained cells, contained chromosomes and contained genetic information are shown in Table 5.5 below.

Table 5.5 - Summary of students' views
(as a % of total responses to each question)

organism	made up of one cell	made up of many cells	contain chromosomes	contain genetic information
a mammal	3.6	90.1	87.1	91.5
an insect	11.4	76.3	81.7	88.4
a tree	7.2	74.8	48.3	68.9
a fern	10.9	57.3	38.0	57.5
a fungus	21.9	56.6	40.6	55.8
a bacterium	48.1	36.0	41.2	55.1
a virus	38.1	36.0	35.2	49.5

Overall, more students believed that organisms contain genetic information than believed that organisms contained chromosomes. As a general principle, the idea that organisms can contain genetic information without containing chromosomes is scientifically valid. Viruses do not contain chromosomes, nor do bacteria - although their circle of 'naked' DNA is often referred to as a chromosome. In contrast, all eukaryotic (complex, multicellular) organisms have the same basic cell structure - an outer membrane enclosing the cytoplasm, which contains the nucleus which contains the chromosomes. In our sample there was little evidence that students were aware that multicellular organisms had the same basic cell structure. Instead, the majority seemed to relate the presence or absence of chromosomes to whether or not the organism was an animal. This lack of understanding of the basic structure of the cell is also reflected in findings from other probes (see sections 4.3 and 6.3) and perhaps reflects the fact that the 1991 National

Curriculum does not explicitly demand that students should be aware of the basic structure of the cell, although the Programme of Study at KS4 does state that:

> *'pupils should explore and investigate how flowering plants and animals are normally organised at the cellular and macroscopic levels'.*

Nor was the relationship between chromosomes and genetic information - the idea that chromosomes contain genetic information - well understood, as can be seen from the first column in Table 5.6b. Depending on the type of organism, between 4% and 11% of responses suggest that it is possible to have chromosomes without having genetic information.

Table 5.6 - Summary of students' views on the relationship between chromosomes and genetic information
(as a % of the total number of responses to both questions)

a) genetic information is present

	+C +G	-C +G	?C +G	total
mammal	83.5	2.5	5.8	91.8
insect	78.0	2.1	8.4	88.5
tree	43.1	14.3	11.7	69.1
fern	33.5	12.7	11.6	57.8
fungus	31.0	13.7	11.5	56.2
bacteria	30.3	12.4	12.4	55.1
virus	24.0	13.9	11.3	49.2

+C - contains chromosomes
-C - does not contain chromosomes
?C - unsure if it contains chromosomes
+G - contains genetic information

b) genetic information might not be present

	+C ?G +C -G	?C ?G, ?C -G -C -G, -C ?G	total %
mammal	4.0	4.2	8.2
insect	4.5	7.0	11.5
tree	5.5	25.4	30.9
fern	4.9	37.3	42.2
fungus	9.7	34.1	43.8
bacteria	11.1	33.8	44.9
virus	10.8	40.0	50.8

+C - contains chromosomes
-C - does not contain chromosomes
?C - unsure if it contains chromosomes
G - does not contain genetic information
?G - unsure if it contains genetic information

Substantial numbers of students appear to think that many organisms do not contain either genetic information or chromosomes. This ranges from 40% for viruses to 4% for mammals. This suggests that students either don't believe that these organisms are living, or don't believe that all living things contain genetic information in some shape or form. In either case this has important implications for their understanding of gene technology.

6 The *Biological Terms* probe

6.1 The probe

6.1.1 Design of the probe

This probe (see Appendix 5a) was designed to investigate students' knowledge and understanding of the terminology used in genetics, and also gives some insight into their perception of the relationship between the different structures.

It covers the following conceptual areas:-
A1a: terms related to basic genetics
A2b: location of genes within cells
A2c: relationship between structures
A3a: genes code for protein
A3b: genetic information is copied to pass on to new cells
A4a: a single gene may exist in more than one form
(see Appendices 1 and 2).

With the exception of '*nucleus*' all of these terms are explicitly mentioned in the National Curriculum, although *chromosomes* are only mentioned in the examples rather than in the Programme of Study or the Statements of Attainment. The inclusion of the nucleus is implied in the Programme of Study, where it states that:-

> *'pupils should explore and investigate how flowering plants and mammals are normally organised at cellular and macroscopic levels'*.

A knowledge of these terms, together with an understanding of their location and function, would form an essential base for understanding genetics and DNA technology.

6.1.2 Structure of the probe

This probe asked students about 6 biological terms and was organised into six parts, one for each term. The terms were *genes, DNA, nucleus, chromosomes, alleles* and *genetic information.*

Each part followed a similar format. It began with a fixed response section asking students to tick one box, indicating their familiarity with the term. This was then followed by a series of more open response questions which probed the student's understanding of the meaning of the term. An example of this format can be seen in Diagram 6.1. The whole probe can be seen in Appendix 5a.

Responses to some of these questions might have differed, depending on which organism the student had in mind when answering the question. To overcome this students were directed to answer in relation to their own bodies (see question (a) in Figure 6.1).

6.1.3 Critique of the probe

The probe was initially designed to investigate students knowledge and understanding of various terms. However, a comparison of their responses to the questions '*What is this structure made up of?*' and '*Why is it important?*' also gave further insights into their understanding of the relationship between various structures.

Figure 6.1 - Part 1 of the *Biological Terms* probe

<u>genes</u>

Tick ONE Box

I have never heard of genes	☐
I have heard of genes but don't really know what genes are	☐
I have heard of genes and could say something about genes	☐

Now, if you can, please answer the following questions. If you can't answer a question, please put a cross beside it.

a) Where, in your body, are genes found? --

----

b) What are genes made up of ? --

----

c) Why are genes important? ---

At times there was some overlap in the responses to two related questions. For example, a response to *'What does the nucleus contain?'* might be 'chromosomes' and a response to *'What is the function of the nucleus?'* might be 'to contain chromosomes'. In these cases answers to both questions were considered together for the purpose of coding. Those aspects of the answers relating to a specific code were then picked out.

Although the questions made students consider the terms and what they meant in more depth than they might have been used to, the questions could be answered at different levels depending on the ability and understanding of the student. What we were looking for were responses which would be consistent with a scientific view (at any level) and responses which suggested an alternative or conflicting view. For example *'genetic material'* and *'genes made up of DNA'* are both scientifically valid responses to the question '*What are chromosomes made up of?*' even though one is very general and one is more specific but the response *'lots of little cells'* suggests a quite different conception about chromosomes which is not consistent with a scientific understanding.

6.1.4 Coding and analysis of the probe

Each part of the probe began with the same fixed response section. The original purpose of this section was to determine what proportion of the sample had heard of each term and thought that they could say something about it. There were three alternative answers :-

- *'I have never heard of .... '*;
- *'I have heard of ... but don't really know what they are '*;
- *'I have heard of ... and could say something about them'*.

Students who said that they could say something about a particular term didn't always go on to answer the subsequent questions. The reverse was also true, some students who indicated that they could say nothing about a particular term then did go on to answer the subsequent questions. Some students bypassed the fixed response question altogether and went straight to the subsequent questions.

Because of this there was no clear cut relationship between answers to the fixed response section and answers to subsequent questions. Analysis of the fixed response section has therefore been simplified into students who said that they had heard of the term (combining those who said that they could say something about it and those who said that they could not) and students who said that they had not heard of the term. In all cases, answers to the more open questions were considered independently of a student's answer to the fixed response section.

Although the probe was set out in six separate parts, a major part of the analysis focuses on the relationship between the responses to each part. For this reason, Section 6.2 reports on themes which run across the different parts e.g. the location of structures, the importance of structures etc. An outline of the coding scheme for each part of the probe can be seen in Appendix 5c, parts 1-6.

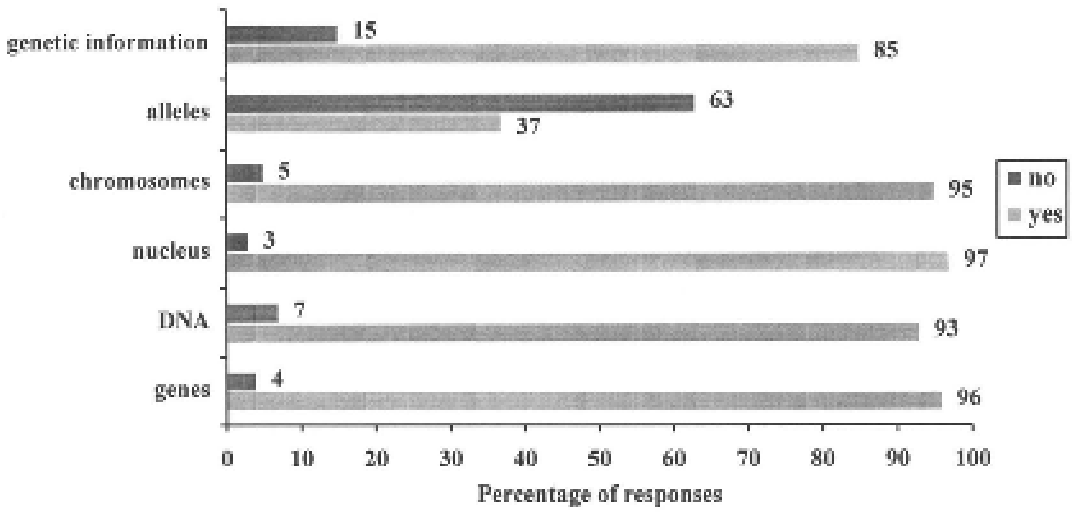
6.2 Analysis of the data

Our sample size for this probe was 478 (99% of those taking part). For a breakdown of the exact numbers responding to each question see Appendix 5(b).

6.2.1 'Have you heard of...?'

As explained in Section 6.1.4, some of the responses to this fixed response section were combined. The results are shown in Figure 6.2.

Figure 6.2 - The percentage of students who had heard of each term



All students answering this question had previously answered the *'Size Sequence'* probe, where they had also been asked if they had heard of '*gene*', '*nucleus*', '*chromosome*' and '*DNA*'. As a result we might have expected an increase here in the number of students saying that they had heard of these four terms. This was not the case. Only '*DNA*' showed a slight increase. The number of students saying that they had heard of '*chromosome*' remained about the same and the numbers of students saying that they had heard of '*gene*' and '*nucleus*' actually went down.

Despite the fact that '*alleles*' are explicitly mentioned within the National Curriculum (Statement of Attainment, level 8c) and that the majority of this sample had been taught genetics, only 37% said that they had heard of '*alleles*'. The implications of this will be considered in Section 6.3, together with relevant findings from other parts of this probe.

15% of students said that they hadn't heard of *'genetic information'* although the concept that genes contain information is taught at KS3 (Programme of Study for AT2), which all of these students had completed.

6.2.2 'Where are .... found?'

This question was asked in respect of four terms: *genes, DNA, nucleus* and *chromosomes.*

The findings for each term are given below.

Genes (Part 1)

The frequencies of the main responses are shown in Table 6.1.

About 3/4 of all responses indicated in various ways that genes are found everywhere. This type of response covered a spectrum from extremely vague (*'they're found everywhere'*) to highly specific (*'in the DNA'*). The frequencies of the different response are shown in Table 6.1.

Table 6.1 - Frequency of main responses to '*Where are genes found?*'
(only the main categories are given here)

coding categories	number of responses
Throughout	**276**
- vague, everywhere	90
- in cells	118
- in the nucleus	19
- in the chromosomes	40
- in DNA	9
Specific areas only	**94**
- reproductive system	38

number of students asked - 477
number of students responding - 370 (78%)

The remainder indicated that genes were only found in specific regions of the body and suggested a wide range of structures, chemicals or fluids were genes might be found. The specific area most frequently mentioned was the reproductive system (10% of responses). About one third of these explicitly mentioned the male reproductive system and two thirds were non specific. No one explicitly mentioned the female reproductive system.

In total, about half of all responses stated that genes are found somewhere within all cells and about a quarter thought that genes were only found in some parts of the body or only in certain cells. This has important implications for their understanding of genetics and will be discussed with other relevant data in Section 8.

DNA (Part 2)
The frequencies of the main responses are shown in Table 6.2.

Almost 70% of all responses indicated in various ways that DNA is found everywhere. The most frequent response was 'in the genes' (21%) closely followed by the more general response 'in cells' (19%). The low response rate for the nucleus and the chromosomes suggests that students are uncertain as to how either of these structures relate to DNA. In all 34% of responses indicated that DNA was found within the nucleus, chromosomes or DNA. This is similar to the response to *'Size Sequence'* (35%, see Section 4.2).

Of those who suggested that DNA was only found in certain areas (about 30%), the most frequent alternative response was 'in the blood' (21%) - a similar number to those specifying 'in the genes'. It is not possible to tell from these written responses whether there is a genuine misunderstanding that DNA is only found in blood or whether 'blood' is simply being used as a specific example of cells containing DNA. If it is a genuine misunderstanding, it might be related to the use of blood in DNA testing, and the frequent references to this fact in the media, for example when reporting on crime. An alternative possibility, that DNA is connected to inheritance and might therefore be considered to be 'in the blood' seems unlikely as there are no comparable findings for '*gene*' or '*chromosome*'.

Table 6.2 - Frequency of main responses to '*Where is DNA found?*'
(only the main categories are given here)

Coding categories	Number of responses
Throughout	**206**
- vague, everywhere	47
- in cells	57
- in the nucleus	19
- in the chromosomes	21
- in the genes	62
Specific areas only	**85**
- blood	64
Other	**7**

number of students asked - 478
number of students responding - 298 (62%)

Nucleus (Part 3)
The frequencies of the main responses are shown in Table 6.3 below.

Table 6.3 - Frequency of main responses to '*Where is the nucleus found?*'
(only the main categories are given here)

coding categories	number of responses
in cells	**349**
- all cells	342
- certain cells (blood, gametes, skin)	7
in atoms	**9**
other	**34**

number of students asked - 475
number of students responding - 392 (82.5%)

Most students had a clear understanding of the location of the nucleus. There was a good response rate to this question and 89% of these responses said that the nucleus was found in cells. A small number of these thought that it was only found in certain types of cell most usually blood, gametes or skin.
The other group of interest were the few who thought it was found inside an atom. This confusion between the biological and the physics use of the word 'nucleus' was consistent across several questions (see Sections 6.2.4 and 6.2.6).

Chromosomes (Part 4)
The frequencies of the main responses are shown in Table 6.4.

Table 6.4 - Frequency of main responses to '*Where are the chromosomes found?*'
(only the main categories are given here)

Coding categories	Number of responses
within cells	**190**
- non-specific	80
- in/around the nucleus	65
- ***in*** genes/DNA	45
within the body	**84**
- non-specific	38
- in the reproductive system	34
- in the bood	11
other	**4**

number of students asked - 476
number of students responding - 278 (58.4%)

The majority of responses (69%) placed chromosomes within cells. Of particular interest are the 17% of responses (nearly 1 in 10 of all those asked) who placed chromosomes ***within*** genes or DNA. While these students were clearly aware that these structures are related (something which 60% of students did not seem to be aware of) they have a confused understanding of what that relationship might be. This echoes findings from the '*Size Sequence*' (Section 4). The possible explanations for, and implications of, this confusion about chromosomes are discussed in Sections 4.3 and 8.

Almost a third of the remaining responses placed chromosomes somewhere in the whole body and about one third of these specified the reproductive system.

6.2.3 'Why are.... important?'

This question was asked in respect of three terms: *genes, DNA,* and *chromosomes.*
The findings for each term are given below.

Genes (Part 1)
The frequencies of the main responses are shown in Table 6.5.

73% of all responses referred to the determination of characteristics. The majority of these were vague or referred to physical characteristics. A few also referred to mental, emotional or behavioural characteristics.

The majority of those who referred to carrying and passing on information specifically related it to inheritance across generations, and the similarity of features within the family.

Table 6.5 - Frequency of main responses to '*Why are genes important?*'
(These responses are not mutually exclusive; only the main categories are given here)

Coding categories	Number of responses
determine characteristics	**280**
- unspecified	154
- physical	126
- mental/emotional/behavioural	23
carry/transfer information	**52**
- between generations (individuals)	36
control	**15**

number of students asked - 477
number of students responding - 383 (80.3%)

4 out of 5 students were able to respond to this question and they showed a good understanding of the various functions of genes. Although the focus was on determination of characteristics, there was also some awareness that information in the genes was passed on in some form and even that genes were implicated in the regulation and development of the body.

DNA (Part 2)
The frequencies of the main responses are shown in Table 6.6.

Table 6.6 - Frequency of main responses to '*Why is DNA important?*'
(These responses are not mutually exclusive; only the main categories are given here)

Coding categories	Number of responses
defines living things	**145**
- ID and characteristics (individuals)	83
- information needed for life	47
- ID and characteristics (organisms)	4
- refers to a code	11
provides information (explicit)	**35**
- non-specific	24
- production of proteins	4
- transfer of information	7
provides information (implicit)	**31**
social use of information	**32**
- genetic fingerprinting	11

number of students asked - 478
number of students responding - 246 (51.5%)

More than half of the responses (59%) said that DNA defined living things. In most cases (34% of responses) what was meant by this was personal/unique identification of individuals. In other cases it meant the information needed for life - 'the blue print for life'(19%). Roughly 5% referred to a code of some sort.

27% of responses (in total) suggested that the important role of DNA was to provide an organism with information. Some responses explicitly mentioned information, usually in a vague way, although a small number of these specifically mentioned the production of proteins or the transfer of information. Others referred to *functions* of DNA e.g. repair of cells, reproduction of genes or chromosomes, production of new cells. In these cases, although 'information' was never mentioned, the implicit assumption seemed to be that DNA provided the information which was needed in order to develop the structure or perform the function.

A smaller but still substantial number of responses (13%) did not consider the biological importance of DNA at all, but focused instead on its social importance - the ways in which people can use DNA. The use most frequently referred to was genetic fingerprinting (5% of all responses).

Chromosomes (Part 4)
The frequencies of the main responses are shown in Table 6.7 below.

Table 6.7 - Frequency of main responses to '*Why are chromosomes important?*'
(These responses are not mutually exclusive; only the main categories are given here)

Coding categories	Number of responses
determine characteristics	**119**
- sex determination	29
- development/function	20
- vague/other	70
refer to number/type/content	**33**
- number	11
- content	19
transfer of information	**22**
- cell division (explicit)	6
social uses	**7**

number of students asked - 476
number of students responding - 189 (39.7%)

Only 39.7% of those asked were able to make suggestions here. Of those who did respond, the most frequently expressed view was that chromosomes determined the characteristics of cells or individuals (63%). Some of these specifically mentioned sex determination (15%), a few referred to control of development and function of the cell or organism (11%), the majority were rather vague. From these responses it seems likely that the majority make no clear distinction between genes and chromosomes.

18% of responses focused on chromosome number, type or content. While some (6%) mentioned number and it's importance, mentioning Down's syndrome for example, a majority (10%) focused on chromosome content - genes, DNA, genetic information.

Although 12% of responses focused on the transfer of information, only a quarter (3% of all responses) specifically referred to cell division - the function of chromosomes which we might expect these students to be most aware of.

As with DNA a small number of students (4%) considered the social rather than the biological importance of chromosomes, for example their importance in prenatal screening for the detection of Down's syndrome.

6.2.4 'What is the function of the nucleus'

The frequencies of the main responses are shown in Table 6.8 below.

Table 6.8 - Frequency of main responses to '*What is the function of the nucleus?*'

(These responses are not mutually exclusive; only the main categories are given here)

Coding categories	Number of responses
control of the cell	**119**
- general	105
- controls cell division	8
reproduction	**12**
- non specific	5
- to produce more cells	6
other functions	**45**
- stores carries information	21
- contains genetic material	11
- keeps cell alive	8
relates to brain analogy	**28**
- appropriate use	22
- inappropriate use	6
relates to atomic structure	**5**

number of students asked - 475
number of students responding - 232 (48.8%)

Although worded differently this question is probing a similar area to that probed in the last section (6.2.3) namely, what do students think these structures are for? What do they think these structures do?

Almost half of the students responded to this question. The majority of responses (51%) said that it controlled the cell. This was usually expressed in a very general way but a few (3% of all responses) specifically mentioned control of cell division.

5% of responses linked the nucleus with reproduction. About half of these explicitly mentioned production of more cells. Most of the remainder were very general.

The other functions mentioned in the responses are listed in Table 6.8 above. There was a substantial group (12%) who described the function of the nucleus through analogy with the brain. The majority did this successfully but some students had clearly been misled by the use of this analogy and seemed to believe that the nucleus functioned in similar ways to the nervous system.

Confusion with atomic structures was again apparent in 2% of responses.

6.2.5 'What are ... made up of?'

This question was asked in respect of two terms: '*genes*' and '*chromosomes*'. The findings for each term are given below.

Genes (Part 1)

The frequencies of the main responses are shown in Table 6.9 below.

Table 6.9 - Frequency of main responses to '*What are genes made up of?*'
(These responses are not mutually exclusive; only the main categories are given here)

Coding categories	Number of responses
cells and cell structures	**164**
- cells	49
- chromosomes	119
- nucleus	2
genetic materials	**84**
- DNA	87
- alleles	6
other biological material	**8**
- proteins/amino acids	4
information	**21**
- general	19
- mentions codes	2
relate to inheritance	**19**

number of students asked - 477
number of students responding - 307 (64.4%)

More than half of the responses (53%) suggested that genes were made up of structures that are actually much bigger than a gene - chromosome (39% of responses) and cell (16% of responses). This highlights the confusion, already evident from other questions and probes, about the relationship between structures.

Most of the responses in the other main categories were scientifically valid, each category representing a different area that students chose to focus on. The inclusion of proteins and amino acids under 'other biological material' suggests a potential confusion between nucleic acids and amino acids or between structure (nucleic acids) and function (production of proteins). In one case this confusion was quite explicit:-

'Genes are made up of...protein based materials called DNA'.

The numbers giving this type of response to this question are very low but this might reflect the small number of students who have reached this level of understanding of genetics. It might be a more significant source of confusion for post 16 students who are working at a higher level.

Chromosomes (Part 4)

The frequencies of the main responses are shown in Table 6.10 below.

Table 6.10 - Frequency of main responses to '*What are chromosomes made up of?*'

(These responses are not mutually exclusive; only the main categories are given here)

Coding categories	Number of responses
genetic structures	**109**
- genes (general)	43
- genes (in different forms)	9
- DNA	67
information	**10**
cells	**23**
- one cell	3
- a mix of cells	20
other chromosomes	**15**
- X and Y	14
other biological material	**3**
- proteins/amino acids	2

number of students asked - 476

number of students responding - 172 (36.1%)

Only about one third of students were able to respond to this question, but the majority of the responses (70%) were scientifically valid.

The response 'other chromosomes' (9%) seems inexplicable at first but the emphasis on sex determination (X and Y) together with the number of responses which say that chromosomes are made up of cells (13%), suggests a possible confusion here with gametes.

The mention of proteins and nucleic acids, under 'biological materials', might indicate a good understanding of chromosome structure (that it is made up of nucleic acids and proteins) but might equally indicate the possible misunderstanding noted above in *'genes'*. Again, numbers are too small to attach any great significance to these responses.

6.2.6 'What does the nucleus contain?'

The frequencies of the main responses are shown in Table 6.11.

Table 6.11 - Frequency of main responses to '*What does the nucleus contain?*'

(These responses are not mutually exclusive; only the main categories are given here)

coding categories	number of responses
genetic materials	**96**
- chromosomes	70
- genes	41
- DNA	35
information	**66**
- unspecified	32
- information about the cell	14
- genetic information	14
cells/lots of cells	**9**
relate to reproduction	**8**
other chemicals/structures (appropriate)	**15**
- liquid/plasma	8
- membranes	4
other chemicals/structures (inappropriate)	**5**
atomic structures	**34**
- protons and neutrons	30
relates to brain analogy	**8**

number of students asked - 475

number of students responding - 272 (57.3%)

This question is related both to Section 6.2.2 and Section 6.2.5. It prompts students to consider the function of the nucleus by asking them to think about the contents of the nucleus. It also probes their understanding of the physical structure of the nucleus and the relationship between different structures within the cell.

The majority of the responses (66%) were scientifically valid. A substantial minority (11%) were confused between the use of 'nucleus' in biology and the use of 'nucleus' in physics, giving responses which related to atomic structure.

Responses which related to reproduction included '*seeds*', '*little tadpoles*', '*nuclei*' and '*ovaries*'. These, together with the 'cells' type of response (6% of response altogether) suggest a possible confusion with gametes - as already seen for chromosomes in Section 6.2.5. This begins to suggest confusion between structures at a quite different level - not just about the structures within cells but also between cells; not just about the relationship between structures, between structures and cells and between cells but also about their functions. These areas are investigated through other probes and the findings are reported in Working Papers 3 and 4 (Wood-Robinson *et al*, in preparation; Lewis *et al*, in preparation).

6.2.7 'What is meant by...?'

This question was asked, in different forms, of two terms: '*alleles*' and '*genetic information*'.
The findings for each term are given below.

Alleles (Part 5)

The frequencies of the main responses are shown in Table 6.12 below.

Table 6.12 - Frequency of main responses to '*How would you describe an allele?*'
(These responses are not mutually exclusive; only the main categories are given here)

coding categories	number of responses
as characteristics	**23**
- in general	11
- refers to relationship between genes	12
as a gene	**4**
related to genes	**3**
as a chromosome	**11**
- related to sex determination	6
related to chromosomes	**4**

number of students asked - 474
number of students responding - 57 (12%)

Only 12% of those asked were able to respond to this question and only 40% of those responding clearly linked alleles with the determination of characteristics. About half of these responses explicitly mentioned different forms of a characteristic e.g. '***black** hair*' or referred to dominance in some form. A smaller group (7% of these responses) who equated allele with gene made no reference to gene expression and appeared to make no distinction between gene and allele.

The second substantial group were those who equated allele with chromosome, or a substantial part of one - '*pairs of X and Y chromosomes*', '*a band on a chromosome*', '*one side of a chromosome*' (26% of responses altogether). This again suggests the confusion about the relationship between structures seen in response to other questions.

It is difficult to identify meaningful patterns of response with such small numbers.

Genetic Information (Part 6)
The frequencies of the main responses are shown in Table 6.13.

Table 6.13 - Frequency of main responses to '*What is meant by genetic information?*'
(These responses are not mutually exclusive; only the main categories are given here)

coding categories	number of responses
information which is stored	**79**
- non-specific	64
- as a code	15
information which gives instructions	**112**
- control of cell	6
- determination of characteristics	106
information which is passed on	**48**
- between people (general)	42
- between people (in sperm)	2
- between cells	6
information which can be used (social aspects)	**40**
a) information obtained from an organism	26
b) application of information gained through (a)	12

number of students asked - 474
number of students responding - 276 (58.6%)

Although there was quite a good response rate for this question a number of the responses were tautologous. Responses which said that genetic information was information found in the genes gave little insight into the students understanding of the concept and are not included in Table 6.13.

The most frequent response (41%) suggested that genetic information gives instructions - either for control of the cells (2%) or for determination of characteristics (38%).

Overall the majority of responses indicated a reasonable but possibly limited understanding of '*genetic information*'. However, about half of those asked could say little or nothing about genetic information.

As in Section 6.2.3, a number of responses (15%) focused on social implications rather than biological meanings. Roughly two thirds of these considered the knowledge we could gain by investigating the genetic information found in organisms and one third considered the uses which we

could make of this knowledge once it was available e.g. screening, genetic engineering. In one case the distinction between the two was uncertain - genetic information means:-
'scientific cells which appear in animals e.g. sheep in Scotland'.

6.3 Discussion of results

Uncertainty about the relationship between structures, confusion between genes and chromosomes and a belief that genetic material is only found in certain types of cell were all common findings, consistent between the different parts and different questions within this probe.

These findings might go some way to explaining why students find the concept of alleles so difficult to grasp. Despite the explicit mention of alleles in the (1991 National Curriculum, Statement of Attainment, Level 8 c):-

> *'pupils should understand the principles of a monhybrid cross involving dominant and recessive alleles'*

Many students said that they had never heard of alleles and only 12 % of students attempted to describe an allele. While knowledge of the term '*allele*' is not essential for an understanding of inheritance, an understanding of the concept is.

Genes may occur in different forms. A gene for fur colour in rabbits, for example, may have a black form or a white form. These two forms are two different alleles of the same fur colour gene. Alleles can be therefore be described as different forms of the same gene. However, understanding that genes can have different forms is not enough for a full understanding of the concept. An awareness of the relationship between alleles, and the implications of this relationship, are also needed. This would require an understanding that:-

- there are usually two copies of each gene in somatic cells
- these two copies may have the same or different forms (alleles)
- the outward appearance (phenotype) is determined by the relationship between these two forms
- gametes contain only one copy of each gene, hence only **one** of the two possible forms.

Students who are confused about the relationship between genes and chromosomes and the different functions of each, and who have little understanding of the location of genetic structures within the cell, are unlikely to have much awareness of the points above. Without such awareness it would be difficult to understand 'allele' as anything other than another word for gene. The use of a second word which appears to mean the same thing as 'gene' is likely to seem illogical and to lead to further confusion.

Another conceptually difficult area seems to be the location of genes or genetic material within the body. Many students seem to believe that only certain cells contain any genetic materials or structures, most frequently those in the reproductive system or the blood. If this is so, then what concept do they have of cells and what do they mean when they say that genes determine characteristics? What image, if any, do they have of how this might be achieved? This area was probed further in the group discussion task which is reported in Working Paper 3 (Wood-Robinson *et al*, in preparation).

In addition to the conceptual difficulties outlined above, there was confusion between different uses of the same word. More than 1 in 10 students confused the biological use of the word nucleus with its use in physics, where it refers to the centre of an atom. The use of the brain analogy when teaching about the nucleus of a cell also had the potential to mislead. Some students were under unable to distinguish between 'similar to' and 'same as' the brain, with obvious consequences for their understanding of the nucleus.

One other interesting feature of the responses was the way that some students focused on social uses (that DNA is important for identification of individuals for example) rather than biological functions when considering the importance of various structures. This could have been for a number of reasons:-

- because it was the only one they were aware of;
- because it was the factor that they felt was *most* important;
- because they were more interested in the social aspects;
- because they became aware of the term through a social context encountered outside the classroom.

It would have been interesting to have more information about this.

7 *The New Genetics* probe

7.1 The probe

7.1.1 Design of the probe

This probe (see Appendix 6a) was designed to investigate students' awareness of DNA technology - what they had heard of, where they had heard of it and what they thought it was.

It covers the following conceptual areas:-
A3a: genes code for protein,
A4c: the code is universal,
A5(iii)c: the code is translated in the same way in all organisms,
B1a: terminology of the technology and
B1b: understanding of the terms
(see Appendices 1 and 2).

The 1991 National Curriculum at KS4, for both double and single science awards, refers to genetic engineering and cloning. Within the Programme of Study it states that pupils should:-

> '*using sources which give a range of perspectives ... have the opportunity to consider the basic principles of genetic engineering (e.g. hormone or drug production); they should consider the social, economic and ethical aspects of cloning*'
> and
> '*study how DNA is able to replicate itself and control protein synthesis by means of a base code*'.

Although it does not state explicitly that pupils should be aware of the universal nature of the genetic code this is implicit in the requirement that pupils should have the opportunity to consider the basic principles of genetic engineering.

7.1.2 Structure of the probe

To probe awareness of current terminology students were presented with a pastiche of terms taken from newspaper cuttings during the preceding year (see Appendix 6a) and asked to tick the ones that they had heard of. The terms were - *genetic mapping, DNA fingerprinting, DNA testing, gene technology, gene transplant, cloning, the human genome project, gene therapy* and *genetic engineering*.

To investigate students understanding of the terminology, and their sources of information, three terms - *genetic engineering, cloning* and *DNA testing* - were chosen. These were the three terms which, on the basis of preliminary work, we believed students would be most aware of and most likely to respond to (see Appendix 6b1). A similar format was used to investigate each of these three terms (see Figure 7.1). A fixed response section asking students whether or not they could say something about the term was followed by two open questions which asked students where they had heard of the term and what they thought it was. In the case of genetic engineering and DNA testing they were also asked to give an example. The whole probe can be seen in Appendix 6a.

DNA technology is only possible because of the universal nature of the genetic code - the fact that all organisms 'read' and respond to the code in a similar way. The final set of questions in this probe were designed to investigate students awareness of the genetic code, and of its importance.

Figure 7.1 - Format of the questions

For each term please tick ONE box to show what you know about it and then answer the questions.

<u>Genetic Engineering</u>

Tick ONE box

I couldn't say anything about genetic engineering ☐

I could say something about genetic engineering ☐

Now, if you can, please answer the following questions. If you can't answer a question please put a cross beside it.

a) I have heard genetic engineering mentioned in/on --

b) I think that genetic engineering is --

----

c) An example of genetic engineering would be ---

7.1.3 Critique of the probe

In the first part of this probe students were asked to tick the terms which they had heard of. We have assumed that if students did not tick an item it was because they had not heard of it. Although some of the terms chosen refer to similar or identical techniques, they were included as they represented the terminology current in the media at that time (1994/5).

In a preliminary study students were asked to select upto 3 items from the initial list of 9 terms and say something more about them. The most frequently selected terms were - *genetic engineering, DNA testing, cloning* and *DNA fingerprinting* (see Appendix 6(b)1 for details). On the basis of this *genetic engineering, DNA testing* and *cloning* were selected as the three technologies to be probed in more depth in the main study. Both genetic engineering and cloning are specifically mentioned in the National Curriculum (1991, KS4, attainment target 2, Programme of Study and Statements of Attainment, level 10c). Results from the first part of the main study (see Section 7.2.1 below) confirm that this was an appropriate choice. Although DNA fingerprinting was also familiar to students it was not included as there was limited space and we felt that it might yield limited information - it was too similar to DNA testing and in the preliminary work it was frequently confused with actual fingerprinting.

Students were asked to complete the sentence *'I have heard ...(e.g. cloning)... mentioned in ....'* because we were interested in the source of the knowledge they were drawing on in answering our other questions in this probe. However, some students seemed to feel it would be unacceptable to quote sources from outside the classroom - especially if they came from the entertainment section of the media rather than documentaries or factual books. It was not uncommon, for example, for the researcher to be asked if 'The X-Files' was an acceptable answer. This should be kept in mind when considering the responses to this question.

In asking students to complete the sentence *'I think that ...(e.g. genetic engineering).... is .....'* we were hoping to probe their understanding of the specific mechanism at whatever level was appropriate for them. In many cases the students actual response focused instead on their feelings about the technology and its uses:-
'I think it is wrong, it is interfering with nature';
'I think it's good if it helps to catch criminals';
'It's exciting'
- a good illustration of the inherent ambiguity of the 'complete the sentence' format and how the intention of the researcher and the perception of the respondent can be two very different things!

As a result of this there was sometimes an overlap between responses to related questions. When this happened, responses to both questions were considered together for the purposes of coding. Those aspects of the answers relating to a specific code were then picked out. In the above example *'I think it's good if it helps to catch criminals'* would be coded under 'attitude' (good) and 'example' (forensic use).

We only asked for examples of genetic engineering and DNA testing. We didn't ask for examples of cloning as we felt that the most common uses (as a standard laboratory technique in molecular genetics) would be outside their experience and so they would have very limited options.

7.1.4 Coding and analysis of the probe

The first part of this probe was a fixed response question asking students to respond to a list of terms, ticking those which they had heard of. Results are given as the frequency of 'yes' responses for each term.

Each of the next three parts (*genetic engineering, cloning* and *DNA testing*) began with the same fixed response section. The original purpose of this section was to determine what proportion of the sample thought that they could say something about the term. There were two alternative answers :-

- *'I couldn't say anything about....'*
- *'I could say something about....'*

As with the *'Biological Terms'* probe, those students who said that they could say something about the technique didn't always go on to say anything at all while some students who said they could say nothing sometimes responded to subsequent questions. The fixed response section of each part was therefore of limited value and is considered quite separately from the open questions which follow it.

Although the probe was set out in 5 separate parts some aspects of the analysis were of general interest and drew on data from several different parts, for example data on the common sources of information. These are reported together under one heading. Where data from different parts are related, they are reported together, where they are not related, they are reported separately.

Where students were asked to complete a sentence and this led to a miss match between the researchers intention and the students perception, the different types of response are coded under different headings.

7.2 Analysis of the data

Our sample size for this probe was 481 (almost 100% of those taking part). For a breakdown of the exact numbers responding to each question see Appendix 6(b).

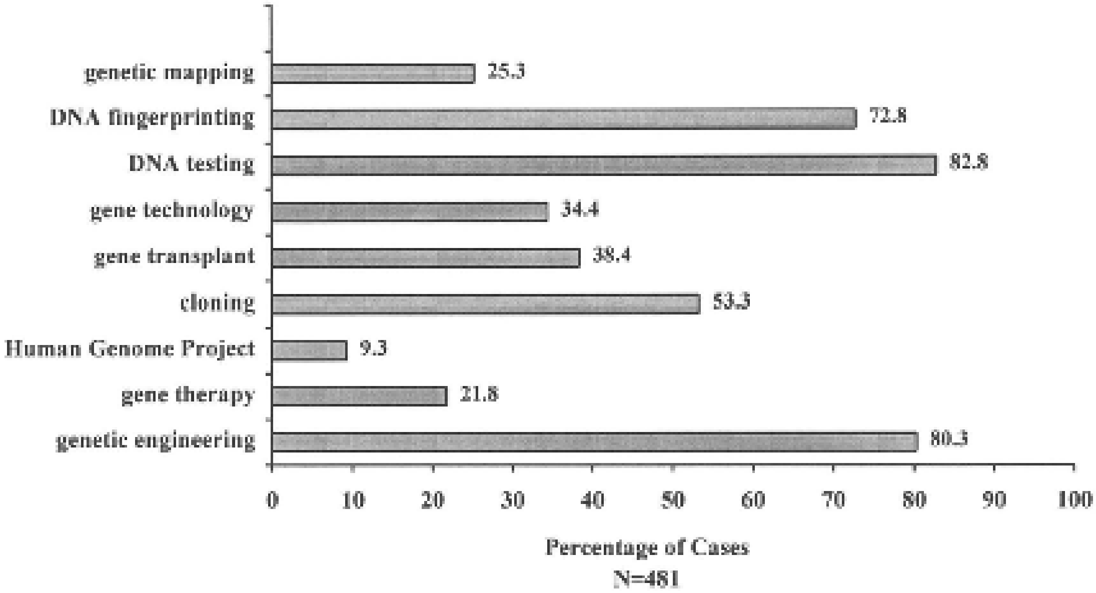
7.2.1 Awareness of the terminology

In response to the question *'Have you heard of ...?'* 464 students ticked one or more boxes. The results are shown in Figure 7.2.

The terms most familiar to these students were:-
DNA testing : 83% of those asked this question,
genetic engineering : 80% of those asked this question,
DNA fingerprinting : 73% of those asked this question and
cloning : 53% of those asked this question.

Their lack of awareness of both '*gene therapy*' (21.8%) and the '*Human Genome Project*' (9.3%) is interesting, given the amount of news coverage these received just prior to and during this project. Perhaps these applications of the technology failed to catch their interest in the way that genetic engineering and DNA testing can (see Section 7.2.2 : '*Where have they heard of ....?*').

Figure 7.2 - Familiarity with the terminology



When questioned about three of these terms in more depth:
59% said that they could say something about DNA testing,
56% said that they could say something about genetic engineering and
42% said that they could say something about cloning

7.2.2 Where had students heard of .....?

For each application of gene technology, 'the media' was the most frequently mentioned source of information (see Table 7.1), despite the fact that both genetic engineering and cloning are included in the National Curriculum. More details can be found in Appendix 6c, parts 2-4.

Table 7.1 - Main sources of information on DNA technology
(These responses are not mutually exclusive)

	school	media	other
Genetic Engineering (n = 338)	166 (49%)	231 (68%)	7 (2%)
Cloning (n = 220)	72 (33%)	166 (76%)	7 (3%)
DNA Testing (n = 331)	117 (35%)	256 (77%)	7 (2%)

NOTE : *all sources for each individual were noted; but only the first reference to each of these sources was included in the count above i.e. if two different types of 'media' were referred to only 1 score for 'media' was noted.*

Of those responses citing 'media' and giving specific details, there were:-
32 references to factual programmes or articles;

78 references to fiction (71 to science fiction; 7 to police/crime fiction);
12 'other' (mostly police programmes, but it was not clear whether they were factual or fiction).

Science fiction in various forms is therefore the main *acknowledged* source of information - and these figures are probably an underestimate. Many young people felt it might not be acceptable to cite such favourite T.V. programmes as 'The X-Files' and 'Red Dwarf' in a survey of this kind and asked whether or not they should include them.

The specific science fiction sources mentioned were :-
Jurassic Park (29 references),
The X-Files (19 references),
Red Dwarf (4 references), and
Star Trek (2 references).

Specific news programs or items were rarely mentioned (7 times in total), and then mainly with reference to DNA testing. The O.J.Simpson trial was referred to three times and murder investigations in general just once. Cloning of sheep was referred to once - this was about the time of Megan and Morag (cloned from a single embryo) but prior to Dolly (cloned from a mature cell).

7.2.3 What do students understand by 'genetic engineering'?

There were 272 responses to '*I think genetic engineering is....*' (57% of those asked). There were three different types of response - those focusing on a possible mechanism, those focusing on a possible purpose and those focusing on personal attitudes towards the technology. The frequency of each type of response is given in table 7.2. Further details can be found in Appendix 6(c) Part 2.

Table 7.2 - Frequency of the different types of response to *'Genetic engineering is ....'*

(These responses are not mutually exclusive)

type of response	number of responses	percentage of total responses (n = 272)
mechanism	218	80.1
purpose	119	43.8
attitude	37	13.6

The term '*genetic engineering*' covers a range of techniques and applications. It could refer to altering genes within one organism, transferring genes between organisms of the same species or transferring genes between organisms of different species. A simple definition of genetic engineering which covered all of these might be 'the manipulation of genes'.

Of the 218 responses which suggested a **mechanism,** 42% gave a description which could be included under this definition i.e. they included the concept of manipulating genetic information in some way:-
'taking genes and using them to make things e.g. food';
'the study of making useful things by manipulating genes and microbes';
'the stage of using other bacteria with genes of humans to produce medicines e.g. penicillin'.

One third gave vague or ambiguous responses which mentioned manipulation of some sort, or implicated genetic material in some way, but didn't show a clear understanding that both manipulation and genetic information were involved in some way:-
'where cells are changed to make things look a certain way';
'artificial creation';
'scientific work on genes'.

10% confused genetic engineering with some other aspect of genetics or DNA technology e.g. inheritance, breeding and testing and 15% suggested a range of other ideas, but there was no obvious pattern to these.

Of the 119 responses which suggested a **purpose,** the majority (72%) suggested it was to design an organism to order.

Of the 37 responses which stated an **attitude**, almost half thought it would be an unqualified 'good thing' and a further 5 felt it could be a good thing under the right circumstances. This latter group saw that there were potential benefits but were also aware of the potential for misuse. The implication was that the technology itself was neither good nor bad, but would depend on the specific purpose for which it was being used:-
'useful but could be very dangerous'
'not good if misused'
'good thing in deciding sex of children but not in the medicines for diabetics'
Some simply expressed their feelings about the possibility of genetic engineering:-
'exciting', 'interesting', 'useful'.

7.2.4 What do students understand by 'cloning'?

There were 198 responses to '*I think cloning is....*' (42% of those asked). Most of these focused on the mechanism, with only 16 responses suggesting a purpose for or an attitude towards cloning. The findings are summarised in Table 7.3. More details can be found in Appendix 6(c) Part 3.

'Cloning' can be used in everyday language to mean making (many) exact copies. When used to describe a form of DNA technology it's most general meaning is to make exact copies of genes. These copies may then be used in a variety of ways.

Table 7.3 - Summary of the main responses to '*Cloning is ....*'
(only the main categories are given here)

coding category	number of responses	percentage of those responding (n = 198)
copying genes	42	21.2
copying (something)	109	55.1
making something	9	4.5
confused with other techniques	13	6.6
fictional	5	2.5

Only about one fifth of those responding (9% of those asked) specifically mentioned copying genes or genetic material/information. The majority suggested 'copying' in some shape or form, but did not refer to genes or genetic material/information.

Those who suggested 'making something' showed no awareness that it was a copying process, but some of them did suggested that genes were used in the process.

7% of those responding confused cloning with other techniques. Most of these seemed to be describing genetic engineering (joining things, changing things or transferring something) or genetic testing (choosing characteristics, matching genes up or sorting genes into different categories).

5 of the responses were not convinced that cloning was a real technique:-
'it's a good idea but animals are a bit far fetched';
'it's only fictional'.

7.2.5 What do students understand by 'DNA testing'?

There were 264 responses to this question (56% of those asked). Most of these focused on the use which could be made of DNA testing. 23 focused on attitudes towards DNA testing. Details of the responses can be found in Appendix 6(c) Part 4.

At a basic level, DNA testing could be described as a means of comparing DNA. Through these comparisons individual similarities and differences can be recognised, leading to the use of DNA testing as a diagnostic tool - to identify individuals, to identify specific forms of a gene (screening for genetic disorders), to compare and define species.

This type of description was given by just over one third of the responses (37%). The majority of these specified identifying individuals and about one quarter specified identifying disease:-
'where you can tell whether a person is connected to some blood or a baby';
'like fingerprints, each person has different DNA';
'to look at DNA to see what could harm you';

'where the DNA of a person can be looked at and tested for a fault which might be corrected'.

In addition, a substantial number of responses (29%) suggested that DNA testing was used for finding out more, either about DNA and genes or about the body or about different organisms:-
'trying to find out more about DNA';
'when you investigate things in the blood';
'looking at a persons/animals DNA to find things out'.
Although the second type of response is less specific than the first type, perhaps reflecting a less detailed understanding, it is still a correct understanding.

A third group (16% of responses) were very vague, suggesting that DNA testing was *'a test for genes'*. Although this is true, to an extent, it suggests a very limited knowledge and understanding of the technique.

About 7% confused DNA testing either with other techniques (for example genetic engineering or cloning) or with the biological function of DNA (for example *'turning genes into proteins'* or *'giving living things their characteristics'*).

About 9% focused on attitudes and of these the majority (13) felt it was a good thing. A few (6) simply expressed their feelings about it - *interesting, very clever, useful, messing with nature.*

7.2.6 Examples of genetic engineering and DNA testing

Genetic engineering
196 students gave examples of genetic engineering (41% of those asked). Coding them presented some difficulties as many were ambiguous. For example, many responses suggested changing or improving crops or livestock as an example of genetic engineering. However, crops and animals can be improved or changed by selective breeding or grafting, as well as genetic engineering. It was difficult to be sure that such students did clearly distinguish between genetic engineering and selective breeding. There was some evidence that this was a difficult distinction for some students, with 4% of responses explicitly referring to breeding as an example of genetic engineering. Conversely, references to transplant of organs, initially suggesting that they had misunderstood the nature of genetic engineering, might actually have been referring to the development of genetically engineered pigs to provide organs for transplants, which was in the news at various points during data collection. Both of these factors should be kept in mind when viewing the data, details of which can be found in Appendix 6(c) Part 2.

63% of the responses *seemed* to be giving valid examples, even when they were fictional. Most of the remainder (33%) *seemed* to indicate a misunderstanding of some sort. The main findings are shown in Table 7.4.

Table 7.4 - Summary of the types of example of genetic engineering
(only the main categories are given here)

type of example	number of responses	percentage of those responding (n = 196)
valid, agricultural	59	30.1
valid, medical/social	57	29.1
confused with other techniques	19	9.7
confused with basic genetics	9	4.6
confused with reproduction	36	18.4

Valid responses divided into two roughly equal groups, one focusing on agriculture and the other on medical and social uses. There were also a small number of examples drawn from fiction (mainly *'Jurassic Park'*). Examples from agriculture focused strongly on plants and included 'improvement' of tomatoes and apples and the introduction of pest resistance. Examples of medical and social uses were more diverse focusing on the correction of genetic 'errors'(both generally - *getting rid of disease*, and more specifically - *gene therapy, cystic fibrosis*), the production of medicines (e.g. *production of insulin, human growth hormone)* and the selection of preferred characteristics (the focus here was mainly on manipulation and selection within the foetus).

The main confusions were with various aspects of reproduction, specifically sex determination, and with other techniques e.g. cloning, testing, grafting (the mouse with the human ear, as featured on *'Horizon'*) and transplanting.

DNA testing

202 students gave examples of DNA testing (76.5% of those asked). Again, coding these responses presented some difficulties as many were ambiguous. For example discussions in the preliminary study showed that many students did not distinguish between traditional fingerprinting and DNA 'fingerprinting'. When 'fingerprinting' was referred to it was difficult to know which type was intended. References to 'screening for disease' were even more problematic. There are several different types of screening and there are different types of disease. DNA screening for an inherited disease would be a valid example, but we could not know if this what the student had in mind when they said things like '*testing for a disease*'. Similarly, there are several different forms of pre-natal diagnosis. What did the student have in mind when they used the term? In analysing such data, ambiguous categories which *could* be interpreted as a valid examples were coded as such. This

should be kept in mind when viewing the data, details of which can be found in Appendix 6(c) Part 4.

171 of the responses (85%) *seemed* to be giving valid examples. Most of the remainder (15%) indicated a misunderstanding of some sort. The main findings are shown in Table 7.5.

Table 7.5 - Summary of the types of example of DNA Testing
(only the main categories are given here)

type of example	number of responses	percentage of those responding (n = 196)
valid, personal ID	136	67.3
valid, identification of specific characteristics	29	14.4
ambiguous	15	7.4
confused with other techniques	13	6.4
confused with other forms of testing	6	3.0

The majority of valid responses (67%) focused on personal identification and the bulk of these (44% of all responses) focused on forensic use of the test. Some of those who gave the example of fingerprinting and blood tests would also have had this use in mind. Most of the remainder focused on the identification of specific characteristics, but many of the categories here are ambiguous.

Most of the misunderstandings related to a confusion about different techniques, in particular a confusion with the genetic engineering techniques used in *Jurassic Park*.

7.2.7 What do students think is meant by 'the genetic code'?

474 people attempted some part of the section which asked about the genetic code. 191 (40% of those asked) said that they had heard of the genetic code. 131 said that they couldn't say anything about it but 171 went on to say what they thought the phrase meant.

A gene could be described as a length of DNA which contains the information that a cell needs to make one polypeptide chain (one or more polypeptide chains combine to make a protein). DNA is made up of a series of units (nucleotides). Each nucleotide contains one of four possible bases. The sequence of bases along the length of DNA are 'read' in groups of three. Each 'triplet' of bases codes for a specific amino acid (except for the few which provide 'punctuation', indicating the beginning and the end of the message). The 'genetic code' refers to this specific relationship between the sequence of bases within a triplet and the amino acid for which that sequence codes. This complex set of ideas, together with an understanding of the

mechanism by which the message in the DNA can be read and converted into a protein was specified within the national curriculum. The Programme of Study (1991 National Curriculum, KS4, Attainment Target 2) states that:-
'they should be introduced to the gene as a section of a DNA molecule and study how DNA is able to replicate itself and control protein synthesis by means of a base code'.
However, only at Level 10 of the Statements of Attainment is it expected that pupils should:-
'understand how DNA replicates and controls protein synthesis by means of a base code'.

A very simple description of the genetic code might refer to the sequence of bases along a strand of DNA. Of the 171 responses to *'what do you think the genetic code means'* 15 (9%) specifically referred to *a sequence* of bases or *a pattern* within the DNA.
'The sequence of chemicals in the DNA chain which is unique to each person';
'the order in which the four chemicals in the DNA are organised';
'the order of elements in the DNA structure'.
A further 11 (6%) referred in a more general way to the structure of DNA or to the four bases (*'things'*) which DNA was made up of:-
'the structure of the bases in the double helix or DNA strand'
'the code that your DNA strings create'.
This was a much less specific group and it was sometimes difficult to differentiate between those who seemed to think that the code related to something within the DNA and those who seemed to think that the code was the total DNA.
In total, 37 responses (22%) seemed to show an awareness that the code was found *within* the gene, although some were ambiguous:-
'the coding found on chromosomes, alleles, DNA etc.'

A similar number, 38 (22%), located the code within the cell. The majority of these (22 of the responses) thought that the code referred to the way in which the genes were organised or sequenced:-
'A pattern of genes that means something but needs to be cracked'
'the genetic code is the arrangement of your genes'.
The largest number of responses, 56 (33%), located the code within the whole organism. The majority of these (46) seemed to have an image of the code as some sort of personal bar code, giving us our unique identity:-
'we all have unique DNA codes - they are printed like bar codes'.
This view may have arisen, or been re-enforced, by the use of autoradiographs in the media to present a visual image of DNA. Such images, which either show bands of DNA arranged in rows or indicate the sequence of bases in a section of DNA, are frequently used in conjunction with discussion of DNA testing and its use in the identification of individuals. Such a link was made quite explicitly in one response. In this case the response to '*What do you think the genetic code means?*' was:-
'refer to earlier question, exactly the same question asked'

and the response to the earlier question '*I think DNA testing is...*' was :-
'*where DNA is taken from someone and made into a bar-code like pattern on X-ray paper*'.

Almost 6% of responses confused the genetic code, a naturally occurring phenomena, with some form of gene technology.

Not one student showed any awareness that the genetic code is related to the production of proteins or even that it controls the nature of the gene product

7.3 Discussion of results

All but one student in our sample responded to this probe (481 out of 482). When asked for further information the response rate remained relatively high for genetic engineering and DNA testing but dropped for cloning and the genetic code, suggesting that they felt less confident about these topics (see Table 7.6).

Table 7.6 - Response rate for individual questions
(as a % of the response rate for each section)

	Genetic Engineering (N = 475)	Cloning (N = 474)	DNA Testing (N = 469)	The Genetic Code (N = 474)
I heard it mentioned...	71.2	46.4	70.6	-
I think it is..	57.3	20.7	56.3	36.1
An example would be..	39.2	-	43.1	-

Looking at students' understanding of the technologies through their responses to '*I think it is ...* ' (see sections 7.2.3 - 7.2.5) it is clear that some students have difficulty distinguishing between the different techniques. 8% of those completing this sentence for genetic engineering showed this type of confusion, compared with 7% of those responding for cloning and 4% of those responding for DNA testing. Some also found it difficult to distinguish between genetic concepts and genetic techniques - 6% of the responses to '*What do you think the genetic code means?*' described a technique, for example DNA testing. It is difficult to quantify the extent of this difficulty as it varied depending on which part of the probe the student was responding to and we can only identify it in those students who actually responded. Some, or even many, of those who didn't respond may have had similar confusions.

Of those students who expressed a view on genetic engineering or DNA testing, more than half thought that these techniques were a good thing (see Table 7.7), although they seemed to be less sure about genetic engineering than DNA testing. A few responses showed an awareness that attitudes towards the techniques might depend on the context in which the technique was being used.

Table 7.7 - Attitudes towards genetic engineering and DNA testing

	Genetic Engineering	DNA Testing
Good	18/37	13/23
Mixed	5/37	1/23
Not Good	9/37	3/23

Overall, of those students *asked* about genetic engineering, cloning and DNA testing (as opposed to those who *answered*) 19%, 9% and 20% respectively showed a generally limited but scientifically valid understanding of the technology. Interestingly, students seem to have least understanding of cloning, which intuitively seems to be the simplest of the techniques.

8% of our sample were aware that the genetic code was located in structures *within* the gene but less than half of these (3% of those asked) showed a limited but scientifically valid understanding of the genetic code as a sequence of bases within the gene/DNA. This is not surprising, given the complexity and abstract nature of the concepts which students need to grasp in order to have a good understanding of what is meant by the genetic code. However, the students' lack of understanding of what is meant by 'the genetic code', together with their confusion about where genes are found (Sections 4.2 and 6.2.2) and whether or not all living things contain genetic information (Sections 5.2.3 and 5.3), must have implications for the ability of these students to develop a better understanding of DNA technologies. An important first step in developing a better understanding of genetic engineering would be the development of an awareness that the genetic code (whatever a student might understand by the phrase) is universal i.e. it is understood by *all* organisms in a similar way. A discussion of this might help to clarify students conceptual understanding of the genetic code and help to explain why a human gene, when transferred into some other animal or a bacterium, will still make a human product. Within our sample the majority of students held the opposite view - that the genetic code was *unique* to each individual.

Although there was some evidence from the '*Biological Terms*' probe that a few students in our sample related some aspect of genetics to the production of proteins (see Section 6.2.3), no evidence of this was found in responses to '*The New Genetics*' probe.

8 Summary of the findings

In undertaking this survey the intention was to gain some insight into the level of understanding of genetics which young people have at the end of their compulsory education. This was why our sample was drawn from across the ability range and from a number of different schools. As the majority of this sample are unlikely to receive any further formal education in science, this is the level of understanding which will be available to them to build on should the future need (or wish) arise. It is likely to be the scientific basis on which they draw when making personal and social decisions related to genetics.

This summary of the findings therefore aims to highlight the general level of understanding of basic genetics and DNA technologies within our sample: the knowledge which these students had, the knowledge which they lacked and their most common misunderstandings. We hope this information will provide teachers, and professional geneticists who wish to communicate with the public, with some indication of where to start and what difficulties to look out for. We also hope that it will be useful in informing those with a responsibility for making decisions about future science curricula.

8.1 The key points

8.1.1 'Gene'

Our sample showed a reasonable understanding of the function of the gene in a general way (that genes determine characteristics and are involved in inheritance) but there is little understanding of the relationship between genes and other structures, including cells (see sections 4.2, 6.2.1, 6.2.2, 6.2.3 and 6.2.5):-

- up to 25% of our sample do not spontaneously locate genes within cells;
- 25% appear to think that genes are only found in certain cells, for example blood or reproductive cells;
- fewer than 40% show any awareness that genes are found within chromosomes;
- there is widespread confusion about the relationship between genes and chromosomes; a common view seems to be that genes and chromosomes are alternatives.

8.1.2 'Chromosome'

There are high levels of confusion and uncertainty about chromosomes and this uncertainty is consistently reflected across a range of questions (Sections 4.2, 5.3, 6.2.1, 6.2.2, 6.2.3 and 6.2.5):-

- only 40% of our sample felt able to say anything about chromosomes; although the majority of these responses were compatible with a scientific view, many showed a very limited understanding;
- fewer than 20% understood the physical relationship between chromosomes and other structures in the cell;

- 11% suggest that it was possible to for chromosomes to contain *no* genetic information;
- 5% said that they had never heard of chromosomes;
- only 3% spontaneously associated chromosomes with cell division.

8.1.3 'Nucleus'

Most of our sample (more than 65%) had a reasonable understanding of the nucleus (Sections 6.2.1, 6.2.2, 6.2.4 and 6.2.6), although some students confused the use of the term in biology with the use of the term in physics. Some students were also confused by analogies which compared the control of the cell by the nucleus with the control of the body by the brain.

8.1.4 'DNA'

The general view of DNA is that it defines living things (60%), but there is little awareness of how it might do this (Sections 6.2.1, 6.2.2, 6.2.3 and 6.2.5):-

- about 5% refer to a code of some sort and about 3% show a scientific understanding, at a basic level, of what the code is;
- about 25% suggest that it provides information but very few spontaneously relate DNA to *genetic* information;
- about 20% spontaneously located DNA in blood rather than in all cells.

8.1.5 'Genetic Information'

- 50% of our sample did not appear to believe that *all* living things contain genetic information (Sections 5.2.4 and 5.3).

8.1.6 'The Genetic Code'

(Section 7.2.7)

- only 13% of our sample had even a limited scientific understanding of what was meant by 'the genetic code'
- not one of our sample made any direct link between the genetic code and the gene product
- none of the sample mentioned the universal nature of the genetic code; in fact the majority view was that the code was unique to each individual, providing a personal identification.

8.1.7 'DNA Technologies'

Despite massive media coverage during the course of our survey, awareness and understanding of DNA technologies was varied.

DNA testing and **genetic engineering**

(Sections 7.2.1, 7.2.2, 7.2.3 and 7.2.5)

- more than 80% of our sample said that they had heard of DNA testing and genetic engineering and more than 50% went on to say something about each of them;
- about 20% of our sample showed a limited but scientifically valid understanding of genetic engineering and DNA testing.

DNA fingerprinting
(Section 7.2.1)

- more than 70% said that they had heard of DNA fingerprinting, but evidence from preliminary work showed that many students confuse DNA fingerprinting with conventional fingerprinting;

cloning
(Sections 7.2.1 and 7.2.4)

- more than 50% said that they had heard of cloning but only about 20% were able to say anything about it;
- fewer than 10% were able to show a limited but scientifically valid understanding of cloning;

gene therapy and the Human Genome Project
(Section 7.2.1)

- fewer than 20% said that they had heard of gene therapy and less than 10% said that they had heard of the Human Genome Project.

8.2 Other findings

8.2.1 The relationship between structures

Very few students had a good understanding of the relationship between different biological structures, or any awareness of the relative scale of different structures (Section 4).

8.2.2 The concept of the cell

Although we didn't question students directly about their understanding of the cell, their views on the relationship between cell structures, the function of cell structures and the nature of living things all give some indication of the students' views of the cell (Sections 4.2, 4.3, 5.2.6 and 6.2.6).

The lack of understanding of the relationship between structures shown by our sample suggests that these students are unaware of the structure of cells, even at the most basic level - that all cells are made up of an outer membrane, which encloses the cytoplasm, which contains a nucleus.

Findings from both the *'Living Things'* and *'Biological Terms'* probes also suggest that our sample had little understanding of the *general* nature of the cell - that all eukaryotic organisms, including plants, are made of cells and that these cells all have the same basic structure.

Nor did our sample seem to have much awareness either of the relative scale/size of cells compared to whole organisms, or of the relationship between cells and organisms - that organisms are made up of cells. This confusion about the general function of the cell was also evident in the *'Biological Terms'* probe, where some students located cells within the chromosomes, sometimes explicitly identifying the cell as the unit of inheritance.

8.2.3 The relationship between genes, inheritance and determination of characteristics

Although the majority of our sample were aware that genes determine characteristics and are involved in inheritance, our findings suggest that most students were unaware of the mechanisms which make this possible.

In order to understand the mechanisms of inheritance and phenotypic expression at a basic level, a student would need to:
- recognise that there is a difference between somatic cells and sex cells (gametes, germ line cells),
- recognise that somatic cells usually carry two copies of each gene,
- understand that these copies of the same gene may have different forms (alleles),
- understand that it is the relationship between these two forms of the gene which determine the phenotype (the characteristic of the individual),
- understand that these copies are separated when sex cells are produced, so that an egg or sperm will contain only one copy of each gene,
- realise that fertilisation allows the single copy of each gene from one parent (e.g. in the egg cell) to pair up with the single copy of the same gene from the other parent (e.g. in the sperm cell),
- understand how this leads to new combinations of alleles, and results in variation (a different combination of characteristics).

However, within our sample the following findings were widespread :
- difficulties in locating genes within the cell,
- difficulties in understanding the relationship between gene and chromosome,
- little awareness of the distinction between gene and allele,
- difficulties with the concept of the cell itself (see section 8.2.2).

In addition, findings from another area of this study (Working Paper 4, Lewis *et al*, in preparation) show that the majority of students are unaware of the nature of the difference between somatic and sex cells, or even that there is a difference.

8.2.4 The relationship between genes and proteins

At a more detailed level, an understanding of phenotypic expression might require an understanding that genes code for proteins. A starting point for this concept would be an awareness that genes 'tell' the cell how to make something i.e. an awareness that there is a gene product of some sort. At a slightly more complex level, there might be an understanding that the structure of the gene determines the structure or form of the gene product.

There was little evidence that our sample were aware of this concept, even in its most basic form. Not one student mentioned gene products when asked why genes were important and just 4 responses (less than 1% of our survey sample) mentioned a product when asked why DNA was important (Section 6.2.3).

Not one student mentioned gene products when writing about the genetic code (Section 7.2.7).

A very basic understanding of the mechanism by which genes can tell the cell how to make something would require an understanding that:
- a gene is a length of DNA,
- DNA is made up of a large number of similar units, held together on a 'backbone',
- there are four different types of basic unit and these can be arranged in any sequence,
- the sequence of these units within the DNA determines the product of the gene.

In order to understand *how* the sequence of bases on the DNA could 'tell' the cell how to make the gene product, students would also have to understand that:
- the sequence of bases are 'read' sequentially in groups of three,
- each combination of three bases is understood in only one way,
- as a result of these two facts, the 'message' within the gene can be 'read' in only one way and so can 'tell' the cell how to make something.

Even presented in this basic way, these are quite difficult concepts to understand. There was no evidence that the students in our sample had any understanding of a possible mechanism by which a gene could tell the cell how to make something. While some students seemed to understand the relationship between genes and DNA (Sections 4.2 and 6.2.2), and some students recognised that there was a relationship between DNA and the genetic code (Sections 6.2.2 and 6.2.3), no student seemed to be aware of the relationship between the genetic code and the gene product - that it is the code which determines what the triplets of bases 'say' and so enables the gene to 'tell' the cell how to make a particular product.

8.2.5 Nucleic acids and amino acids

Some students appeared to be confused about the relationship between DNA, nucleic acids, amino acids and proteins (Section 6.2.5). Although the numbers were small this might reflect the small number of students in our sample who cold comment at all using such terminology. This source of confusion might be more significant amongst post 16 students who are working at a higher level.

9 Implications

In this study our interest was in the knowledge and understanding of genetics which students might draw on in adult life when considering issues raised by DNA technology. Our focus was therefore on the students' understanding of general principles - for example, that all living things contain genetic information - rather than the detailed recall of content which might be required for exams. Despite this we believe that our findings have important implications for teachers.

The size and spread of our sample (482 students in 12 different schools, drawn from across the ability range) and the consistency of our findings across different questions and different probes within this study, suggest that our findings are a reasonably accurate reflection of the understandings which students hold towards the end of their compulsory science education. Similar findings, from a similar but quite independent Spanish study (Banet and Ayuso, 1995) suggest that the difficulties identified in our study are common and widespread.

Within this working paper we have shown how an understanding of some fundamental genetic concepts, like inheritance and the determination of characteristics, requires an understanding of a number of very basic concepts - for example, the basic structures of the cell, the function of these structures and the relationship between these structures (Sections 6.3, 8.2.3 and 8.2.4). We have also shown that the majority of students coming to the end of their compulsory science education do not have a clear understanding of these basic concepts (Sections 8.1 and 8.2).

Given the international nature of this problem, the National Curriculum for England and Wales can hardly be held responsible for these difficulties. However, the National Curriculum can give valuable insights into some possible causes of the problem. The lack of coherence within the genetics component of the 1991 National Curriculum has been considered elsewhere (Wood-Robinson *et al*, 1996). The failure of this curriculum to explicitly include key basic concepts, (the basic structure of the cell or the relationship between chromosomes and genes for example) and the inclusion of complex concepts like protein synthesis or genetic engineering, without any explicit recognition of the basic concepts which underpin them and which might need to be understood first, could not have helped the teaching of genetics. While some of these shortcomings have been rectified in the 1995 National Curriculum (the basic structure of the cell and the relationship between genes and chromosomes are both made explicit in this version), there is still a heavy emphasis on complex genetic concepts without any explicit requirement that the basic ideas which underpin them should also be taught.

As a result, any teacher who took the National Curriculum literally and who taught only what was required by it would not be able to teach genetics very effectively. Although few teachers are likely to do this, the time constraints which most teachers have to work within and the need to satisfy the demands of both the National Curriculum and the exam syllabus does mean that the curriculum is often delivered as neat parcels of content information, tailored to fit conveniently into one lesson. There is little opportunity to explain or to build up the links between the topics or to include information or ideas not explicitly required by either the National Curriculum or the exam syllabus.

An additional problem is the organisation of topics within the curriculum. Within the National Curriculum, the syllabuses and the textbooks, the different topics which students need to connect in order to understand the mechanisms of genetics - cell structure, cell division, determination of characteristics and inheritance - tend to be separated. At the point of delivery, within the classroom, the teaching of these topics may be separated by months or years rather than days or weeks. For example, basic cell structure might be taught at Key Stage 3 and cell division might be taught early in Key Stage 4 while inheritance is often not taught until the very end of Key Stage 4. By requiring that pupils should be taught:-
'that the nucleus contains chromosomes that carry the genes'
at Key Stage 4 (Life Processes and Living Things, 1.e) the 1995 National Curriculum not only makes an important relationship between cell structures explicit, it also gives teachers some opportunity to revisit the basic structure of the cell (originally taught at Key Stage 3). By directly following this requirement with the requirement that pupils should be taught:-
'how cells divide by mitosis so that growth takes place and by meiosis to produce gametes'
(Life Processes and Living Things, 1.f) the 1995 National Curriculum also encourages the idea that there is an important relationship between these two areas.

If genetics, which is often seen as a difficult subject, is to be taught more effectively then the links between different topics - for example the relationship between different structures within the cell - need to be made explicit, as do the basic ideas which underpin the more complex concepts. While such an approach can't guarantee that all students will develop a good understanding of genetics, it will at least give students the basic information which they need if they wish to develop a deeper understanding. Asking students to learn the more complex genetic concepts without first giving them these basic ideas is akin to asking them to complete a cross word but hiding half the clues - it might not be impossible, but it is unnecessarily hard.

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Appendix 1- List of Concepts Related to A Basic Understanding of Genetics and DNA Technology

A) Basic Genetics

1. Language

a) terms related to basic genetics (knowledge of terminology)
b) range of organisms

2. Location

a) location of genes within organisms (relationship between structures)
b) location of genes within cells
c) relationship between structures, from gene to whole organism
d) site of mitosis (somatic cells)
e) site of meiosis (germ cells)

3. Function of Genes

a) genes code for proteins (expression/replication)
b) genetic information must be copied to pass on to new cells during cell division

4. Mechanism of Gene Action

a) a single gene may exist in different (switches/codes/variation) forms (alleles) which may produce different phenotypes; this results in variation
b) gene expression depends on environment (internal and external) to 'trigger' switches
c) the 'code' is universal - the same in all organisms
d) mitotic cell division (somatic cells, for growth) results in new cells containing identical numbers of chromosomes and exactly the same genetic information
e) meiotic cell division (germ cells, for reproduction) results in new cells containing half the chromosome number and different genetic information (increases variation)
f) fertilisation gives continuity, (genetic information passes from parents to child), and variation (mixing of alleles)

5. Similarities/Differences Between Cells

i) within one organism
a) different types of somatic cells all contain the same information
b) different cell structure/function (somatic cells) achieved by differential activation of genes (notion of gene 'switches') - see 4b
c) germ cells contain different genetic information even though they are the same type of cell (see 4e)

ii) between organisms/within species

a) production of germ cells results in variation (see 4e/5a) ; random combination of germ cells at fertilisation leads to even greater variation; result is that cells from different organisms always contain different genetic information (exception = monozygous twins - they arise from same fertilised egg)

b) alleles are source of variation

c) selective pressures will alter the frequency of different variations within the gene pool (i.e. alter the frequency of different alleles)

iii) between different species

a) all organisms contain genetic (prokaryotic vs. eukaryotic; information plant vs. animal)

b) the genetic information is always coded in the form of nucleic acids

c) the code is understood or 'read' (translated) in the same way in all organisms

d) genetic information is copied and passed on during cell division in all organisms

B) DNA Technology

1. Techniques

a) terms used to describe techniques

b) understanding of the terms

2. Applications

a) real or potential

Appendix 2 - Conceptual Areas Covered By The Written Probes

a) Probes reported in this Working Paper

Area	*'Size Sequence'*	*'Living Things'*	*'Biological Terms'*	*'The New Genetics'*
A1a	●		●	
A1b		●		
A2a	●			
A2b	●		●	
A2c	●	●	●	
A2d				
A2e				
A3a			●	●
A3b			●	
A4a			●	
A4b				
A4c				●
A4d				
A4e				
A4f				
A5ia				
A5ib				
A5ic				
A5iia				
A5iib				
A5iic				
A5iiia		●		
A5iiib				●
A5iiic				●
A5iiid				
B1a				●
B1b				●
B2a				

b) Probes reported in Working Paper 4

Area	*'Cells'*	*'Cell Division'*	*'Reproduction'*	*'Information Transfer'*
A1a				
A1b				
A2a				●
A2b				●
A2c				
A2d		●		●
A2e		●		
A3a				
A3b		●		●
A4a				
A4b	●			
A4c				
A4d	●	●		●
A4e	●	●		
A4f			●	
A5ia	●			●
A5ib	●			
A5ic	●		●	
A5iia	●		●	
A5iib	●			
A5iic				
A5iiia				
A5iiib				
A5iiic				
A5iiid		●		
B1a				
B1b				
B2a				

Appendix 3(a) - The Size Sequence Probe

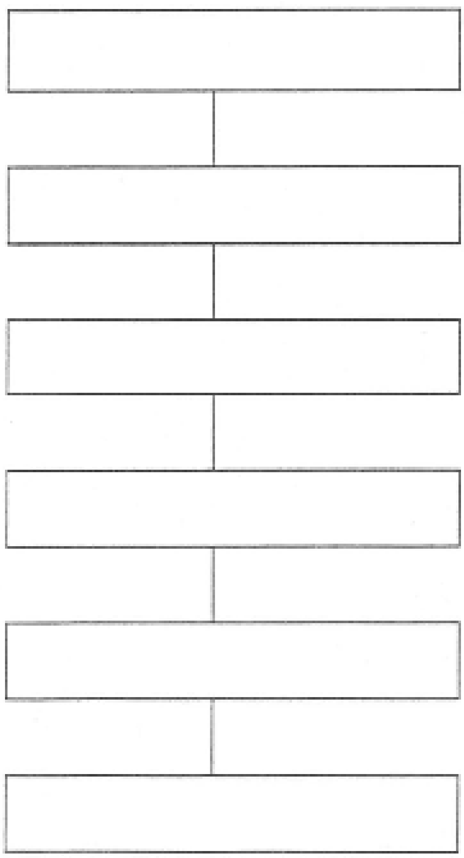
The six biological items in the list below are all parts of living systems.

Please tick those that you have heard of.

- cell ☐
- chromosome ☐
- gene ☐
- DNA ☐
- organism ☐
- nucleus ☐

Now write the items that you have ticked, in order of size, in the boxes below. Start with the largest.

LARGEST



SMALLEST

Appendix 3(b) - The Size Sequence Probe; Frequency Of Responses

Response	**Number (%)**
Sample size for this question*	**482 (100%)**
Responses to 'terms'	**482 (100% of the sample)**
Responses to 'sequence' Of these :- a) unambiguous b) unambiguous and including all six terms	**479 (99.4% of the sample)** 436 (90.5 % of the sample) 400 (83.0 % of those asked)
Of group b • **not beginning** the sequence with *'organism'* • **beginning** the sequence with *'organism, cell..'* • **beginning** the sequence with *'organism, cell, nucleus..'* - scientifically valid sequence • suggesting *'chromosome'* larger than *'nucleus'* • suggesting *'gene'* larger than *'nucleus'* • suggesting *'gene'* larger than *'chromosome'*	 87 (18.0% of the sample; 21.7% of group b) 234 (48.5% of the sample; 58.5% of group b) 140 (29.0% of the sample; 35.0% of group b) 85 (17.6% of the sample; 21.3% of group b) 70 (14.5% of the sample 17.5% of group b) 75 (15.6% of the sample 18.8% of group b) 101 (21.0% of the sample 25.3% of group b)

* *'sample size' refers to the total number of students who attempted some part of this question.*

Appendix 3(c) - The Size Sequence Probe; Range of Unambiguous Responses

Codes:
1 = cell 2 = chromosome 3 = gene 4 = DNA 5 = organism 6 = nucleus

1) those **not** beginning with '*organism*'

Sequence	N of responses	Sequence	N of responses
132456	1	315462	1
132465	1	325641	1
132546	2	341256	1
132645	1	342156	1
132654	1	352146	1
135426	1	352416	1
135624	1	356421	2
136524	1	362451	1
143526	1	412356	2
143625	1	413256	1
145236	1	416325	1
153246	1	423651	1
154326	1	426315	1
156324	1	431265	1
162346	1	431562	2
162453	1	432165	1
163245	1	432561	1
163425	1	432615	1
165234	1	435126	2
165243	1	435162	1
165324	1	451263	1
215346	1	451632	1
231456	1	452136	2
236451	1	452316	1
243156	1	453162	2
245136	1	453216	1
253416	1	456231	2
254361	1	456321	1
256134	2	462135	1
256314	4	463125	1
256341	2	465213	1
256431	1	625431	1
261345	1	635421	1
263514	1	643251	1
312456	1	652314	2

Appendix 3 (c) cont.

2) those beginning with '*organism*'

i) '*organism, cell....*'

Sequence	N of responses
512346	8
512364	17
512436	5
512634	12
512643	1
513216	1
513246	7
513264	9
513426	3
513462	2
513624	12
513642	2

Sequence	N of responses	
514236	4	
514326	3	
514362	2	
514623	1	
514632	5	
516234	70	
516243	9	
516324	40	*'organism, cell, nucleus..'*
516342	5	
516423	6	
516432	10	

ii) '*organism, chromosome....*'

Sequence	N of responses
521436	1
521634	7
521643	1
523164	1
523416	1
523641	1

Sequence	N of responses
524163	1
524316	2
526314	1
526341	1
526413	2

iii) '*organism, gene....*'

Sequence	N of responses
531264	3
531624	4
532164	2
532416	5

Sequence	N of responses
532461	2
534126	2
534162	2
534216	2

Appendix 3 (c) cont.

iv) *'organism, DNA....'*

Sequence	N of responses	Sequence	N of responses
541234	1	542316	3
541236	1	542613	1
541263	1	543126	4
541326	4	543162	2
541623	2	543216	4
541632	1	543612	1
542163	1	546213	2

v) *'organism, nucleus....'*

Sequence	N of responses	Sequence	N of responses
561243	1	562341	1
561324	1	562413	1
561342	1	562431	1
561423	1	563421	1
562134	3	564231	1
562314	1		

Appendix 4(a) - The Living Things Probe

This question is about different living things.

a) Have you heard of the following organisms?

For each organism please tick 'yes' or 'no'.

	yes	no
trees	☐	☐
mammals	☐	☐
ferns	☐	☐
viruses	☐	☐
fungi	☐	☐
bacteria	☐	☐
insects	☐	☐

b) How many cells do you think each organism is made up of?

For each organism please tick only ONE box.

	none	one	many	don't know
a tree	☐	☐	☐	☐
a mammal	☐	☐	☐	☐
a fern	☐	☐	☐	☐
a virus	☐	☐	☐	☐
a fungus	☐	☐	☐	☐
a bacterium	☐	☐	☐	☐
an insect	☐	☐	☐	☐

c) For each type of organism please say whether or not it contains chromosomes.

For each organism please tick only ONE box.

	yes	no	don't know
a tree	☐	☐	☐
a mammal	☐	☐	☐
a fern	☐	☐	☐
a virus	☐	☐	☐
a fungus	☐	☐	☐
a bacterium	☐	☐	☐
an insect	☐	☐	☐

d) For each type of organism, please say whether or not it contains genetic information.

For each organism please tick only ONE box.

	yes	no	don't know
a tree	☐	☐	☐
a mammal	☐	☐	☐
a fern	☐	☐	☐
a virus	☐	☐	☐
a fungus	☐	☐	☐
a bacterium	☐	☐	☐
an insect	☐	☐	☐

Appendix 4(b) - The Living Things Probe; Frequency Of Responses

Part a: 'Have you heard of ...?'

474 (100% of total responses to the probe)

Type of organism	**Number of responses (as a % of Part a responses)**
tree	474 (100%)
mammal	474 (100%)
fern	467 (98.5%)
virus	468 (98.7%)
fungus	472 (99.6%)
bacterium	474 (100%)
insect	474 (100%)

Part b: 'How many cells..?'

473 (99.8% of total responses to the probe)

Type of organism	**Number of responses (as a % of Part b responses)**
tree	472 (99.8%)
mammal	473 (100%)
fern	466 (98.5%)
virus	470 (99.4%)
fungus	470 (99.4%)
bacterium	472 (99.8%)
insect	473 (100%)

Part c: 'Do they have chromosomes...?'

474 (100% of total responses to the probe)

Type of organism	**Number of responses (as a % of Part c responses)**
tree	470 (99.2%)
mammal	472 (99.6%)
fern	468 (98.7%)
virus	470 (99.2%)
fungus	471 (99.4%)
bacterium	470 (99.2%)
insect	474 (100%)

Part d: 'Do they have genetic information...?'

472 (99.6% of total responses to the probe)

Type of organism	**Number of responses (as a % of Part d responses)**
tree	472 (100%)
mammal	472 (100%)
fern	470 (99.6%)
virus	470 (99.6%)
fungus	472 (100%)
bacterium	471 (99.8%)
insect	472 (100%)

Appendix 4(c) - The Living Things Probe; Relationship Between Chromosomes and Genetic Information

	+C +G	-C +G	?C +G	+C ?G +C -G	?C ?G, ?C -G -C -G, -C ?G	total number
mammal	393	12	27	19	20	471
insect	367	10	40	21	33	471
tree	202	67	55	26	119	469
fern	156	59	54	23	174	466
fungus	145	64	54	47	160	470
bacteria	142	58	58	52	158	468
virus	113	65	53	51	187	468

+C - contains chromosomes
-C - does not contain chromosomes
information
?C - unsure if it contains chromosomes

+G - contains genetic information
-G - does not contain genetic
?G - unsure if it contains genetic information

Appendix 5(a) - The Biological Terms Probe

In this question we are interested in what you know about the following biological terms :-

- **genes**
- **DNA**
- **nucleus**
- **chromosomes**
- **alleles**
- **genetic information**

We will ask you about them one at a time.

For each term, please tick ONE box to show what you know about it and then answer the questions.

<u>genes</u>

	Tick ONE Box
I have never heard of genes	☐
I have heard of genes but don't really know what genes are	☐
I have heard of genes and could say something about genes	☐

Now, if you can, please answer the following questions. If you can't answer a question, please put a cross beside it.

a) Where, in your body, are genes found?

b) What are genes made up of ?

c) Why are genes important?

DNA

Tick ONE Box

I have never heard of DNA ☐

I have heard of DNA but don't really know what DNA is ☐

I have heard of DNA and could say something about DNA ☐

Now, if you can, please answer the following questions. If you can't answer a question, please put a cross beside it.

a) Where, in your body, is DNA found? --

----

b) Why is DNA important? ---

----

nucleus

Tick ONE Box

I have never heard of a nucleus ☐

I have heard of a nucleus but don't really know what a nucleus is ☐

I have heard of a nucleus and could say something about a nucleus ☐

Now, if you can, please answer the following questions. If you can't answer a question, please put a cross beside it.

a) Where is the nucleus found ? --

b) What does the nucleus contain? ---

----

c) What is the function of the nucleus? --

----

chromosomes

Tick ONE Box

I have never heard of chromosomes ☐

I have heard of chromosomes but don't really know what they are ☐

I have heard of chromosomes and could say something about them ☐

Now, if you can, please answer the following questions. If you can't answer a question, please put a cross beside it.

a) Where are chromosomes found? --

----

b) What are chromosomes made up of? --

----

c) Why are chromosomes important? --

----

alleles

Tick ONE Box

I have never heard of alleles ☐

I have heard of alleles but don't really know what alleles are ☐

I have heard of alleles and could say something about alleles ☐

Now, if you can, please answer the following question. If you can't answer the question, please put a cross beside it.

a) How would you describe an allele ? --

----

genetic information

Tick ONE Box

I have never heard of 'genetic information' ☐

I have heard of 'genetic information' but don't really know what it is ☐

I have heard of 'genetic information' and could say something about it ☐

Now, if you can, please answer the following question. If you can't answer the question, please put a cross beside it.

a) What do you think is meant by 'genetic information'? --------------------

----

Appendix 5(b) - The Biological Terms Probe; Frequency Of Responses

Part of probe	Number of responses
Part 1 - genes	**477 (99.8% of total responses to the probe)**
(i) fixed response	462 (96.9% of those asked)
(ii)a. where are they found?	370 (77.6% " " ")
b. what are they made of?	307 (64.4% " " ")
c. why are they important?	383 (80.3% " " ")
Part 2 - DNA	**478 (100% of total responses to the probe)**
(i) fixed response	468 (97.9% of those asked)
(ii)a. where is it found?	298 (62.3% " " ")
b. why is it important?	246 (51.5% " " ")
Part 3 - nucleus	**475 (99.4% of total responses to the probe)**
(i) fixed response	461 (97.1% of those asked)
(ii)a. where is it found?	392 (82.5% " " ")
b. what does is it contain?	272 (57.3% " " ")
c. what is its function?	232 (48.8% " " ")
Part 4 - chromosomes	**476 (99.6% of total responses to the probe)**
(i) fixed response	463 (97.3% of those asked)
(ii)a. where are they found?	278 (58.4% " " ")
b. what are they made of?	172 (36.1% " " ")
c. why are they important?	189 (39.7% " " ")
Part 5 - alleles	**474 (99.2% of total responses to the probe)**
(i) fixed response	464 (97.9% of those asked)
(ii)a. how would you describe one?	57 (12.0% " " ")
Part 6 - genetic information	**471 (98.5% of total responses to the probe)**
(i) fixed response	98.1 (96.9% of those asked)
(ii)a. what is meant by this?	276 (58.6% " " ")

Appendix 5(c) - The Biological Terms Probe; Outline Of The Coding Scheme

Analysis Of Responses

The main responses to each question are set out part by part in the following pages. Ambiguous or incomprehensible responses are not listed, nor are views expressed by very few (one or two) individuals. In many cases the coding is not exclusive (more than one of the listed views may have been expressed by one person) therefore the total may add up to more than 100% at times.

Part 1: Genes
477 students responded to some part of 'Genes'
(99.8% of those responding to some part of this probe).

'Where are genes found?'

370 students answered this question (77.6% of those answering some part of 'Genes'; 77.4% of those answering some part of this probe)

	Number of Responses	**% of those answering this question (n = 370)**	**% of those answering this part (n = 477)**
Throughout	**276**	**74.6**	**57.9**
• everywhere (vague)	90	24.3	18.9
• in cells (any, all)	118	31.9	24.7
• in the nucleus	19	5.1	4.0
• in the chromosomes	40	10.8	8.4
• in DNA	9	2.4	1.9
Specific Regions only	**94**	**25.4**	**19.7**
• reproductive system	38	10.0	7.7
• 1/3 = male system, 2/3 = non-specific			
• other	58	15.4	11.9

Appendix 5(c), Part 1 cont.

'What are genes made of?'

307 students answered this question (66.4% of those answering some part of 'Genes'; 64.2% of those answering some part of this probe)

	Number of Responses	% of those answering this question (n =307)	% of those answering this part (n = 477)
Cells and Cell Structures	**164**	**53.4**	**34.4**
• cells	49	16.0	10.3
• chromosomes	119	38.8	24.9
• nucleus	2	0.7	0.4
Genetic Material	**89**	**28.9**	**17.6**
• DNA	84	27.4	18.2
• alleles	6	2.0	1.3
Other Biological Material	**8**	**2.6**	**1.7**
• proteins/amino acids*	4	1.3	0.8
Information	**21**	**6.8**	**4.4**
• general	19	6.2	4.0
• mentions codes	2	0.7	0.4
Relate to Inheritance (things received from parents and/or things to be passed on to offspring)**	**19**	**6.2**	**4.0**

*(sugars, bases, proteins, hydrocarbons, amino acids - note the inclusion of proteins and amino acids; genuine confusion proteins and nucleic acid or misplaced knowledge about chromosomes and their protein chromatic)

** a few (3) relate to reproduction; eggs, sperm or *particles* of sperm!

Appendix 5(c), Part 1 cont.

'Why are genes important?'

383 students answered this question (80.3% of those answering some part of 'Genes'; 80.1% of those answering some part of this probe)

	Number of Responses	**% of those answering this question (n = 383)**	**% of those answering this part (n = 477)**
Determine Characteristics	**280**	**73.1**	**58.7**
• unspecified	154	40.2	32.3
• physical	126	32.9	26.4
• mental/emotional/ behavioural	23	6.1	4.8
Carry/Transfer Information	**52**	**13.5**	**10.9**
• between generations	36	9.4	7.5
Control	**15**	**3.9**	**3.1**

Appendix 5(c), Part 2: DNA

478 students responded to some part of 'DNA '
(100% of those responding to some part of this probe).

'Where is DNA found?'

298 students answered this question (62.3% of those answering some part of 'DNA'; 62.3% of those answering some part of this probe)

	Number of Responses	% of those answering this question (n = 298)	% of those answering this part (n = 478)
Throughout	**206**	**69.1**	**43.1**
• everywhere (vague)	(47)	(15.8)	(9.8)
• in (all) cells	(159)	(53.4)	(31.3)
- in cells (any, all)	57	19.1	11.9
- in the nucleus	19	6.4	4.0
- in the chromosomes	21	7.0	4.4
- in the genes	62	20.8	13.0
Specific Body Structures, Fluids or Chemicals	**85**	**28.5**	**18.5**
• blood	64	21.5	13.4

Appendix 5(c), Part 2 cont.

'Why is DNA important?'

246 students answered this question (51.5% of those answering some part of 'DNA'; 51.5% of those answering some part of this probe)

	Number of Responses	% of those answering this question (n = 246)	% of those answering this part (n = 478)
Defines Living Things	**145**	**58.9**	**30.3**
• identity and characteristics of individuals	83	33.7	17.2
• information needed for life	47	19.1	9.8
• identity and characteristics of types of organism	4	1.6	0.8
• refers to code	11	4.5	2.3
Provides The Organism With Information (Explicit)	**35**	**14.2**	**7.3**
• vague	24	9.8	5.0
• production of proteins	4	1.6	0.8
• transfer of information	7	2.8	1.5
Provides The Organism With Information (Implicit)	**31**	**12.6**	**6.5**
Provides *People* With Information (i.e. social use)	**32**	**13.0**	**6.7**
• genetic fingerprinting	11	4.5	2.3

Appendix 5(c), Part 3: Nucleus

475 students responded to some part of 'Nucleus '
(99.4% of those responding to some part of this probe).

'Where is the nucleus found?'

392 students answered this question (82.5% of those answering some part of 'Nucleus'; 82% of those answering some part of this probe)

	Number of Responses	**% of those answering this question (n = 392)**	**% of those answering this part (n = 475)**
In Cells	**349**	**89.0**	**73.5**
• all cells	342	87.2	72.0
• certain cells (blood, gametes, skin)	7	1.8	1.5
In Atoms	**9**	**2.3**	**1.9**
Other	**34**	**8.5**	**7.2**

Appendix 5(c), Part 3 cont.

'What does the nucleus contain?'

272 students answered this question (57.3% of those answering some part of 'Nucleus'; 56.9% of those answering some part of this probe)

	Number of Responses	**% of those answering this question (n = 272)**	**% of those answering this part (n = 475)**
Genetic Materials	**96**	**35.3**	**20.2**
• chromosomes	70	25.7	14.7
• genes	41	15.1	8.6
• DNA	35	12.9	7.4
• RNA*	2	0.7	0.4
Information	**66**	**24.3**	**13.9**
• unspecified	32	11.8	6.7
• information about the cell	14	5.1	2.9
• genetic information	14	5.1	2.9
Cells	**9**	**3.3**	**1.9**
Reproductive Materials (others included seeds, living organisms, nuclei, little tadpoles, ovaries and things needed for the baby)	**8**	**3.0**	**1.7**
Other Chemicals/Structures (appropriate)	**15**	**5.5**	**3.2**
• liquid/plasma	8	2.9	1.7
• membranes	4	1.5	0.8
Other Chemicals/Structures (inappropriate) - includes haemoglobin, blood, hormones and cell wall	**5**	**1.8**	**1.1**
Atomic Structures	**34**	**12.5**	**7.2**
• protons and neutrons	30	11.0	6.3
Relates to Brain Analogy	**8**	**2.9**	**1.7**

*remember these are not mutually exclusive

Appendix 5(c), Part 3 cont.

'What is the function of the nucleus?'

232 students answered this question (48.8% of those answering some part of 'Nucleus'; 48.5% of those answering some part of this probe)

	Number of Responses	% of those answering this question (n = 232)	% of those answering this part (n = 475)
Control of Cell	**119**	**51.3**	**25.1**
• general (controls the cell, determines characteristics, centre of activity)	105	45.3	22.1
• controls cell division	8	3.4	1.7
• controls growth	3	1.3	0.6
Reproduction	**12**	**5.2**	**2.5**
• non-specific	5	2.2	1.1
• to produce more cells	6	2.6	1.3
Other Functions	**45**	**19.4**	**9.5**
• store/carries information	21	9.1	4.4
• contains genetic material (DNA, chromosomes, genes)	11	4.7	2.3
• keeps cell alive	8	3.4	1.7
• passes on genetic information	3	1.3	0.6
Relates to Brain Analogy	**28**	**12.1**	**5.9**
• appropriate use	22	9.5	4.6
• inappropriate use	6	2.6	1.3
Relates to Atomic Structure	**5**	**2.2**	**1.1**

Appendix 5(c), Part 4: Chromosomes

476 students responded to some part of 'Chromosomes'
(99.6% of those responding to some part of this probe).

'Where are chromosomes found?'

278 students answered this question (58.4% of those answering some part of 'Chromosomes'; 58.2% of those answering some part of this probe)

	Number of Responses	% of those answering this question (n = 278)	% of those answering this part (n = 476)
Within Cells	**190**	**68.7**	**40.0**
• non-specific	80	28.8	16.8
• in/around the nucleus	65	23.4	13.7
• in genes/DNA	45	16.5	9.7
Within the Body	**84**	**30.2**	**17.6**
• non-specific	38	13.7	8.0
• in the reproductive system	34	12.2	7.1
• in the blood	11	4.0	2.3

'What are chromosomes made of?'

172 students answered this question (36.1% of those answering some part of 'Chromosomes'; 36.0% of those answering some part of this probe)

	Number of Responses	% of those answering this question (n = 172)	% of those answering this part (n = 476)
Genetic Structures	**109**	**63.4**	**22.9**
• genes; general	43	25.0	9.0
• genes; different forms of (alleles - 8; dominant/recessive - 1)	9	5.2	1.9
• DNA	67	39.0	14.1
Information (general-7; genetic-3)	10	5.8	2.1
Cells	**23**	**13.4**	**4.8**
• one cell	3	1.7	0.6
• mix of cells	20	11.6	4.2
Other Chromosomes (X and Y-14; other-1)	**15**	**8.7**	**3.1**
Other Biological Material (proteins, amino acids, bases)	**3**	**1.7**	**0.6**

Appendix 5(c), Part 4 cont.

'Why are chromosomes important?'

189 students answered this question (39.7% of those answering some part of 'Chromosomes'; 39.5% of those answering some part of this probe).

	Number of Responses	% of those answering this question (n = 189)	% of those answering this part (n = 476)
Determine Characteristics of Cells/Individuals	**119**	**63.0**	**25.0**
• refer to sex determination	29	15.3	6.1
• refer to control of development or function	20	10.6	4.2
• other	70	37.0	14.7
Number/Type of Chromosome	**33**	**17.5**	**6.9**
• number	11	5.8	2.3
• content	19	10.1	4.0
Transfer of Information	**22**	**11.6**	**4.6**
• cell division (explicit)	6	3.2	1.3
The use we can make of them (Social Importance)	7	**3.7**	**1.5**

Appendix 5(c), Part 5: Alleles

474 students responded to some part of 'Alleles '
(99.2% of those responding to some part of this probe).

'How would you describe one?'

57 students answered this question (12% of those answering some part of 'Alleles'; 11.9% of those answering some part of this probe)

	Number of Responses	**% of those answering this question (n = 57)**	**% of those answering this part (n = 474)**
As Characteristics	**23**	**40.4**	**4.9**
• general	11	19.3	2.3
• refers to relationship between genes	12	21.1	2.5
As a Chromosome	**11**	**19.3**	**2.3**
• related to sex determination	6	10.5	1.3
Relate to Chromosomes	**4**	**7.0**	**0.8**
As a Gene	**4**	**7.0**	**0.8**
Relate to Genes	**3**	**5.3**	**0.6**

Note

It is difficult to pull out any patterns with so few responses.

Appendix 5(c), Part 6: Genetic Information

471 students responded to some part of 'Genetic Information' (98.5% of those responding to some part of this probe).

'What is meant by this?'

276 students answered this question (58.6% of those answering some part of 'Genetic Information'; 57.5% of those answering some part of this probe)

	Number of Responses	% of those answering this question (n = 276)	% of those answering this part (n = 471)
Information which is stored	**79**	**28.6**	**16.8**
• non specific	64	23.2	13.6
• as a code	15	5.4	3.2
Information which gives instructions	**112**	**40.6**	**23.8**
• control (of cell)	6	2.2	1.3
• determination of characteristics (whole body)	106	38.4	22.5
Information which is passed on	**48**	**17.4**	**10.2**
• between people; general	42	15.2	8.9
• between people; in sperm	2	0.7	0.4
• between cells	6	2.2	1.3
Information which can be used (social uses)	**40**	**14.5**	**8.5**
• (a) information obtained from an organism	26	9.4	5.5
• (b) application of the information gained through (a)	12	4.3	2.5

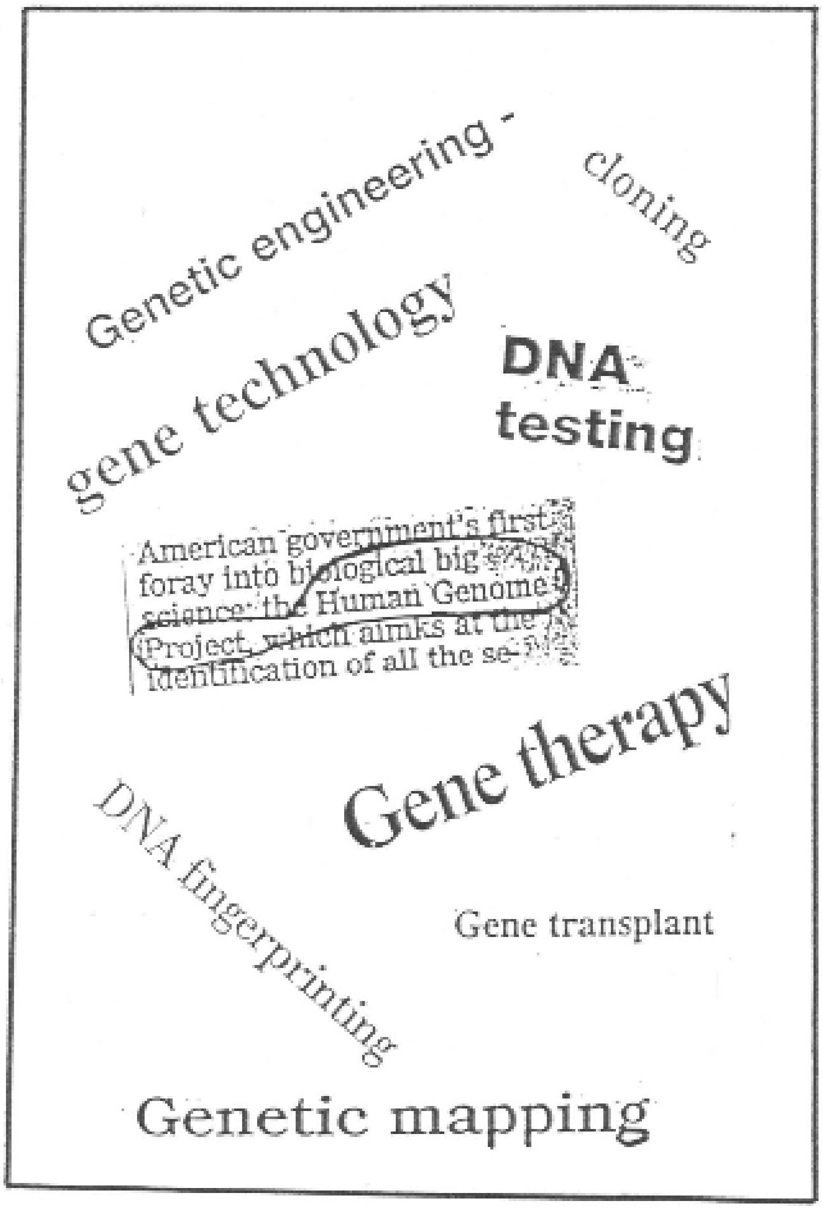
Appendix 6(a) - The New Genetics Probe

In this question we are interested in what you know (or don't know) about DNA technology - 'The New Genetics'.
The leaflet printed below is made up of newspaper cuttings collected over the past year.

Look at the 9 items.

They are listed for you again at the side.

Please tick the ones that you have heard of.



- genetic mapping ☐
- DNA fingerprinting ☐
- DNA testing ☐
- gene technology ☐
- gene transplant ☐
- cloning ☐
- Human Genome Project ☐
- gene therapy ☐
- genetic engineering ☐

Now, if you can, we would like you to tell us a little more about the following three terms :-

*** genetic engineering**

*** DNA testing**

*** Cloning**

For each term please tick ONE box to show what you know about it and then answer the questions.

Genetic Engineering

	Tick ONE box
I couldn't say anything about genetic engineering	☐
I could say something about genetic engineering	☐

Now, if you can, please answer the following questions. If you can't answer a question please put a cross beside it.

a) I have heard genetic engineering mentioned in/on ------------------------------------

b) I think that genetic engineering is --

----

c) An example of genetic engineering would be ---

Cloning

	Tick ONE box
I couldn't say anything about cloning	☐
I could say something about cloning	☐

Now, if you can, please answer the following questions. If you can't answer a question please put a cross beside it.

a) I have heard cloning mentioned in/on --

b) I think that cloning is --

DNA Testing

Tick ONE box

I couldn't say anything about DNA testing ☐

I could say something about DNA testing ☐

Now, if you can, please answer the following questions. If you can't answer a question please put a cross beside it.

a) I have heard DNA testing mentioned in/on --

b) I think that DNA testing is --

----

c) An example of DNA testing would be --

Newspaper articles and tv reports on these topics often refer to 'the genetic code' and 'cracking the code'.

Please say whether or not you have heard of 'the genetic code'.

Tick ONE Box

yes ☐

no ☐

Do you have any idea what is meant by 'the genetic code'?

Tick ONE Box

yes ☐

no ☐

Please say what you think 'the genetic code' means.

Appendix 6(b) - The New Genetics Probe; Frequency Of Responses

Appendix 6(b)1 - The Preliminary Study: The Choices

In the 64 responses, only 5 of the 9 items were picked out in any numbers. The frequencies were as follows:-
genetic engineering - 23
DNA fingerprinting - 21
DNA testing - 20
gene transplant - 15
cloning - 13

Genetic engineering was chosen for the main study as it was the term which the greatest number of students felt able to respond to.
DNA testing and DNA fingerprinting are two terms relating to similar techniques. DNA testing was chosen in preference to DNA fingerprinting as there were a similar number of responses to each term but there was a tendency to confuse genetic fingerprinting with ordinary fingerprinting. Responses to DNA testing were therefore likely to give us more useful information.
Cloning was chosen as the third term in order to extend the range of techniques.

Appendix 6(b) cont.

Appendix 6(b) 2 - The Main Study: The Number Of Responses To Each Part Of The Probe

Part of probe	Number of responses
'Have you heard of ...'	**481 (100% of total responses to the probe)**
- genetic mapping	122 (25.3% of those asked)
- DNA fingerprinting	351 (72.8% of those asked)
- DNA testing	399 (82.8% of those asked)
- gene technology	166 (34.4% of those asked)
- gene transplant	185 (38.4% of those asked)
- cloning	257 (53.3% of those asked)
- Human Genome Project	45 (9.3% of those asked)
- gene therapy	105 (21.8% of those asked)
- genetic engineering	387 (80.3% of those asked)
Genetic Engineering	**475 (98.8% of total responses to the probe)**
- fixed response	461 (97.1% of those asked)
- where heard of ?	338 (71.2% of those asked)
- what is it?	272 (57.3% of those asked)
- example	196 (39.2% of those asked)
Cloning	**474 (98.5% of total responses to the probe)**
- fixed response	472 (99.6% of those asked)
- where heard of ?	220 (46.4% of those asked)
- what is it?	198 (20.7% of those asked)
DNA Testing	**469 (97.5% of total responses to the probe)**
- fixed response	450 (95.9% of those asked)
- where heard of ?	331 (70.6% of those asked)
- what is it?	264 (56.3% of those asked)
- example	202 (43.1% of those asked)
The Genetic Code	**474 (98.5% of total responses to the probe)**
- have you heard of it?	474 (100% of those asked)
- have you any idea what it is?	470 (99.2% of those asked)
- what do you think it means?	171 (36.1% of those asked)

481 students attempted some part of this probe.

Appendix 6(c) - The New Genetics Probe; Outline Of The Coding

Analysis Of Responses

The main responses to each question are set out part by part in the following pages.

Ambiguous or incomprehensible responses are not listed, nor are views expressed by very few (one or two) individuals.

In many cases the coding is not exclusive (more than one of the listed views may have been expressed by one person) therefore the total may add up to more than 100% at times.

Each part of the probe began with a fixed response question which would enable the student to opt out of the subsequent questions. For analysis and comparisons we have therefore taken the total number of people responding to *any* question within one part to equal the number of people asked *each* question within that part. We assume that, within one part, those who have answered only some of the questions had nothing to say in response to those which they did not answer.

Part 2: Genetic Engineering

475 students responded to some part of 'Genetic Engineering ' (98.5% of those responding to some part of this probe).

'What can they say about genetic engineering?'

461 students answered this question (97.1% of those answering some part of 'Genetic Engineering'; 95.8% of those answering some part of this probe)

	Number of Responses	% of those answering this question (n = 461)	% of those answering this part (n = 475)
Something	**257**	**55.7**	**54.1**
Nothing	**204**	**44.3**	**42.3**

Appendix 6 (c), Part 2 cont.

'Where have they heard of genetic engineering?'

338 students answered this question (71.2% of those answering some part of 'Genetic Engineering'; 70.3% of those answering some part of this probe).

	Number of Responses	% of those answering this question (n = 338)	% of those answering this part (n = 475)
At School	**166**	**49.1**	**34.9**
• unspecified	83	24.6	17.5
• within science	78	23.1	16.4
• within drama	5		
In The Media	**231**	**68.3**	**48.6**
• news: general, all forms	72 (+3)	22.2	15.9
• news: specific items	0		
• viewing, unspecified	151 (+1)	45.0	32.0
• reading, unspecified	11 (+15)	7.7	5.5
• entertainment, specified context	26	7.7	5.5
Other	**7**	**2.1**	**1.2**
• family	4	1.2	0.9

NOTE: *some responses indicated more than one source of information in the media; only the first was counted when totalling the number of individuals getting their information through the media; the second source is given in brackets so that it can be totalled for type of media source.*

Appendix 6 (c), Part 2 cont.

'What do they think genetic engineering is?'

272 students answered this question (57.3% of those answering some part of 'Genetic Engineering'; 56.5% of those answering some part of this probe).

There were three types of response to this question, each with a different focus:-

- **mechanism** - there were 218 responses of this type; 80.1% of those responding to this question;
- **purpose** - there were 119 responses of this type; 43.8% of those responding to this question;
- **attitude** - there were 37 responses of this type; 13.6% of those responding to this question.

(**Note**: these responses are *not* mutually exclusive.)

a) Mechanism

218 students gave this type of response (80.1% of those answering this question; 46.1% of those answering some part of 'Genetic Engineering'; 45.3% of those answering some part of this probe)

	Number of Responses	% of those giving this response (n = 218)	% of those answering this question (n = 272)	% of those answering this part (n = 275)
Manipulation Of Genetic Material	**162**	**74.3**	**59.6**	**34.1**
• explicit	91	41.7	33.5	19.2
• implied (ambiguous)	71	32.6	26.1	15.0
Confused With Other DNA Technologies	**22**	**10.1**	**8.1**	**4.6**
Other	**32**	**14.7**	**11.8**	**6.7**

Appendix 6 (c), Part 2 cont.

b) Purpose

119 students gave this type of response (% of those answering this question; 25.3% of those answering some part of 'Genetic Engineering'; 24.7% of those answering some part of this probe)

	Number of Responses	% of those giving this response (n = 119)	% of those answering this question (n = 272)	% of those answering this part (n = 275)
To Produce A New Organism	**96**	**80.7**	**35.3**	**20.2**
• design something to order	89	74.8	32.7	18.7
• produce something novel	7	5.9	2.6	1.5
To Repair Faulty Genes	**8**	**6.7**	**2.9**	**1.7**
Other	**15**	**12.6**	**5.5**	**3.2**
• related to reproduction	4	3.4	1.5	
• to make more of something	2	1.7	0.7	

c) Attitude

37 students gave this type of response(13.6% of those answering this question; 8.0% of those answering some part of 'Genetic Engineering'; 7.7% of those answering some part of this probe)

	Number of Responses	% of those giving this response (n = 37)	% of those answering this question (n = 272)	% of those answering this part (n = 275)
Good	**18**	**48.6**	**6.6**	**3.8**
• benefits	6	16.2	2.2	1.3
• progress	3	8.1	1.1	
• exciting	3	8.1	1.1	
Not Good	**9**	**24.3**	**3.3**	**1.9**
• relates to 'natural'	5	13.5	1.8	
• dangerous	2	5.4		
Potential To Be Either	**5**	**13.5**	**1.8**	**1.1**
Other Views	**5**		**1.8**	**1.1**

Appendix 6 (c), Part 2 cont.

'Examples of Genetic Engineering'

196 students answered this question (41.3% of those answering some part of 'Genetic Engineering'; 40.7% of those answering some part of this probe)

	Number of Responses	**% of those answering this question (n = 196)**	**% of those answering this part (n = 275)**
Valid Responses	**124**	**63.3**	**26.1**
• agriculture	(59)	(30.1)	(12.4)
- changing/improving plants	41	20.9	8.6
- changing/improving animals	11	5.6	2.3
- creating new plants and animals	7	3.6	1.5
• medical/social	(57)	(29.1)	(12.0)
- to produce medicines	14	7.1	2.9
- to put things right (people)	22	11.2	4.6
- to put things right (environment)	2	1.0	<1.0
- to select preferred	19	9.7	4.0
characteristics	(8)	4.1	1.7
• fictional			
Misunderstandings	**64**	**32.7**	**13.5**
• other techniques	(19)	(9.7)	(4.0)
- cloning	4	2.0	<1
- testing	5	2.6	1.1
- transplants	11	5.6	2.3
• aspects of genetics	(9)	(4.6)	(1.9)
- cross breeding	7	3.6	1.5
• aspects of reproduction	(36)	(18.4)	(7.6)
- sex determination	18	9.2	3.8

Appendix 6 (c), Part 3: Cloning

474 students responded to some part of 'Cloning'
(98.3% of those responding to some part of this probe).

'What Can They Say About Cloning?'

472 students answered this question (99.6% of those answering some part of 'Cloning'; 98.2% of those answering some part of this probe)

	Number of Responses	% of those answering this question (n = 472)	% of those answering this part (n = 474)
Something	**200**	**42.4**	**42.2**
Nothing	**272**	**57.6**	**57.4**

'Where Have They Heard Of Cloning?'

220 students answered this question (82.5% of those answering some part of 'Cloning'; 82.0% of those answering some part of this probe)

	Number of Responses	% of those answering this question (n = 220)	% of those answering this part (n = 474)
At School	**72**	**32.7**	15.2
• unspecified	39	17.7	8.2
• within science	33	15.0	7.0
• within drama	0		
In The Media	**166**	**75.5**	35.0
• news: general, all forms	31 (+1)	14.5	6.8
• news: specific items	1	<1	<1
• viewing, unspecified	92 (+4)	43.6	20.3
• reading, unspecified	5 (+7)	5.5	2.5
• entertainment, specified context	48	22.0	10.2
Other or Additional	**7**	**3.2**	1.5
• family	2	<1	<1

Appendix 6 (c), Part 3 cont.

'What Do They Think Cloning Is?'

198 students answered this question (41.8% of those answering some part of 'Genes'; 41.2% of those answering some part of this probe)

	Number of Responses	% of those answering this question (n = 198)	% of those answering this part (n = 474)
Copying	**151**	**76.3**	**31.9**
• copying genes/genetic information	42	21.2	8.9
• copying (unspecified)	109	55.1	23.0
Making	9	4.5	1.9
• making something from genetic materials	6	3.0	1.3
• making something from bits of something	3	1.5	<1
Confused With Other Technologies	**13**	**6.6**	**2.7**
Alternative/Additional Comments	**16**	**8.1**	**3.4**
• purpose	7	3.5	1.5
• attitudes/feelings	8	4.0	1.7
• fictional	5	2.5	1.1
• examples	1	<1	<1

Appendix 6, Part 4: DNA Testing

469 students responded to some part of 'DNA testing'
(97.3% of those responding to some part of this probe).

'What Can They Say About DNA Testing?'

450 students answered this question (95.9% of those answering some part of 'DNA Testing'; 93.6% of those answering some part of this probe)

	Number of Responses	% of those answering this question (n = 450)	% of those answering this part (n = 469)
Something	**265**	**58.9**	**56.5**
Nothing	**185**	**41.1**	**39.4**

'Where Have They Heard Of DNA Testing'

331 students answered this question (70.6% of those answering some part of 'DNA Testing'; 68.8% of those answering some part of this probe)

	Number of Responses	% of those answering this question (n =)	% of those answering this part (n = 469)
At School	**117**	**35.3**	**24.9**
• unspecified	63	19.0	13.4
• within science	52	15.7	11.1
• within drama	2	<1	<1
In The Media	**256**	**77.3**	**54.6**
• news: general, all forms	63 (+1)	19.3	13.6
• news: specific items	4	1.2	<1
• viewing, unspecified	165 (+3)	49.8	23.2
• reading, unspecified	6 (+10)	4.8	3.4
• entertainment, specified context	45	13.6	9.6
Other or Additional	**7**	**2.1**	**1.5**
• family	0		

Appendix 6 (c), Part 4 cont.

'What Do They Think DNA Testing Is?'

264 students answered this question (56.3% of those answering some part of 'DNA Testing'; 54.9% of those answering some part of this probe)

	Number of Responses	% of those answering this question (n = 264)	% of those answering this part (n = 469)
Comparing Or Identifying	**98**	**37.1**	**20.9**
• in general	5	1.9	1.1
• to identify individuals	69	26.1	14.7
• to identify disease	25	9.5	503
Finding Out More	**76**	**28.8**	**16.2**
• about DNA or genes	33	12.5	7.0
• about the body or organisms	43	16.3	9.2
'A Test For Genes' (Very General)	**43**	**16.3**	**9.2**
Confused With Other Techniques	**10**	**3.8**	**2.1**
Confused With Aspects Of Genetics	**8**	**3.0**	**1.7**
Attitude	**23**	**8.7**	**4.9**
• good	13	4.9	2.8
• not good	3	1.1	<1
• mixed	1	<1	<1
• other feelings (non-judgmental)	6	2.3	1.3

Appendix 6 (c), Part 4 cont.

'Examples of DNA Testing'

202 students answered this question (43.1% of those answering some part of 'DNA Testing'; 42% of those answering some part of this probe).

	Number of Responses	% of those answering this question (n = 202)	% of those answering this part (n = 469)
Valid Examples	**171**	**84.7**	**36.5**
• personal identification	(136)	(67.3)	(29.0)
- forensic	88	43.6	18.8
- paternity	23	11.4	4.9
- fingerprinting*	25	12.4	5.3
• identification of specific characteristics	(29)	(14.4)	(6.2)
- inherited disorder	11	5.4	2.3
- diseases**	3	1.5	<1
- prenatal diagnosis***	15	7.4	10.7
• other potentially valid but ambiguous examples	(15)	(7.4)	(10.7)
- blood tests****	14	6.9	3.0
Specific Misunderstandings	**31**	**9.5**	**6.6**
• other techniques	(13)	(6.4)	(2.8)
- refer to Jurassic Park	8	4.0	1.7
• other testing	(6)	(3.0)	(1.3)
- AIDS/HIV	4	2.0	<1
- animals	2	<1	<1
Other	**11**	**5.5**	**2.3**
• scientific research	5	2.5	1.1

All responses marked with an asterix are ambiguous -

* Sometimes fingerprinting was used to refer to DNA testing and sometimes to refer to traditional fingerprinting; it was not possible to separate these.

** DNA tests can only identify genetic disease; other tests can be used to identify many other diseases; it was not possible to separate out those who were aware of this and those who were confusing types of test and types of disease.

*** There are several different forms of prenatal diagnosis, only one of which involves DNA testing; it was often not possible to identify which type the student had in mind.

**** These may have been referring to the DNA testing of blood samples or they may have been referring to traditional blood testing for blood groupings; it was not possible to separate these out.

Appendix 6, Part 5: The Genetic Code

474 students responded to some part of 'The Genetic Code '
(98.3% of those responding to some part of this probe).

'Have They Heard Of 'The Genetic Code'?'

474 students answered this question (100% of those answering some part of 'The Genetic Code'; 98.5% of those answering some part of this probe)

	Number of Responses	% of those answering this question (n = 474)	% of those answering this part (n = 474)
Yes	191	40.3	40.3
No	283	59.7	59.7

'Do They Have Any Idea What 'The Genetic Code' Means?'

470 students answered this question (99.2% of those answering some part of 'The Genetic Code'; 97.7% of those answering some part of this probe)

	Number of Responses	% of those answering this question (n = 470)	% of those answering this part (n = 474)
Yes	131	27.9	27.6
No	339	72.1	71.5

Appendix 6 (c), Part 5 cont.

'What Do They Think 'The Genetic Code' Means?'

171 students answered this question (36.1% of those answering some part of 'The Genetic Code'; 35.6% of those answering some part of this probe)

	Number of Responses	% of those answering this question (n = 171)	% of those answering this part (n = 474)
Information Within The	**56**	**32.7**	**11.8**
Person	46	26.9	9.7
• personal ID or 'bar code'	9	5.3	1.9
• genetic make up of a	1	<1	<1
person			
• other			
Information Within The	**38**	**22.2**	**8.0**
Cell	22	12.9	4.6
• organisation of the genes	3	1.8	<1
• information in the genes	2	1.2	<1
• function of the genes	7	4.1	1.5
• the type of gene	4	2.3	<1
• other			
Information Within The	**37**	**21.6**	**7.8**
Gene	(26)	(15.2)	(5.5)
• organisation of the	11	6.4	2.3
DNA/bases	15	8.8	3.2
- structure of gene/DNA	(10)	(5.8)	(2.1)
- sequence of the	(1)	(<1)	(<1)
bases/DNA			
• information in the DNA			
• other			
Other	**41**	**24.0**	**8.6**
• very general	25	14.6	5.3
• confusion with other	10	5.8	2.1
techniques			