Rationale, Design and Methodology

Young People's Understanding
Of, And Attitude To, 'The New
Genetics'
Working Paper 1

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Working Paper 1:

Young people's understanding of, and attitudes to, "The New Genetics" Rationale, design and methodology

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Abstract

This paper places the research of the project in the context of school science education and the public understanding of science. It poses the research questions which the project sought to answer and explains the methodology involved in addressing them. The various research instruments used in the gathering of data are described and the approaches to the design of these instruments are justified. The manner of administration of the research instruments is explained and details are provided of the sample population surveyed. Exemplary coding schemes developed from the student responses and used in the analysis of the data are discussed. Brief details are given of subsequent Working Papers in this series.

1 Introduction

In recent years there has been a rapid increase in the development of a range of genetic technologies. Food derived from genetically modified organisms is appearing on the shelves of supermarkets and pharmaceutical products such as insulin and growth hormone, produced in genetically modified bacteria, are in daily use. The creation of transgenic animals has further increased the availability of a range of therapeutic substances. Somatic gene therapy is being trialled for the treatment of genetic disorders such as cystic fibrosis, adenosine deaminase deficiency (SCID) and haemophilia. DNA fingerprinting has become a standard tool in the detection of crime. The complete genome for the first eukaryote (*Saccharomyces cerevisiae*) has been sequenced and work on the Human Genome Project is on target for the sequencing the entire human genome by the end of the century. Media attention has kept pace with these developments with the creation of transgenic sheep and the role of DNA fingerprinting in well-publicised murder trials becoming front page news.

This new technology raises social and ethical questions. To what extent is it legitimate to modify the genomes of plants to create 'improved' food for human consumption? If it is legitimate for plants, is it also acceptable for mammals to be genetically modified? Who should make decisions about the availability of genetic screening for inherited diseases and other characteristics? Who has ownership of information derived from such screening or from DNA fingerprinting? What will be the effect on the environment if genetically modified organisms are released into it? What

will be the effect of gene therapy on the human gene pool? Who should have control over the development and use of new technologies? It is worth emphasising that plant and animal breeders have been modifying the genomes of organisms for centuries and their work has rarely been questioned. But developments involving recombinant DNA technology are perceived in quite a different way - perhaps because of the transfer of genetic material from one species of organism to another.

There is also another, perhaps more personal aspect to these developments. Each one of us has our own unique complement of DNA, our own particular set of genes - or more correctly alleles. This is shared by no-one else unless we have monozygotic siblings. Manipulation of genes and the other technologies associated with our genetic makeup are therefore of significance to all of us.

Young people in schools today are increasingly becoming part of a society in which these and other genetic technologies are commonplace. They will be required to choose personal courses of action related to the results of these technologies and many of them will become decision makers influencing societal attitudes to these and other related issues. Yet we have little knowledge either of the levels of understanding of modern genetics possessed by young people, or of their opinions and attitudes to the issues arising from work in the field, although evidence presented to the House of Commons Science and Technology Committee (1995) suggested that the understanding of genetics demonstrated by the general public is very poor. It is likely that young people's knowledge and understanding and their opinions and attitudes are derived in part from formal schooling, but also from a range of other sources in the media and elsewhere. It is against this background that the research reported here was undertaken.

This Working Paper considers the rationale for the research set in the context of genetics education for scientific literacy. It examines the place of genetics within the National Curriculum for Science before framing the research questions which the project sought to address. It reports on the methodologies adopted in order to address the research questions, on the design of the research instruments and on the ways in which the responses were coded and analysed. Information is given on the administration of the test instruments and on the sample population used before finally outlining details of subsequent Working Papers in this series.

2 Rationale for the study: genetics education and scientific literacy

2.1 *Scientific literacy for specific purposes*

Education in science is afforded a high priority in Western countries, and a case is often made that scientists and technologists should be trained in order to contribute to national economies. One approach for ensuring an adequate supply of well-trained professionals would be to select the most able students at an early stage in their education, and offer them a specialist curriculum in science. However, the aims of science curricula around the world tend to be broader than this. In addition to supplying highly qualified specialists, a stated aim of the science curriculum is to promote the *scientific literacy* of all students as part of their general education (American Association for the Advancement of Science, 1989; National Curriculum Council, 1993; Royal Society, 1985; European Union, 1993).

Although promoting scientific literacy is often stated as an aim for science education in public policy documents, little attention is given to defining what scientific literacy might involve, or what a scientifically literate person might be able to do. In the science education literature, however, a number of types of scientific literacy have been characterised, according to the ways in which individuals draw upon and use scientific knowledge for particular purposes (for a full discussion of this issue, see Driver *et al.*, 1996).

Using scientific knowledge for ***utilitarian*** purposes involves individuals in drawing upon scientific knowledge that is useful to them in a practical way. An example of this is using knowledge about the germ theory of disease to prevent contamination during the preparation of food. It has also been argued that individuals need a degree of scientific knowledge in order to deal with science and technology as they are encountered in modern society. In modern societies, decisions have to be taken about matters with a science dimension, such as how energy should be generated and used, how refuse should be disposed of, how the safety of food should be maximised and so on. Using scientific knowledge for ***democratic*** purposes involves individuals in drawing upon knowledge to understand and participate in such debates. In addition, ***cultural*** scientific literacy involves individuals in understanding science as a cultural achievement of modern society, along with art, music and literature.

These characterisations of scientific literacy go some way to delineating the different ways in which scientific knowledge might be drawn upon in different situations. However, it is far from clear how the school science curriculum might support scientific literacy. Consider the ***utilitarian*** case. Can a school science curriculum be designed to equip all individuals with the scientific knowledge that they may need in various personal and professional contexts during the rest of their lives? In one sense it clearly cannot. The development of knowledge over the next 40 years (the working life of school leavers) is unknown and unpredictable, so how can school science prepare

them for it? There is also an argument that individuals need very little conceptual understanding of science in order to deal with the artefacts of science and technology. Electricians do not need to draw upon formal knowledge of current and potential difference when wiring houses, for example. A similar argument applies to the ***democratic*** case. How can a school science curriculum be designed to equip individuals with an appropriate range of scientific knowledge to deal with the issues that they may encounter in future adult life? Even experts are often cautious about expressing opinions on issues outside their own specialisms (Millar, 1996). A science curriculum aiming to promote understanding of the ***cultural*** significance of science might be designed in a very different way and focus on key historical episodes, such as the Copernican revolution, the emergence of evolutionary theory or 'the DNA revolution' commenced by Watson and Crick forty years ago. Such topics, however, would not necessarily be included in the curriculum for utilitarian or democratic reasons.

2.2 *Genetics and scientific literacy*

Turney (1995) has suggested three principal motives for developing an understanding of genetics amongst members of the public. In some ways these overlap the utilitarian/democratic/cultural classification referred to above. Turney's first motive relates to the need for individuals to be able to give informed consent to, and also be able to interpret the results of, the multiplicity of screening tests that will theoretically become available as the work of the Human Genome Project nears completion. This is clearly a ***utilitarian*** justification. The second relates to the need for a fuller understanding to underpin policy-making in the field. Lastly, there is a desire on the part of researchers for the public to be better informed in order that their research is allowed to continue and is funded. The regulation and supervision of work in the field needs to be undertaken in an informed climate rather than one of ignorance. Such ***democratic*** reasons for public understanding in relation to genetic engineering were highlighted nearly 20 years ago by Senator Edward Kennedy when he suggested that 'The assessment of risk and the judgement of how to balance risk against benefit of recombinant DNA research are responsibilities that clearly rest in the public domain. And it follows that these issues must be decided through public processes' (Dutton, 1984, quoted by Michie *et al*, 1995).

Following up the first of Turney's motives, health care is perhaps the most likely area in which people may encounter the new genetic technologies at first hand in ways which can affect them deeply. Increasingly, people may be offered screening for various genetic conditions prior to starting a family, during pregnancy, or perhaps even before marriage. In deciding whether to take up offers of screening, and deciding how to act upon information from such screening, individuals may draw not only upon what they have understood as a result of their interaction with specialists (genetic counsellors, those administering the screening, medical practitioners, etc.) but also upon their knowledge of genetics.

Griffiths (1993) has put forward five reasons for teaching about genetics. The first of these relates to the ways in which genetics has affected human views of our species and its relation to the rest of the universe. Chromosomal studies suggesting our relationship to other primates and the universality of the genetic code are two important and relevant examples in this context. A second reason is the insight that genetics can give to crucial social and environmental issues. The genetic component of racial and gender differences and global genetic diversity are two examples here. Thirdly, society has been dependent on genetics through many centuries of plant and animal breeding and is now increasingly dependent on 'the new genetics' for a range of food and pharmaceutical products. Fourthly, Griffiths points out that, now that many infectious diseases are conquered, a large proportion of human ill health has a genetic basis. Finally he suggests that genetics provides classic examples of logical reasoning and therefore can be used to train students in problem solving. Interestingly Dawkins (1996) has recently made a very similar point about the subject of biology as a whole. 'It teaches you how to think and how to write. It teaches you a statistical way of reasoning as well as a merely logical way'. Similar arguments have been put forward in the past for the study of classical languages and mathematics and should perhaps be viewed with some scepticism.

The processes by which human beings select and use knowledge in particular contexts are, however, very complex. People identify the salient features of a situation from a range of possibilities, decide what knowledge may be relevant to the situation, possibly seek out further information and ultimately reach a decision. For these reasons, a ***'deficit view'*** of scientific literacy seems inappropriately naive. Deficit views of scientific literacy involve defining the scientific knowledge that people ought to have, and then determining whether they do have such knowledge. Consider a situation involving genetics: a couple are expecting a baby, and following positive tests on themselves for cystic fibrosis carrier status, they are offered prenatal screening to find out more about the cystic fibrosis status of the foetus. Understanding some of the important aspects of this case requires some knowledge of genetics, an appreciation of the reliability and risks of this form of prenatal screening, the likely prognosis for babies born with cystic fibrosis, and a forecast of future possibilities for the development of gene therapy and other treatments. Other aspects of the situation relate more to ethical commitments and personal priorities. For example, some couples may have to consider their own attitudes to health and abortion in the light of their situation.

The above example is complicated: how might a 'scientifically literate' individual go about reaching a decision? It does not seem to make sense to talk about reaching 'rational' decisions based on the 'appropriate' use of 'relevant' scientific knowledge. The personal priorities of different individuals are different: we might therefore expect to see some diversity in the range and use of knowledge by different people. On the other hand, all couples in such a situation would be presented with broadly similar

information about the condition of cystic fibrosis, the nature of its inheritance and the process of screening. Couples would then be in the position of having to interpret the information presented and decide what was relevant to their situation and what was not. In this situation, individuals with some basic knowledge of the nature of inheritance and genetic illness would be in a better position to make sense of the information presented.

It is not realistic to expect the school science curriculum to include detailed information about every genetic disease, or every other scientific context, likely to be encountered by students. We know very little about the ways in which people actually draw upon and use various forms of knowledge in problematic contexts with a science dimension (see Layton *et al.*, 1993). A more realistic aim for the school science curriculum might be to equip all young people with a range of more basic scientific knowledge, together with some understanding of the sorts of situations in which such knowledge might be useful.

The issues that arise from applications of genetic technology are context-specific. Let us return to the example of prenatal screening for genetic disease. Cystic fibrosis is a condition which affects sufferers from birth, typically resulting in a difficult childhood and adolescence and in premature death during early adulthood. Couples who take up offers of prenatal screening and find out that their unborn child will have, or may have, cystic fibrosis may be offered the possibility of an abortion. However, rather different issues arise in the case of other genetic diseases. People with Huntington disease, for instance, are normally free from symptoms until the age of about 40. The issues surrounding the desirability of prenatal screening for cystic fibrosis and for Huntington disease are therefore quite different. We will use the term 'issue' to mean any matter arising from a particular context which potentially involves a decision being made. In this study, we were interested in the issues that young people identify as emerging from particular contexts relating to 'the new genetics', and the ways in which they interpret information that bears upon those issues.

People may form opinions about specific issues that emerge in particular contexts. We will use the term 'opinion' to mean a value position relating to particular issues in specific contexts. For example, someone may form an opinion that the abortion of foetuses with cystic fibrosis is unacceptable. The term 'attitude' will be used to refer to value positions which are more general. Some individuals, for example, may have an attitude that abortion is ethically wrong in any circumstances. Of course, it is not always possible to know whether an expressed value position is specific to one context, or more general.

2.3 *Previous research in the field*

A number of studies have focused on the knowledge of genetics and attitudes to modern developments in the field amongst students, members of the

general public and professionals. Some of these will now be discussed briefly not to examine their findings, but more importantly in the context of this paper, to review the methodologies involved.

In the conceptual field a number of studies of young people's understandings of inheritance have been reported. These have been reviewed by Wood-Robinson (1994 and 1995). The majority of these involved probing the students' understanding through clinical interviews based on tasks framed around particular contexts. This approach follows the line of research pioneered by Piaget and developed further in scientific contexts by Osborne and Gilbert (1980) who described their approach as Interviews About Instances (IAI). The principal focus of such work has been to elicit students' explanations for particular events or phenomena. It is the student who selects the language they wish to use to describe or explain the phenomena in question. A ***phenomenological*** approach of this kind has implications for the ways in which students' responses are coded and analysed and this issue will be considered later in terms of the methodology employed in this study.

Ponder *et al* (1996) report on a study of 58 students at a further education college, who had recently completed the National Curriculum in Science, together with 54 of their parents. Each student was interviewed individually by a researcher. The parent, or parents, were subsequently interviewed by another researcher. All interviews were audio-recorded and later transcribed. Interviews had the same structure for the students as for their parent(s) and were framed in non-technical language. Words such as 'gene' or 'genetic' were only used if the interviewee used them first. In the first part of the interview the interviewee was presented with a list of 14 conditions (e.g. cancer, heart disease, diabetes, etc.) and asked whether they thought they were more or less or equally likely to suffer from this condition than others of the same age. They were then asked for the reasons for their response. Any reference to inheritance or family history was followed up by the interviewer. In the second part of the interview a family tree was drawn and details of family health history were recorded including information on smoking, drinking, height, weight etc. The methodological feature of the approach used in this study was thus to explore individuals' understanding of genetics and their perceptions of the importance of environment and individual behaviour in the context of their own genetic health and their knowledge of family health history. Both qualitative and quantitative approaches were used in analysing the data.

Exploring more attitudinal aspects Michie *et al* (1995) involved Gallup in surveying 973 individuals drawn as a stratified random sample from the general public aged 18-45. Their approach involved presenting the respondents with a list of twelve words, such as 'concerned', 'enthusiastic', 'cautious', 'indifferent', etc., and asking them to indicate which word or words best described their feelings about developments arising from new discoveries in genetics. In order to investigate attitudes to pre-natal screening the respondents were presented with a list of diseases and characteristics and

asked for their views on the conditions under which screening should be available - on the assumption that the screening was reliable and that the testing was being done with the possibility of ending the pregnancy. The diseases and characteristics included Down syndrome, cystic fibrosis, anencephaly (the implications of each of which were briefly explained), low intelligence, child of unwanted sex, homosexuality, etc. The third area explored in this work concerned who should decide on the availability of a new genetic test - individual parents or doctors, an advisory group, parliament, etc. Similar questions were put to three selected smaller groups of people with a professional interest in the field. These professional groups were geneticists from regional genetics centres (n=58); obstetricians (n=30); and medical ethicists (n=46). Comparisons were then made between the members of the general public and the professional groups.

Lock and Miles (1993) and Lock *et al* (1995) sought the views of school students' on a number of aspects of biotechnology - including a range of DNA technologies - both before and after relevant teaching. Their study involved the subjects indicating their support or opposition to particular technologies and contexts through paper and pencil questionnaires and the use of Lickert-type scales. Their work did not attempt to explore the subjects' understandings of the technologies nor the reasons which underpinned the students' decisions to express particular opinions. It also did not seek to investigate the nature of the issues which the students perceived as being important in the particular contexts with which they were presented.

Scriver (1993) investigated interest in genetics, compared with other areas of the biology curriculum, among francophone high school students in Montreal. Students were asked to indicate their level of interest on a five-point Lickert-type scale. He demonstrated that they had a higher level of interest in genetics than in any other aspect of the biology curriculum except human biology. Over the last two decades Scriver has used this interest to carry out voluntary screening programmes to detect carriers of three genetic conditions (Tay-Sachs disease, β-thalassemia and cystic fibrosis) among high school students and reports this to have been an important initiative in public education in genetics. However, Tyler *et al* (1995) have expressed concern about such testing in the absence of proper pre-test counselling and have questioned whether guidelines should not be drawn up.

Our experience of working on this research suggests that there is a need for the development of curriculum materials which address not only the conceptual aspects of genetics, but also the personal and social implications of the new genetic technologies. McInerney (1993) makes this same point in an American context and highlights a number of deficiencies in this field of American science education. As a response to this need the Biological Sciences Curriculum Study (1992) has produced a module of curriculum materials, concerned with some of the implications of the Human Genome Project, which has been distributed to 50 000 high school biology teachers in the United States.

In order to facilitate both curriculum development and teaching in the United Kingdom, to achieve the aims discussed earlier in this paper, empirical information about students' starting points in given curriculum areas, such as genetics, is essential. In this study we were interested to find out more about the sort of genetic knowledge that young people have at the end of their compulsory science education, and their knowledge of the range of applications of genetic technology. This would give us some idea of the sort of knowledge that might be available to be drawn upon in the future, in order to understand particular issues with a genetic component. Only with this well-documented information about students' current knowledge and understanding of genetics, and about their perceptions of the issues arising from, and their opinions on, genetic technologies can we begin to address meaningfully questions about curriculum design and pedagogy.

One final point needs to be made in relation to the different circumstances inherent in school students answering surveys - whatever their format - compared with how these same individuals might react in the face of real life decisions involving them personally in the application of genetic technologies. We acknowledge that the relationship between the two may be very tenuous.

3 Genetics and the National Curriculum for Science

All students in state schools in England and Wales follow a science course defined by the National Curriculum. This includes elements of genetics which are addressed at the secondary school levels of Key Stages 3 and 4. For the last two years of compulsory schooling (Key Stage 4) this can take the form of either a Single Science or a Double Science course leading to either a single or double subject award at GCSE. Study to this level therefore represents the compulsory science education that all members of the population are likely to receive.

At the time of the research all students at Key Stage 4 were following Science in the National Curriculum (Department of Education and Science, 1991). Those sections relevant to genetics are shown in Appendix 1.

The National Curriculum appears quite explicit in what it requires students to be taught. In genetics the emphasis is mainly on basic genetics with some requirement for explicit teaching on issues more related to scientific literacy. Questions arise as to what is implicitly included under the various elements set out in the Programme of Study. For example how should the variation in genetic information among the gametes of a single individual be addressed? It can be seen that an example is given suggesting that "genetic variation is brought about (partly) by reshuffling chromosomes" and there is the further example of "chromosomes divide equally during meiosis". But what do these examples convey about the level of understanding required of the way in which genetic information is apportioned in the events taking place during meiosis? Other than these examples, no indications are given about an approach to teaching and teachers have to make decisions about this themselves.

Other implicit aspects of the formal requirement can also be questioned. Is it necessary for students to appreciate that genes are arranged along chromosomes, which normally lie within nuclei contained in cells which make up organisms? Should they therefore be able to arrange these terms - cell, chromosome, gene, DNA, organism, nucleus - in a logical sequence according to size? Should students understand that the genetic information in all somatic cell nuclei of a given organism is the same, but is interpreted and utilised differently in cells from different tissues? Do students need to understand the overall results of a meiotic division resulting in egg and sperm cells having the haploid number of chromosomes? Do they even need to know of the existence of chromosomes, which are not specifically mentioned in the National Curriculum except by way of an example? Should they know the term 'allele' or is the concept of a gene existing in more than one form sufficient ? (Note that 'allele' is specifically used in one of the Statements of Attainment at level 8 of the National Curriculum). These are questions which teachers must address on a regular basis in preparing teaching. We would argue that there are many aspects of genetics which are implicitly

included in the various elements of the National Curriculum and some of these have justifiably formed the basis of our research instruments.

It is worth emphasising that the legal requirement is for schools to cover the Programme of Study. The Statements of Attainment set out at their various levels are not expected to be reached by all students by the time at which they leave school - indeed only exceptional students will reach Level 10 at which they should, for example, understand how DNA replicates, or understand the basic principles of genetic engineering. But the Programme of Study does make clear that students "should ... study how DNA is able to replicate itself ..." and "should have the opportunity to consider the basic principles of genetic engineering, ...". Thus there is a legal requirement that these elements be taught to all students by teachers in schools, but an understanding will not necessarily be grasped by all those students.

There are also obvious but important aspects of genetics which are excluded from the National Curriculum itself and, it could be argued, are not even implied within this framework. Polygenic or multifactorial inheritance is one such example - though human eye colour is specified as an example. This is not the place to comment on the appropriateness of a science course at this level which excludes such a central concept. But its absence did shape our research and we have therefore not attempted to include any investigation of students' understanding of this concept.

The National Curriculum for Science was an important influence on our research design, but it was not our only source in determining the genetics concepts which we sought to investigate. We were also interested in students' knowledge and understanding of a range of genetic technologies many of which are not specified in the National Curriculum. Thus, for example, there is no reference to pre-natal genetic screening in the National Curriculum. Yet this is a central application of genetics that is likely to have an impact on many, perhaps most, students who are currently still in school. We therefore set out to explore students understanding of the issues involved in making decisions related to pre-natal screening. This aspect of our work is described in detail in Leach *et al* (1996). Furthermore in exploring students' opinions on particular technologies it was important for us to consider what aspects of genetics they might need to know in order to form reasoned opinions. All these dimensions were therefore considered in determining what conceptual and issues-based aspects to investigate.

In 1995 a revised version of Science in the National Curriculum was published. This was to be taught to Key Stage 1, 2 and 3 students from 1 August 1995. Those students in Key Stage 4 will follow the revised version from 1 August 1996 (Year 10) and from 1 August 1997 (year 11). We believe that our research will have implications both for the curriculum itself and for the way in which teachers might approach teaching genetics. Those sections of the 1995 version of Science in the National Curriculum relevant to genetics are therefore shown in Appendix 2.

Questions also arise about the interpretation of this requirement. For example it is difficult to see how students following a Single Science course could be taught "the basic principles of.....genetic engineering" without this being built on some understanding "that the gene is a section of DNA". Yet this latter concept is only required to be taught to Double Science students.

4 Research questions

Four principal research questions arose from the consideration of the place of genetics in the public understanding of science and from the agenda set by the National Curriculum for Science. These determined the direction of this study.

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

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

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

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

It was also planned that the work would address a number of other questions.

- Is there any relationship between the level of understanding of basic genetics that students have and the extent to which they perceive new genetic technologies as raising ethical and social issues ?

- Is there any relationship between the level of understanding of basic genetics that students have and the opinions that they have formed in relation to these technologies?

- To what extent do the knowledge and opinions documented through pencil and paper questions hold constant when the same students are questioned through a group interview ?

5 Design and Methodology

As has been suggested in earlier Sections (2 and 4), this work has both conceptual and issues-based dimensions.

5.1 Conceptual areas for investigation

In terms of research design our examination of the National Curriculum for Science together with our perception of the other dimensions discussed briefly in the final paragraph of Section 3 led us to the construction of a content list which it seemed appropriate to use as a basis for investigation in this study. This comprised those aspects of genetics specified in the National Curriculum for Science as well as the background knowledge that people might need if they are to understand the issues arising from DNA technology. This content list is outlined below.

A) BASIC GENETICS

1. Language (knowledge of terminology):
   a) terms related to basic genetics;
   b) range of organisms.

2. Location (relationship between structures):
   a) location of genes within organisms;
   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 (expression/replication):
   a) genes code for proteins;
   b) genetic information must be copied to pass on to new cells during cell division.

4. Mechanism of gene action (switches/codes/variation):
   a) a single gene may exist in different forms (alleles) which may produce different phenotypes resulting in variation;
   b) gene expression depends on environment (internal and external) to 'trigger' switches;
   c) the 'genetic 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');
   c) germ cells contain different genetic information even though they are the same type of cell.

   ii) between organisms within a species
   a) production of germ cells results in variation; 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 of monozygotic twins arising from the same fertilised egg);
   b) alleles are the 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 information (prokaryotic/eukaryotic, plant/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.

Our original aim was to design probes that covered these areas, but not necessarily in the language used here or to the depth suggested. In the event the experience of trialling the probes led us to restrict somewhat the areas covered to those that were most central to our work and to those to which the students could respond in a meaningful way. Details of the content covered by the probes is given in other Working Papers in this series.

5.2 Methodology for investigating conceptual areas

Driver and Erickson (1983) have contrasted ***phenomenologically-framed*** approaches to documenting students' understanding, such as those described in Section 2.3, with that which they call a ***conceptually-framed*** approach

where students are asked to give explanations for scientific terms presented to them. The work reported here concerned with students knowledge and understanding of genetics, and of genetic technologies, combined both these approaches in that we were frequently setting the scene in ways reminiscent of a phenomenologically-framed approach, but also exploring students' meanings of terms - such as 'gene', 'allele', 'genetic information', etc. in ways more associated with a conceptually-framed approach. Both approaches are conceptual in that they attempt to explore students' conceptual understanding of genetics. And both approaches were considered important in extending our knowledge of young people's understanding of basic genetics and in broadening our knowledge to include their familiarity with and their understanding of the new technologies.

5.2.1 *Knowledge and understanding of genetics*

Students' knowledge and understanding of genetics was investigated using both paper and pencil probes and a discussion task. Written responses were used for much of the data collection in this area. This has the advantage of maximising the sample size as such paper and pencil instruments can be administered to a whole class of students at one time. A series of 7 written probes were used to gather data on the students' knowledge and understanding. A consideration of one of these written probes - *Cells* - will illustrate our approach both to probe design and to coding the students' responses.

The "Cells" probe

The *Cells* probe is shown in full in Appendix 3. The first part of the probe was designed to investigate students' understanding of the nature and role of genetic information in four different pairs of cells from the same individual:

- two somatic cells of the same type (cheek epithelial cells)
- two somatic cells of different types (a cheek cell and a nerve cell)
- a somatic cell (cheek cell) and a germ cell (a sperm), and
- two germ cells (sperms).

Thus the probe was designed to explore whether students were aware that the genetic information in all the somatic cells of the same individual is the same - but is used in different ways by different cells. It was also designed to assess their understanding of the essential differences between the genetic information in somatic and germ cells and the variation in genetic information in different germ cells resulting from the way in which spermatogenesis and oogenesis takes place.

The second part of the probe considered students' understanding of the nature and role of genetic information in two similar somatic cells (cheek cells) from two different individuals of the same gender. This was designed to explore the students' understanding of the variability of genetic information from one individual to another.

Coding the "Cells" probe

As we have already outlined, we were particularly interested in the reasons that underpinned students' knowledge and understanding of genetics. Many of the probes called for open responses from students on a range of conceptual matters. In considering their knowledge and understanding of genetics our principal focus was to characterise their responses in an ideographic way and to compare such characterisations to the normative model of science. Thus the students ideas themselves were the basis for our characterisation and coding rather than any pre-determined categories devised by ourselves. We were concerned with what explanations the students offered for particular events and with how they conceptualised the processes by which, for example, genetic information is passed from cell to cell as they divide and how genetic information is transmitted from one generation to the next. For such an approach a more elaborate method of coding and analysis was required. This leads to an important consequence which is central to our work. The coding schemes are themselves derived from the students responses. They are therefore not merely a research tool which is necessary for analysis. They are an important end-product of the research itself. They also enable us to make statements about the representation of particular ideas at the population level.

Each section of the *Cells* probe began with a question calling for a fixed response indicating whether the genetic information in two cells was the same or different. This could obviously lead to one of three options (the same/different/don't know) with the further possibility of no response at all. Coding and analysis of these questions was therefore unproblematic. In some instances students ticked the 'don't know' box, but then went on to demonstrate clear reasoning in completing the open-ended part of the section. In such cases the responses to the open-ended question were considered along with all similar responses and independently of the fixed response questions.

The first two sections considered comparisons between somatic cells (cheek/cheek and cheek/nerve) and, from a coding point of view, were considered together. This enabled us to establish whether individual students appreciated the identical nature of the genetic information in the somatic cells of an organism and gave them the opportunity to explain how the same genetic information could be 'used' in different ways by different cells. Three different reasoned explanations were given here.

All cells contain the same information

Some students suggested that all cells contain the same genetic information. Of these some made reference to cell division while of these only a few went on to explain differential gene expression in cells of different types. This thus led to three sub-codes within this coding category.

All cells of the same type contain the same information
Such students stated that the two cheek cells contained the same information, but that the nerve cell would contain different information from the cheek cell.
All cells contain different information
A variety of explanations were given under this heading all suggesting that every individual cell is supplied with different information from all other cells.

In addition to these reasoned explanations - albeit some of them incorrect - other students gave responses which appeared confused and sometimes contradictory when their answers to Part 1a (two cheek cells) and Part 1b (cheek cell and nerve cell) were compared. A further group of students' responses combined various elements of reasoned and unreasoned lines of thinking.

When it came to Part 1c and the students were asked to compare the genetic information between a cheek cell and a sperm cell from the same individual, four categories of reasoned explanation were identified.

A sperm contains different information from a cheek cell
A variety of explanations were put forward here suggesting in fairly general terms that the information would be different in the two cells.
A sperm contains less information than a cheek cell
Some of these went on to explain - perhaps in a fairly general way - the reduction in genetic information that takes place at meiosis during the formation of sperms - without necessarily any reference to meiosis as such.
A sperm contains more information than a cheek cell
Some responses in the category maintained that a sperm must contain information on all types of cell whereas a cheek cell would only have "cheek cell information".
A sperm contains the same information as a cheek cell
Students in this category were frequently of the belief that all cells contain the same information and that sperms are no exception.

Once again there were other students who used conflicting or confused reasoning in response to this question, while a further group combined various elements of the coding categories.
Similar approaches were used for the coding of the other two sections of this probe calling for comparisons between two sperm cells (Part 1d) and cheek cells from two different male individuals (Part 2).

Response to this probe were also coded in two other ways. The first considered conflict in a student's responses to all four sections of Part 1 together (cheek/cheek; cheek/nerve; cheek/sperm; and sperm/sperm). The second considered whether students appeared to be aware of a potential conflict in their responses and how they addressed this.

The detailed coding scheme for this probe in its entirety can be found in Lewis *et al* (1996b).

The "Understanding of Genetics Discussion Task"

The trialling of the *Cells* probe and other related written probes suggested that many students held inconsistent and confused ideas about the nature of genetic information in different cells. The *Understanding of Genetics Discussion Task* was therefore designed to explore further the ideas inherent in the *Cells* probe. Discussion with small groups of students allowed us to probe students' understanding of some of the ideas and issues raised by them in responses to the written probes. The *Understanding of Genetics Discussion Task* concentrated on aspects of the nature of the genetic information in cells and on the transfer of this information from cell to cell and from organism to organism. For this task groups of four students were each presented by a researcher with a picture of a cheek cell from a hypothetical animal. In that cell were drawn three pairs of chromosomes and the students were told that the chromosomes behaved in exactly the same way as they did in human beings - there were simply fewer chromosomes in this animal. The three pairs of chromosomes were different in size and one member of each pair was coloured red, while the other member of each pair was coloured blue. After being asked to explain the relationship between chromosomes, genes and genetic information, they were then each presented with a drawing of a nerve cell from the same animal and asked to draw in it the chromosomes that they thought it would contain. Each student was provided with a set of coloured pens. Through a series of semi-structured questions, each student was asked individually to explain their responses. They were also asked about the relationship between the genes and genetic information present in this nerve cell in comparison with that in the cheek cell. The researcher then went on to present them with drawings of a sperm cell, an egg cell, a fertilised egg, a two-celled embryo and a cheek cell from the fully formed embryo of the same species of animal. In each case they were asked individually to draw the chromosomes in the cell and then, through a semi-structured interview schedule, to explain the relationship between the genes and genetic information present in the cell in question in comparison with the other cells they had considered. Each discussion was audio-taped and later transcribed for coding and analysis.

In this way the researcher leading the discussion was able to probe the underlying reasons for the particular choice made by an individual student and to identify and explore further any inconsistencies in their understanding.

The approach to coding the data from the *Understanding of Genetics Discussion Task* was essentially similar to that used for the written *Cells* probe, but the data from the discussion task was both fuller and richer. It also demonstrated how students faced up to inconsistencies in their reasoning when these were made explicit. Defending their viewpoint in response to questions raised by other students in the group was also found to be a powerful additional stimulus to individual students' explanations. Fuller

details of this discussion task and the approach to coding the responses is discussed in Wood-Robinson *et al* (1996).

5.2.2 *Knowledge and understanding of DNA technology*

Pencil and paper probes were also used to investigate students knowledge and understanding in this area. One written probe - *The New Genetics* - listed a number of aspects of DNA technology and asked students to indicate which of them they had heard of. The probe then went on to ask for fuller explanations for genetic engineering, cloning and DNA testing and also for 'the genetic code'. *The New Genetics* probe is shown in Appendix 4 and is discussed in detail in Lewis *et al* (1996). Two other written items - from a group collectively described as *Stop Press* probes - sought to investigate students knowledge of current or potential developments in DNA technology. Each of these probes began with an account - in tabloid newspaper format - of 'a new development' in genetic technology and asked the students to say whether they thought the report was true or not and to give their reasons. These probes also sought to explore their opinions and attitudes to such developments. An example of a *Stop Press* probe - *Milk : the new wonder drug* is given in Appendix 5. Our approach to coding responses in this area can be illustrated by a consideration of *The New Genetics* probe.

Coding "The New Genetics" probe

Coding the first part of this probe, which called for a fixed response indication of whether students said that they had heard of a range of DNA technologies, was straightforward. Frequency counts could be made for each technology and then calculated in percentage terms.

For each of the three technologies explored in more detail - genetic engineering, cloning and DNA testing - students were asked to indicate what they thought this technology involved, to give an example of its application and to state their source(s) of information. The section on genetic engineering can be taken as an example. An open response was called for in answer to the question "I think that genetic engineering is ...". Students responses fell into three categories reflecting whether they chose to answer in terms of the mechanism involved in the technology, its purpose or their attitude towards it. Those responding in terms of mechanism could be further subdivided according to their level of understanding of the technology. Those responding in terms of purpose almost invariably referred to designing organisms to order. Some of those expressing their attitudes towards the technology were clearly against the technology while others were in favour. A third group listed points in favour and also points against. A wide range of responses was obtained in answer to the question calling for students' sources of information. These were grouped into three categories - school, media, and others. The media category included those that were very specific about particular television programmes or magazine articles and those that much more generally referred to television or the printed press.

The other sections of this probe were analysed in a similar way and full details of the coding and analysis is given in Lewis *et al* (1996a).

5.3 *Issues-based and attitudinal areas for investigation*

In contrast to this conceptually-based work, we were also concerned with obtaining students' perceptions of the issues that they saw as arising from the application of new genetic technologies, the opinions they held on these technologies and their attitudes to them. Though we have separated the identification of issues as a free-standing research question from the formation of opinions and attitudes, we are well aware that such a separation is largely artificial. The two are inextricably entwined as the following example illustrates.

We have already made reference in Section 2.2 to genetic screening for Huntington disease. This is the subject of one of the probes used in this research which will be explored in more detail in Section 5.32. A complex of issues that arises from such screening relates to the right of access to information. Among our students there was frequently a naive assumption that all those who had access to the results of screening would assist an affected individual. Thus they might express the opinion that employers had the right to know the results so that they could provide support. They might completely ignore the possibility that they might not employ an affected individual in the first place. Hence opinions were frequently expressed without a full understanding of the issues. In reality the opinions on and attitudes towards particular technologies are entirely dependent on the particular issues that are considered in the formation of those opinions and attitudes.

As we have suggested, the precise context in which the new technologies were applied were seen as likely to influence the opinions expressed by the young people. For example, manipulating microbial DNA might be viewed in a very different way from altering the genome of an animal or more especially the genome of a human being. Similarly the type of technique employed might be important in leading to the formation of an opinion. Thus the use of recombinant DNA technology, genetic screening and gene therapy each raise a different set of issues. Indeed in each case the issues raised will differ with the precise context. Finally the rationale for the application may also raise somewhat different sets of issues. For example the development of a particular technique for what is seen to be commercial gain might be viewed in a rather different light from one developed for medical purposes.

A matrix was therefore constructed (see Table 1) as a basis for the generation of the test instruments. This matrix was used to ensure that the test instruments were seeking to answer all four major research questions across a wide range of contexts.

Table 1 - The Matrix Against Which The Issues-Based And Attitudinal Probes Were Set.

Contexts through which issues arise	Types of issue which might arise (see below for key) a	b	c	d	e	f	g	h	i	j	k	l
1) type of organism a- microbes b- plants c- animals (non human) d- human												
2) type of technique a- recombinant DNA technology (i) transgenic animals b- DNA fingerprinting c- genetic screening (i) embryo (ii) individual d- gene therapy (i) somatic (ii) germ line e- DNA sequencing (Human Genome Project) f- cloning												
3) type of application a- commercial (i) industry (ii) agriculture (iii) business b- medicine c- environmental d- social e- research												

types of issue :-

a) effect on gene pool
b) effect on environment
c) freedom of choice (personal rights)
d) confidentiality
e) interfering with nature
f) playing God
g) economic implications
h) animal rights
i) status/power (linked with c?)
j) ownership
k) control
l) the role of science/scientists

5.3.1 The identification of issues arising from new genetic technologies

Our concerns in exploring this area were to determine what issues arising from contexts related to new genetic technologies students identify as being of concern to them; how they evaluate these issues and how they then form opinions and adopt attitudes towards the applications of the technologies. We were **not** concerned with the identification of attitudes which we might judge to be good or bad. But we **were** concerned to examine the ways in which students justified, or were unable to justify, their opinions.

As we have already stated in Sections 2 and 5.3, the social and ethical issues that arise from new genetic technologies are dependent upon the particular context in which the technology is being applied. In order to explore the issues that students perceived as being important we therefore created a number of contexts - some genuine and some fictitious - which were presented to the students in order to serve as a basis for investigating their views. As will be seen later, three approaches - pencil and paper probes answered individually without discussion, paper probes answered individually after paired discussion, and audio taped discussion task.

In one of the *Stop Press* probes already mentioned - concerned with the fictitious creation of 'Designer Babies' to specifications chosen by its parents - students were also asked individually to identify the issues raised by this technology that struck them as worrying and those that they thought were good. Similar questions were asked in relation to the recreation of the extinct American Passenger Pigeon, DNA testing, the insertion of a scorpion venom gene into viruses as a way of controlling caterpillars on cabbages, and the treatment of cystic fibrosis by gene therapy. A further probe, which will be considered in detail below, also sought to explore issues perceived by students as being raised by genetic testing for Huntington disease. For these last five probes the students discussed the issues raised by the technologies with a neighbouring student before committing their views to paper individually. The final way in which the identification of issues was investigated was through two group discussion tasks. One of these - the *Genetic Engineering Discussion Task* - considered a range of applications of recombinant DNA technology, while the other - the *Prenatal Screening Discussion Task* is considered in detail by Leach *et al* (1996), and will not be discussed further here.

5.3.2 The expression of opinions and attitudes to applications of new genetic technologies

Central to this research was the principle that the investigation of issues and attitudes is only valid if the context is explicit, and that the opinions formed will be greatly dependent on the context. Thus questions which ask students for the extent of their support or opposition to statements such as "Changing the genetic make-up of farm animals should be banned by law" or "Inserting genes from human cells into the fertilised eggs of sheep is acceptable to me" (see Lock and Miles, 1993, page 269) are likely to lead to different responses

in different contexts. Thus the creation of transgenic sheep for the production of human insulin in order to treat diabetes may be viewed very differently from the creation of genetically modified cattle whose meat has a better flavour or a longer shelf-life. The technological principles employed and the types of organisms used are similar, but the contexts are very different. In a similar way the patenting of a gene for a blue pigment in roses for commercial profit may be seen as unproblematic. But the patenting of a gene for human growth hormone by a company seeking to market a drug to improve the height of potential basket-ball players, might lead to the technology itself and its subsequent patenting being viewed in a quite different way. Views might be even more antagonistic if such patenting was seen to restrict the treatment of pituitary dwarfism and hence preventing the reduction of human suffering.

If it is accepted that people's opinions on, and attitudes to, issues raised by new genetic technologies are context-dependent, there are two important consequences arising from this model. Firstly, it would be unwise to generalise from the results obtained from questions framed in specific contexts. Secondly, great care must be taking in clarifying the particular context in which a question is embedded. The development of one of the written probes used in this study will serve as an example to illustrate these points.

Some of the issues arising from genetic screening for Huntington disease have already been mentioned briefly in Sections 2.2 and 5.3. Huntington disease is an inherited autosomal dominant condition. That is to say it becomes manifest if the appropriate allele is inherited from one parent only, i.e. Huntington disease sufferers are normally heterozygous for that allele and the condition is not sex-linked. Individuals who inherit the allele from both parents, i.e. are homozygous for the allele, are known, but are indistinguishable phenotypically from heterozygotes. Sufferers normally do not begin to be affected until they are around the age of 40. Until that age there is little or no consequence for the sufferer and no evidence of the potential development of the condition. With the onset of the disease, there is progressive deterioration of bodily control which eventually leads to premature death. Individuals can now be screened for the presence or absence of the causative allele. The availability of such screening raises many questions which may or may not be apparent at first sight. Should all individuals be screened as a matter of policy ? If not, who should be selected for screening? Who should make the decision on whether or not an individual should be screened ? Who has the right to the information gained from the screening ? Should affected individuals be prevented from having children ? There is an extra dimension of uncertainty here as such individuals are heterozygous for the condition and therefore have a 50% chance of passing on an unaffected allele to an offspring. All of these questions are raised in one of the written probes - *The Telephone Tale*.

However, most young people at the end of their 11 years of compulsory schooling know nothing of Huntington disease, the likelihood of it being inherited from an affected parent, the possibility of treatment being available, or the impact of the condition on those who sufferer from it. Hence they would be unable to give sensible responses to these questions. They must be provided with appropriate information in order to come to a reasoned opinion. In the case of *The Telephone Tale*, this information was provided through an audio-taped discussion which was played to the students. A transcript of the conversation was also provided for the students' reference. Students were then asked to discuss their views with a neighbouring student and to record their individual opinions in response to a number of questions related to the various issues outlined above. The transcript provided for the students, along with the questions which they were asked to consider, is given in Appendix 6.

This example will also serve to illustrate the strategy of using paired discussion between students to elicit opinions and attitudes from students, expressed individually. The rationale for this approach was the recognition that an opportunity to talk through a question may assist students in being more explicit about their opinions. After the playing of the audio-taped recording the students were asked to discuss in pairs the issues raised by the subsequent questions and to share their opinions on each question with their partners. Only after this discussion were they each asked to address each question on an individual basis. The same procedure was adopted for 4 other written probes which sought to document the students opinions on a range of new genetic technologies (DNA fingerprinting, gene therapy, and two probes concerned with recombinant DNA technology one of which raised questions about patenting) as well as a further probe concerned with the control of genetic research, the release of genetically modified organisms into the environment, and the extent to which individuals might want to know the details about their own genome.

Coding the "Telephone Tale" probe

As can be seen from the probe itself (see Appendix 6), there are six questions raised.

1. Should Jane be tested for Huntington disease ?
2. Who should decide on whether or not Jane has the test ?
3. Who should have access to the results ?
4. If tested positive, should Jane have children ?
5. If tested positive, should Jane be prevented from having children ?
6. What additional information would have helped in responding to this probe ?

Taking the question on which the first section focuses 'Do you think that Jane should have the test ?' the aim here was not only to seek an opinion, but also to investigate the factors which the students considered to be important in coming to hold that opinion. Thus this probe also sought to identify the

issues perceived as being important by the student. The first part of the probe called for a fixed response (yes/no) and clearly gave no problems of coding or analysis. Some of the underlying factors which students gave as the reasons for their opinion were embedded in the text of the audio-taped conversation itself, such as whether Jane might prefer not to know, while others were raised by students in addition to those raised by the text, such as Jane's ability to plan for the future. A further issue also arises here. Should individuals be confronted with the option of having a test or not, when there is no foreseeable treatment or cure for the disease ?

Alongside considering the reasons underlying students' opinions, another factor was evident in their responses. Some students assumed a positive result - i.e. that Jane would develop Huntington disease. Others assumed a negative result while a third group made no obvious assumption, but appeared to consider both possible outcomes.

Those who gave a 'yes' response (i.e. that Jane should have the test) gave reasons which could be grouped under a number of headings:-

- *Reasons related to "the need to know" and avoiding uncertainty*
- *Reasons related to planning and management*
- *Reasons related to emotional preparation*
- *Reasons related to children*
- *Reasons related to a consideration for a future husband*
- *Other reasons*

Each of these reasons could be further sub-divided. Note that these categories are not mutually exclusive and that some students mentioned a number of the reasons listed above. In such cases they were coded into all of the categories they mentioned.

We have considered here only the coding for the range of explanations which followed a "yes" response to the first question "Do you think that Jane should have the test ?" A similar approach was used for those responding "no" and for the other five questions in this probe. These coding categories will be published at a later date.

Opinions and attitudes held were also investigated using four written questions - a series of twelve *Attitude Statements* and parts of the three *Stop Press* probes already referred to and to which students responded on an individual basis. Our research raises questions about the use of Lickert-type scales for investigating students' opinions on particular issues which are so context-dependent. They have the superficial advantage of easy analysis, but they give no indication of the reasons underpinning the student's view or of the factors taken into account in forming an opinion. However, we did include a series of twelve such statements in our research. Students were asked to respond to each statement indicating their view on a scale from

'strongly agree' to 'strongly disagree'. The statements were paired with one indicating approximately the opposite view to another placed somewhere else in the list. This enabled us to check on the consistency of the students' responses. As we show elsewhere students' responses to particular statements of opinion are frequently inconsistent and contradictory.

Both the *Attitude Statements* themselves and a discussion of the findings resulting from them will be found in Leach *et al* (1996). Suffice it to state here that a significant number of students agreed or strongly agreed with both members of a pair of statements expressing opposite viewpoints.

One of the three *Stop Press* probes '*Milk - the new wonder drug'* is shown in Appendix 5. This was designed not only to explore students knowledge of the possibilities in the field of genetic technology but also to investigate their opinions on recombinant DNA technology in a number of contexts.

A third strategy was used to try and identify the underlying issues and concerns that students' perceived as arising from new genetic technologies and also to explore their opinions and attitudes to the technologies. This was small-group *Discussion Tasks* led by a researcher. Two such tasks were used. The first - the *Prenatal Screening Discussion Task* - addressed issues concerned with prenatal genetic screening for Cystic Fibrosis, while the second - the *Genetic Engineering Discussion Task* - focused on recombinant DNA technology in a number of contexts. Both were designed with four phases involved in the task.

1. Providing the students with relevant conceptual information through specially constructed video-recordings. These were designed to ensure that the students grasped the genetics and other information necessary for them to understand the social and ethical issues and hence enable them to come to reasoned opinions and attitudes.

2. Ensuring that the members of the group had grasped the basic concepts involved. This was done by providing the students - working in groups of four - with a series of questions written on cards, each of which they were asked to address and discuss. A researcher then checked that the necessary information had been understood and where necessary explained it further.

3. Raising some issues arising from the technology by means of an audio-recording played to the students.

4. Discussing the issues raised by the audio-recording and enabling the students to highlight others which the technology in question raised leading to the students forming opinions on and attitudes towards these issues. During this phase the researcher explored their opinions and attitudes further.

The second and final phases of the tasks were audio-recorded and transcribed and it was these transcripts - supported where necessary by the recordings themselves - which served as the basis for the coding procedures. The coding of these *Discussion Tasks* will not be considered here except to state that the approach was ideographic and iterative - ideographic in that it was derived from the students' ideas, iterative in that approach based on students' ideas necessitates returning to the data several times to ensure that all coding categories are included and all responses are coded. The *Prenatal Screening Discussion Task* is discussed in detail by Leach *et al* (1996).

5.4 Summary of approach to data gathering

Three different approaches were thus employed to gather data from students.

- paper and pencil probes calling for written responses from students individually;
- paper and pencil probes calling for written responses from students individually, but following discussion with another student;
- discussion tasks put to students in small groups by a researcher who encouraged discussion among the members of the group and audio-recorded their responses.

Table 2 shows how the three data-gathering approaches were used to address the four major research questions.

Table 2: Approaches To Data Collection For Each Research Area Being Investigated.

Areas of research	Paper and pencil probes completed individually - no discussion	Pencil and paper probes completed individually following paired discussion	Discussion tasks
Knowledge and understanding of genetics	7 probes	-	1 task
Knowledge and understanding of DNA technology	1 probe + Parts of 2 other probes	-	-
Identification of issues	Parts of 3 probes	6 probes	2 tasks
Formation of opinions and attitudes	Parts of 3 probes + 12 attitude statements	6 probes	2 tasks

6. Administration of the test instruments

The seventeen written probes and the attitude statements were assembled into two packs as shown in Table 3, for separate administration.

Table 3: The arrangement of written probes between two packs

Area of research	Pack 1 Pencil and paper probes completed individually with no discussion	Pack 2 Pencil and paper probes completed individually with paired discussion
Knowledge & understanding of genetics	7 probes	-
Knowledge & understanding of DNA technology	1 probe + parts of 2 other probes	-
Identification of issues	Parts of 3 probes	Parts of 6 probes
Formation of opinions and attitudes	Parts of 3 probes	Parts of 6 probes + 12 attitude statements completed individually
Total number of probes in the Pack	11 probes	6 probes + 12 attitude statements

There were three reasons for this separation into two packs of probes. Firstly, experience with piloting suggested that the perceptions of issues, opinions and attitudes dimensions of the work necessitated the provision of factual information in order to contextualised a probe. We were therefore anxious to separate such probes from ones calling for factual information. Secondly the time taken for students to complete all the probes was too great for them to be administered as a single pack of questions. Thirdly, the knowledge-based probes were to be answered by students individually, whereas for the issues/opinions/attitudes probes we wanted to enable paired discussion between students. Pack 1 was administered to whole classes of students (for details of the sample see Section 7 below) who were asked to respond to the probes on an individual basis. Pack 1 was assembled in three versions in which the orders of the knowledge and understanding probes - but not the probes themselves - were different. A third of each class was given each version of the pack. This served two purposes. Firstly it ensured that the same probes were not always at the end of the pack and hence attempted

by students who were tired - or perhaps not attempted at all in cases where students did not complete the pack. Secondly, in classrooms that were occasionally crowded, it minimised the chance of students overlooking the responses of their neighbours to the probes they were attempting as each neighbour would be working on a different pack and thus almost certainly a different probe at any given time. The three *Stop Press* probes were always placed at the end of Pack 1 after the knowledge and understanding probes.

Pack 2 was also administered to whole classes of students. But as has been explained the students discussed each probe with a neighbouring student before committing their response to paper. Once again this pack of probes was in three versions which contained identical probes but with the middle section assembled in three different orders. The *Telephone Tale*, requiring the playing of an audio-tape to the whole class was always placed first. The *In General* probe that explored opinions and attitudes to DNA technology in a more general way possibly raised by the earlier probes was always placed after the earlier five probes. The twelve *Attitude Statements* were placed at the end of Pack 2 and were completed by the whole class of students, starting at the same time and without discussion with a neighbour.

7 The sample

During the development of the test instruments, all the written probes and the discussion tasks were piloted and trialled in a number of schools, and one post-16 college, on an opportunistic basis. Though no systematic attempt was made to obtain a representative sample of students for this developmental work, students with a range of abilities were used.

The sample of students used for the final data collection for this research was drawn from twelve comprehensive schools in the West Yorkshire region of England. They covered a range of rural, urban and suburban catchment areas and the full ability range within each school. Most of the students (84%) were in their final year of compulsory schooling (aged 15-16). The remainder (16%) were in their penultimate year (aged 14-15). Aside from a smaller second set of schools used in the trialling of the research instruments, a total of 743 students were involved and together produced 1098 sets of responses to written and discussion tasks. A number of students were asked to respond to more than one of the test instruments as is indicated in Table 4 below.

All the schools which supplied our sample taught science in classes which were grouped by ability and it was these groups which were used for data collection. Viewed as a whole, the students involved covered the full range of ability normally experienced in maintained secondary schools in West and North Yorkshire. Information on the coverage of genetics in the curriculum was collected from 11 of the 12 schools involved in providing students for the research.

54% of the sample came from schools which stated that they had been taught all the basic genetics components of the National Curriculum, with a further 11% having been taught some genetics. 39% of the sample were from schools which stated that they had been taught about genetic engineering. Details of the sample for each probe are given along with the findings of that probe (see Lewis *et al*, 1996a and 1996b; Leach *et al*, 1996, Wood-Robinson *et al*, 1996)

Table 4: The sampling matrix

Test Instrument	*Number of students responding*
Written Pack 1 only	127
Written Pack 2 only	261
Written Pack 1 + Written Pack 2	183
Prenatal Screening Discussion Task + Written Pack 1	75
Genetic Engineering Discussion Task + Written Pack 1	62
Knowledge and Understanding of Genetics Discussion Task + Written Pack 1	35
Total for Written Pack 1	482
Total for Written Pack 2	444
Total number of responses	1098
Total number of students involved	743

Key:

Written Pack 1 = Written probes investigating knowledge and understanding of genetics and new technologies and the identification of issues arising from and opinions on the technologies answered by students individually.

Written Pack 2 =Written probes investigating identification of issues arising from and opinions on the new technologies answered individually after paired discussion.

Written Pack 2 =Written probes investigating identification of issues arising from and opinions on the new technologies answered individually after paired discussion.

8 Overview of the project

This survey documents secondary school students' knowledge and understanding of genetics and of DNA technology, the issues they perceive to be involved in applications of the new technologies and their opinions related to selected applications. A range of methods of data collection were used and have been described above. Our approach to coding students' responses has been to base our categories on the range of responses given by the students themselves but not to adopt mutually exclusive methods. Students frequently respond to such probes in a multiplicity of ways and forcing these into predetermined categories is not helpful in coming to an appreciation of their ideas. Inconsistency of response was another aspect which was frequently encountered. With written responses we were unable to address it, but simply note its existence. However, with the *Discussion Tasks* the interviewer was often able to draw individual students' attention to any inconsistency in their ideas or their opinion - in fact such inconsistencies were sometimes also challenged by other members of the discussion group. In this way students were brought face to face with this aspect of their response and in some cases modified their views.

This paper has addressed some of the design and methodological issues arising from a large and complex project which has sought to explore not only students' knowledge and understanding in a particular domain, but also the social and ethical issues which they see arising from the application of a range of technologies and their opinions on those technologies. The work has also placed students in a decision-making role with respect to a number of issues.

Full details of the probes used in the research, together with the responses of the students, our coding schemes, and the analysis of the results will be published in other Working Papers in this series. These will be as follows:

Working Paper 2
Understanding Of Basic Genetics And DNA Technology
- findings from some of the written probes concerned with students' understanding of genetics and of new genetic technologies.

Working Paper 3
Understanding The Genetics Of Cells
A: The Discussion Task
- findings from the 'Understanding of Genetics Discussion Task'.

Working Paper 4
Understanding The Genetics Of Cells
B: The Written Probes
- findings from some of the written probes concerned with students' understanding of gene expression and the transfer of genetic information between cells.

Working Paper 5
Opinions on and attitudes Towards Genetic Screening
A: Pre-Natal Screening (Cystic Fibrosis)
- Pre-natal screening for Cystic Fibrosis - findings from the 'Prenatal Screening Discussion Task' and from the twelve Attitude Statements'.

Working Paper 6
Opinions on and Attitudes Towards Genetic Screening
B: Individual Screening (Huntington Disease)
- findings from the written probe.

Working Paper 7
Opinions on and Attitudes Towards Genetic Engineering
A: Acceptable Limits
- findings from the 'Genetic Engineering Discussion Task'.

Working Paper 8
Opinions on and Attitudes Towards Genetic Engineering
B: Acceptable Limits
- findings from written probes.

It is hoped that the findings from the remaining written probes, and a discussion of the implications of the research for the science curriculum and for classroom practice will be published in subsequent Working papers.

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Appendix 1: Science in the National Curriculum (1991)

This version of the National Curriculum was laid before Parliament in December 1991. The provisions of the Order relating to the third key stage came into force on 1st August 1992 in respect of all pupils in that key stage. The provisions of the Order relating to the fourth key stage came into force on 1st August 1992 in respect of all pupils in the first year of that key stage; and on 1st August 1993 in respect of all other pupils. This version of Science in the National Curriculum applied to the students under investigation in this study and was used, along with other considerations, as a basis for the design of the research instruments.

The sections of Science in the National Curriculum (1991) which are relevant to genetics are shown below.

Key Stage 3

In the introduction to the Programme of Study

The application of science: pupils should be given opportunities to develop their awareness of the importance of science in everyday life, and, building on their earlier experience, their growing knowledge and understanding and their increasing maturity, to study how science is applied in a variety of contexts. They should consider the benefits and drawbacks of applying scientific and technological ideas to themselves, industry, the environment and the community. They should begin to make decisions and judgements based on their scientific knowledge of issues concerning personal health and well-being, safety and the care of the environment. Through this study they should begin to understand how science shapes and influences the quality of their lives.

Attainment target 2: Life and living processes
Pupils should develop knowledge and understanding of:
i) life processes and the organisation of living things
ii) variation and the mechanisms of inheritance and evolution

Programme Of Study
Pupils should explore and investigate how flowering plants and mammals are normally organised at cellular and macroscopic levels. They should study life processes, ..., reproduction, ...
.... They should measure and investigate variation between individuals in a range of living things, giving attention to their welfare. They should translate data into trends and norms and consider genetic and environmental causes of variation and extinction. They should study how information in the form of genes is passed from one generation to the next. They should be introduced to the idea of selective breeding.

Statements Of Attainment
Pupils should:
LEVEL 3

a) know the basic life processes common to humans and other animals.
Examples: identify processes such as ...reproducing as common to themselves and familiar animals.

LEVEL 5

b) know that information in the form of genes is passed on from one generation to the next.
Example: use information from an extended family (humans, guinea-pigs, rabbits) to show that a feature may be inherited.

LEVEL 6

a) be able to relate structure to function in plant and animal cells.
Examples: explain how the structure of a neurone enables nerve impulses to be transmitted over a long distance and the structure of a palisade cell facilitates photosynthesis in a leaf.
c) know that variation in living organisms has both genetic and environmental causes.
Example: explain some possible causes of variation in human birth weight.

LEVEL 7

c) understand how selective breeding can produce economic benefits and contribute to improved yields.
Example: describe how modern varieties of wheat have been produced from wild strains to give greater yield, improved disease resistance and shorter cropping periods.

Key Stage 4 (Double science)
Key Stage 4 (Single science)

As far as Science in the National Curriculum (1991) relates to genetics, there are no differences between the Programme of Study and the Statements of Attainment for Double and for Single Science.

In the introduction to the Programme of Study

The application and economic, social and technological implications of science: pupils should be given opportunities to develop awareness of science in everyday life. Building on earlier experience, breadth of knowledge and understanding, and increased maturity, they should study how science is applied in a variety of contexts, ... They should use their science knowledge and skills to make decisions and judgements concerning personal health and safety. They

should consider the effect of scientific and technological developments, ... on individuals, communities and environments. Through this study, they should begin to understand the power and the limitations of science in solving industrial, social and environmental problems and recognise competing priorities.

The nature of scientific ideas: pupils should be given opportunities to develop their knowledge and understanding of how scientific ideas change through time and how their nature and the use to which they are put are affected by the social, moral, spiritual and cultural contexts in which they are developed. In doing so they should begin to recognise that, while science is an important way of thinking about experience, it is not the only way.

Attainment target 2: Life and living processes
Pupils should develop knowledge and understanding of:
i) life processes and the organisation of living things;
ii) variation and the mechanisms of inheritance and evolution.

Programme Of Study
In the context of their study of the major human organs they should consider the factors associated with a healthy life-style and examples of technologies used to promote, improve and sustain the quality of life.
They should consider the interaction of genetic and environmental factors (including radiation) in variation. 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. Using the concept of the gene, they should explore the basic principles of inheritance in plants and animals and their application in the understanding of how sex is determined in human beings and how some diseases can be inherited. Using sources which give a range of perspectives, they should have the opportunity to consider the basic principles of genetic engineering, for example *in relation to drug and hormone production*, as well as being aware of any ethical considerations that such production involves. They should consider the evidence for evolution and explore the ideas of variability and selection leading to evolution and selective breeding. They should consider the social, economic and ethical aspects of cloning and selective breeding.

Statements Of Attainment
In addition to those Statement of Attainment for Levels 4 to 7 identified above for Key Stage 3, pupils should:

LEVEL 8
b) know how genetic information is passed from cell to cell and from generation to generation by cell division.
Examples: sequence photographs showing how the chromosomes first appear and then divide equally between daughter cells during

mitosis and how the pairs of chromosomes divide equally during meiosis.

c) understand the principles of a monohybrid cross involving dominant and recessive alleles.
Example: explain or predict the ratios between phenotypes and genotypes in simple monohybrid crosses between, for example, different strains of Drosophila.

LEVEL 9

b) understand the different sources of genetic variation.
Example: explain how genetic variation is brought about by reshuffling chromosomes and gene mutation.

c) understand the relationships between variation, natural selection and reproductive success in organisms and the significance of these relationships for evolution.
Examples: explain how organisms such as Galapagos Island finches and British peppered moths evolved to fit the ecological niches they now occupy.

LEVEL 10

b) understand how DNA replicates and controls protein synthesis by means of a base code.
Example: outline the self-replicating nature of DNA and how the sequence of bases can code for amino acids in a protein.

c) understand the basic principles of genetic engineering, selective breeding and cloning, and how these give rise to social and ethical issues.
Examples: explain how human insulin can be obtained from genetically engineered bacteria; discuss the issues raised for society by the possibility of correcting human genetic disorders.

Appendix 2: Science in the National Curriculum (1995)

This version of the National Curriculum superseded the 1991 version and came into force for Key Stage 3 on 1st August 1995 in respect of all pupils in that key stage. The provisions of the Order relating to the Key Stage 4 came into force on 1st August 1996 in respect of all pupils in year 10; and on 1st August 1997 in respect of all pupils in year 11.

The sections of Science in the National Curriculum (1995) which are relevant to genetics are shown below.

Key Stage 3 (Years 7-9, ages 11-14)

Introductory section

Pupils should be given opportunities to:

2 Application of science

b) consider how applications of science, including those related to health, influence the quality of their lives,

d) consider the benefits and drawbacks of scientific and technological developments in environmental and other contexts.

Attainment Target 2: Life Processes and Living Things

1 Life processes and cell activity

a) that many animals and plants have organs that enable life processes, *eg reproduction*, to take place;

b) that animals and plants are made up of cells;

e) ways in which some cells, including ciliated epithelial cells, spermova, ... are adapted to their functions;

4 Variation, classification and inheritance

Variation

a) that there is variation within species and between species;

b) that variation within a species can have both environmental and inherited causes;

Inheritance

e) that selective breeding can lead to new varieties.

Key Stage 4 (Years 10-11, ages 14-16) - Single Science

Introductory section

Pupils should be given opportunities to:

2 Application of science

a) consider ways in which science is applied and used, and to evaluate the benefits and drawbacks of scientific and technological developments for individuals, communities and environments;
b) use scientific knowledge and understanding to evaluate the effects of some applications of science on health and on the quality of life;
c) relate scientific knowledge and understanding to the care of living things and of the environment;
e) consider the power and limitations of science in addressing industrial, social and environmental issues and some of the ethical dilemmas involved.

3 The nature of scientific ideas

b) consider ways in which scientific ideas may be affected by the social and historical contexts in which they develop, and how these contexts may affect whether or not the ideas are accepted.

Attainment Target 2: Life Processes and Living Things

1. Life processes and cell activity

c) that cells have a nucleus, a cell membrane and cytoplasm;
d) that the nucleus contains chromosomes that carry the genes;
e) how cells divide by mitosis so that growth takes place, and by meiosis to produce gametes.

3 Variation, inheritance and evolution

Variation

a) how variation may arise from both genetic and environmental causes;
b) that sexual reproduction is a source of genetic variation, while asexual reproduction produces clones;
c) that mutation is a source of genetic variation and has a number of causes;

Inheritance

d) how gender is determined in humans;
e) the mechanism of monohybrid inheritance where there are dominant and recessive alleles;
f) that some diseases can be inherited;
g) the basic principles of cloning, selective breeding and genetic engineering.

Key Stage 4 (Years 10-11, ages 14-16) - Double Science

In addition to what is required for Single Science:

Attainment Target 2: Life Processes and Living Things

1 Life Processes and cell activity

c) that plant and animal cells have some similarities in structure; (note that this programme does not include "that cells have a nucleus, a cell membrane and cytoplasm" which is included in the Single Science programme)

4 Variation, inheritance and evolution

Inheritance

g) that the gene is a section of DNA;

The relevant Level statements for Attainment Target 2 are as follows:

LEVEL 4

Pupils demonstrate knowledge and understanding of aspects of life processes and living things drawn from the Key Stage 2 or Key Stage 3 programme of study. ...

LEVEL 5

Pupils demonstrate an increasing knowledge and understanding of aspects of life processes and living things drawn from the Key Stage 2 or Key Stage 3 programme of study. ...

LEVEL 6

Pupils use knowledge and understanding drawn from the Key Stage 3 programme of study to describe and explain life processes and features of living things. ... They distinguish between related processes, such as pollination or fertilisation. They describe simple cell structure and identify differences between cells, such as differences in structure between simple animal and plant cells. They describe some of the factors that cause variation between living things. ...

LEVEL 7

Pupils use knowledge and understanding of life processes and living things drawn from the Key Stage 3 programme of study, to make links between life processes in animals and plants and the organ systems involved. ... They use their knowledge of cell structure to explain how cells, such as the ovum, sperm or root hair, are adapted to their functions. They identify characteristic variations between individuals, including some features, such as eye colour, that are inherited and

others, such as height, that can also be affected by environmental factors. ...

LEVEL 8
Pupils demonstrate an extensive knowledge and understanding of life processes and living things drawn from the Key Stage 3 programme of study, in describing how biological systems function. They relate their knowledge of the cellular structure of organs to the associated life processes, ... They explain how characteristics can be inherited by individuals and apply their knowledge to contexts such as selective breeding. ...

EXCEPTIONAL PERFORMANCE
Pupils demonstrate both breadth and depth of knowledge and understanding of the Key Stage 3 programme of study and draw on aspects of the Key Stage 4 programme of study when they describe and explain how biological systems function. ... They relate their understanding of the life processes of reproduction and growth to the processes of cell division. They use their understanding of genetics to explain a variety of phenomena, such as mutation or the production of clones. ...

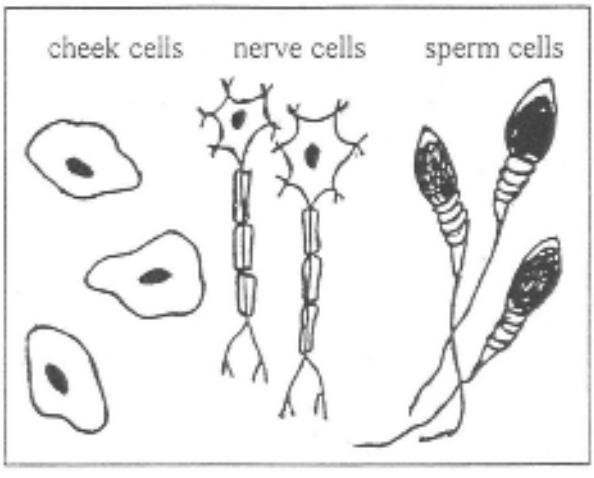
Appendix 3

'Cells'

Part 1

This part of the question is about different types of cells from the same person - Robert.

Cells from Robert



Please answer the following questions by ticking ONE box. Explain your reasons.

a) If you could take two of Robert's cheek cells would the genetic information in them be :-

Tick ONE Box

the same ☐

different ☐

don't know ☐

Please give the reasons for your answer - ----------

---

b) If you could take one of Robert's cheek cells and one of Robert's nerve cells would the genetic information in them be :-

Tick ONE Box

the same ☐

different ☐

don't know ☐

Please give the reasons for your answer - ----------

---

c) If you could take one of Robert's cheek cells and one of Robert's sperm cells would the genetic information in them be :-

Tick ONE Box

the same ☐

different ☐

don't know ☐

Please give the reasons for your answer - ----------

---

d) If you could take two of Robert's sperm cells would the genetic information in them be :-

Tick ONE Box

the same ☐

different ☐

don't know ☐

Please give the reasons for your answer - ----------

Part 2

This part of the question asks you to make comparisons between the cells from two different people - Danny and John.

a) Danny's cheek cell

John's cheek cell

If you could take one of Danny's cheek cells and one of John's cheek cells would the genetic information in them be :-

	Tick ONE Box
the same	☐
different	☐
don't know	☐

Reasons ----------

Appendix 4

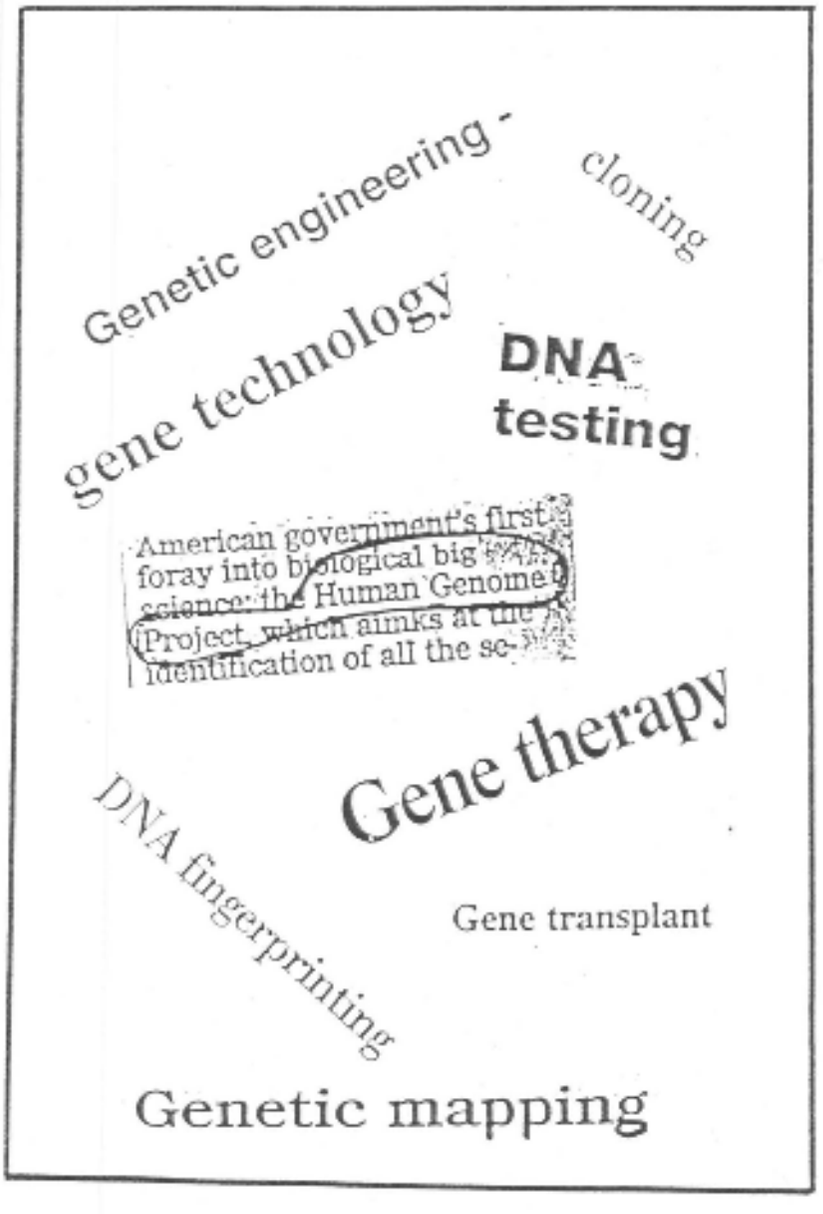
'The New Genetics'

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.
