Biotechnology and the relationship between university expectations and school provision

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Biotechnology and the Relationship between University Expectations and School Provision

The word "biotechnology" has only come into general use since the publication of the Spinks Report in 1981. There has been uncertainty over its precise meaning, and controversy over the introduction of degree courses entitled "Biotechnology" which were first established in 1981. The thesis deals first with a definition of the term "biotechnology" and then examines the development of biotechnology at British Universities between 1981 and 1986. By 1985, ten University degree courses were listed in the UCCA Handbook (1985) under the title "Biotechnology". The aim of the thesis was to investigate the expectations of University Admissions' Tutors when selecting applicants for these University degree courses. The investigation was by means of a questionnaire sent to all the Admissions' Tutors. In their replies they stated not only what they were looking for in successful applicants but also how they would like to see the school science curriculum change in order to improve the background of potential students. The current examination syllabuses for 1986 were used as a way of gauging to what extent science courses prepared students for entry to these degree courses. By comparing Admissions' Tutors expectations with the current science syllabuses the extent of this match was determined. It should be noted that field work for this thesis was carried out between 1984 and 1986 and that GCSE and AS Level syllabuses were not available for consultation at that time. Admission Tutors were asked how they would like biotechnology to be represented in the school curriculum. Their suggestions have been discussed in light of the changes which were being made to the school science curriculum.

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CHAPTER ONE

What is Biotechnology?

What is biotechnology ?

Biotechnology has been defined as "the application of biological organisms or systems or processes to manufacturing and service industries".[1]

The term itself is in fact quite old. It is noted that in 1920 a Bureau of Biotechnology existed in Leeds in Yorkshire and published a "Bulletin" which included articles on the role of microbes in a range of industries including leather making and pest control.[2]

However, it is only since 1980 that the term biotechnology has been in common use by the media as well as the scientific institutions. The word biotechnology was introduced following the need for a collective term to describe a range of recently developed techniques (since 1970) in microbial and biochemical technology and their application to industry.

Biotechnology is an interdisciplinary pursuit derived from chemistry, chemical engineering, biochemistry, molecular biology, cell biology, microbiology, computer science and economics.[3] It is now emerging as a discipline in its own right with its own characteristic concepts and methodologies, in a similar way to the emergence of chemical engineering earlier this century.[4]

There is often confusion and misunderstanding of the term biotechnology by not only the general public but also academic scientists. Taking the Spinks Report's (mentioned later in this chapter) definition of biotechnology, ie the application of biological organisms or systems or processes to manufacturing and service industries , as an accepted standard definition , biotechnology encompases not only the new techniques but also the traditional use of microorganisms in brewing , baking, and cheese and yoghurt making etc. These traditional forms of biotechnology have ancient origins. For example, as early as 6000BC the Sumerians and Babylonians exploited yeast to make beer.[5] These traditional forms of biotechnology were in the past known as applied microbiology, and their reclassification under the umbrella term biotechnology has been misleading as some people regard biotechnology as simply a new name for these traditional process.

It is the present writer's opinion that it is the new techniques (new biotechnology) which are at the centre of the modern day interpretation of the term biotechnology; therefore, these will be described in this chapter. These new techniques not only introduce novel processes to biotechnology but also have the potential to revolutionize the traditional ones.

The importance of biotechnology

In today's world as the population grows steadily (it is estimated that it will exceed five billion by the year 2000),[6] and the supply of fossil fuels diminishes, man must look for ways to improve agriculture in order to feed the population, for means to improve the standard of health care available, as well as to search for new types of fuel. In addition, as the population size increases and the demands on industry and agriculture also increase, the problem of the disposal of industrial, agricultural and human waste escalates.

Biotechnology is envisaged as creating :-

> .....wholly novel industries, with low fossil energy demands which will be of key importance to the world economy of the next century. Over the next two decades [1980-2000], biotechnology will effect a wide range of activities such as food and animal feed production, provision of chemical feedstocks, alternative energy sources, waste cycling, pollution control and medical and veterinary care. [7]

Biotechnology is, therefore, of significant importance to both developed countries and the third world.

The world wide development of the biotechnology industry

World wide the great potential of biotechnology has been recognised not only by academic scientists but also by Governments and well established industries. The countries which are at present (1986) most involved with biotechnology are Japan, the United States and some European countries (West Germany, France and Great Britain).

Between 1967 and 1971 Britain held a leading position in biotechnology research and produced thirty percent of the world's biotechnology patents.[8] However, as many academic scientists in the United Kingdom were ignorant of patenting proceedures and at that time there was no official support for biotechnology or a link between industry and academic scientists, many of the opportunities available to convert a process or product into a sort after marketable commodity were lost. (A classic example is the Monoclonal Antibody Production Technique developed by Dr Caesar Milstein in 1975).[9]

By contrast, other countries had officially recognised the scope of biotechnology and were promoting its development.

In 1972, in West Germany, the Federal Ministry of Research and Technology (BMFT) launched a programme to develop biotechnology, and it invested £35 million in biotechnology research and development between 1972 and 1978.[10] By 1980, the annual budget was £10 million.[11] (In addition to this, fundamental biosciences receive £60 million a year from the Deutsche Forschungsgemeinschaft [DFG]).[12] West Germany was also the first European country to establish (1975) a Biotechnology Centre. It is the Gesellschaft fur Biotechnologische Forschung mbH (GBF) at Braunschweig-Stockheim. Its role is to fulfil an intermediary role between public institutions, particularly universities and industry.[13]

Japan too, was ahead of Britain in noting the potential of biotechnology and giving it official support. In 1975, Japan's Ministry of Trade and Industry (MITI) classed biotechnology as a "priority technology"[14] and by 1977, Japan had become a world leader in taking out patents on biotechnological processes.[15] In 1981, biotechnology was included in its "Basic Industrial Research Programme". £8 million per year was spent on developing biotechnology in universities , Governmental institutes and industry.[16] Japan had been a world leader for many years in the production of amino acids, nucleotides, microbial enzymes and antibiotics using traditional fermentation technology techniques. It was mainly the large companies involved in food, beverage, pharmaceutical and chemical production which became involved with biotechnology in Japan. For example the following Japanese companies became involved in biotechnology:-[17]

Sumi- Tomo Chemicals	(Chemicals)
Toray	(Synthetic fibres)
Takeda	(Pharmaceuticals)
Ajinomoto	(Food Processing)
Suntory	(Brewing)

In the United States, numerous small biotechnology firms were established in the late 1970's, many of them situated along the Californian coast; these have since been christened the "sunrise industries". The companies are mostly privately funded, the major ones being Genetech, Hybritech and Cetus. The largest of these, Genetech, went public in 1980. Public interest in biotechnology was reflected by the massive share price increase which accompanied its floatation. Shares doubled in value in the first twenty minutes on the stock exchange.[18]

By the late 1970s there was widespread concern in the United Kingdom that, in comparison to our world competitors, eg West Germany, Japan and the United States, opportunities to develop biotechnolgy to the full were being lost. There was also deep concern about the significant number of academic biotechnologists who were emigrating. For example 250 British biotechnologists emigrated to the United States and Switzerland between 1975 and 1984.[19]

Publication of the Spinks Report in 1980

Against this background of concern the Advisory Council for Applied Research and Development (ACARD) decided in conjunction with the Royal Society and the Advisory Board for the Research Councils (ABRC) to set up a Joint Working Party to study the industrial applications of biological knowledge, ie biotechnology. Their purpose was:-

1. To review existing and prospective industrial opportunities in biotechnology and
2. to recommend necessary action to the Government and other bodies to facilitate British industrial development in this field.[20]

The report was chaired by Dr Alfred Spinks and has since become known as the Spinks Report. It shall be referred to as such in this text and the endnotes.

The report stated that "by comparison with our world competitors - West Germany, Japan and the United States - investment is low and opportunities have been missed."[21] It recommended a "technology push" reflected in a firm commitment to strategic applied research.[22] The report recognised that industrial success relies upon "good communication and rapid transfer of knowledge and expertise between research workers in industry, universities and Governmental laboratories"[23].

Among its proposals the Spinks Report recommended the following:-[24]

1 The research councils should with the Advisory Board for Research Councils (ABRC) set up a Joint Committee for Biotechnology. This should coordinate research in biotechnology and spend at least £3 million per year on research in this field.

2 The National Enterprise Board (NEB) in conjunction with the National Research Development Corporation (NRDC) should investigate the possibility of using some public funds to establish a research orientated biotechnology company of the kind now (1980) taking shape in the United States.

3 The University Grants Committee (UGC) and the Research Councils, with the backing of the universities should support the expansion of a limited number of centres of excellence in biotechnology from the best existing in universities.

   A minimum of twenty new teaching and research posts should be created over the next five years [1980-1985].

4 The Confederation of British Industry, the Association of the British Pharmaceutical Industries, the Chemical Industries Association, the Food and Drink Industries Research Council and other trade associations, should actively seek to identify opportunities for advances in

biotechnology in the fields of potential interest to their members.

5 That if there is to be a substantial gain from biotechnology, local authorities, teachers, parents and pupils must be informed of its significance.

Following the publication of the Spinks Report, the Joint Institute of Biology/Royal Society Biological Education Committee and the Society's Education Committee, Council of the Royal Society endorsed the establishment of a working group under the chairmanship of Professor W D P Stewart to follow up issues made in the Spinks Report relating to biotechnology and education. Their brief was to consider:-

> ......the implications for secondary school and further education of the likely growth in biotechnology over the next 30 years, in terms of both an adequate provision of suitably trained manpower and a balanced appreciation of its role in industrial development and national economic well-being.[25]

The findings of this working party were published by the Royal Society in 1981, in a report entitled Biotechnology and Education. This report will be referred to as such in both this text and the endnotes.

The new techniques fundamental to modern biotechnology

The new technologies which are at the centre of modern biotechnology are:-

1 Fermentation Technology.
2 Enzyme Technology.
3 Genetic Engineering/Recombinant DNA Technology.
4 Cell Hybridisation.
5 Waste Treatment Technology.

Fermentation Technology

Of the above list of technologies, fermentation technology has the most ancient origins. Brewing, vinegar production, cheese and yoghurt making, all processes which man has carried out for centuries, are examples of fermentations. However, it was not until Louis Pasteur's research[26] on the spoilage of wine (1857-1876) that the chemical reactions accompanying fermentation processes were recognised as the result of microbial activity. Pasteur studied a considerable number of fermentations and showed that each particular type of fermentation (defined by its principle end product eg alcohol, lactic acid, butyric acid), was brought about by the activity of a particular type of microorganism.[27] Pasteur also noted that specific conditions were necessary in order for certain organisms to live and carry out their particular fermentation. For example, lactic acid fermentation requires a neutral medium, whereas alcohol fermentation is best performed in an acidic medium.[28] Apart from noting the need to control the acidity (pH) of the medium, Pasteur also noted that there is a need to monitor the aeration of a reactor vessel during the fermentation. Certain fermentations only occur in oxygen free (anaerobic) environments eg butyric acid fermentation, whereas others for example the alcohol production by yeast, need an aerobic environment.[29]

A significant development in fermentation technology occurred during the First World War (1914-1918), when Britain required large amounts of acetone for making munitions. It was discovered by Chaim Weizmann, a chemist working in Britain, that the microorganism Clostridium acetobutylicum converts sugar to butyric acid and then subsequently can convert the butyric acid to acetone and butanol.[30] This acetone-butanol fermentation was developed on a large scale in both Britain and the United States. It was the first large scale microbiological process in which the exclusion of other kinds of organisms from the culture vessel (fermenter) was critical to the success of the fermentation. This type of fermentation is now known as pure culture fermentation.

Thus, knowledge about fermenter design and control of reactor conditions developed initially from the work of Pasteur and later from the large scale industrial fermentations carried out during the first world war. (eg acetone-butanol fermentation and glycerol fermentation [31]) This knowledge was to prove invaluable for the introduction of large scale antibiotic fermentation in the 1940's.

Alexander Flemming's discovery, in 1929, of the antibacterial substance (penicillin) produced by the mould Penicillium notatum, and later its purification by Florey and Chain in 1939, saw the onset of the "antibiotic era".[32] It was, however, the Second World War (1939-1945), with the fear of casualties and epidemics, that accelerated the research and development needed for the commercial production of penicillin by large scale fermentation.

Since Flemming's discovery of penicillin, some 6 000 other antibiotics have been isolated.[33] They are mostly produced by three genera of microorganisms: Penicillium, Cephalosporium and Streptomyces.[34] Antibiotic production has become the most profitable part of the Pharmaceutical Industry. The annual antibiotic turnover in the United Kingdom is approximately £300 million.[35] Out of the 6 000+ known antibiotics, only about 100 are marketed.[36] Those of commercial interest have been improved by random mutations of the original strain followed by selection of the mutants for those mutants producing increased yields of antibiotic or for those mutants producing penicillin with a broader spectrum of action.

Today (1986) penicillin is produced by batch fermentation using the mould Penicillium chrysogenum and corn steep liquor as a substrate.[37] The strain of mould used today yields 10 000 fold more penicillin than the original.[38] The fermentation occurs in sterilised reaction vessels of capacity 10^5dm^3. The vessels are continuously stirred and phenyl acetic acid is added to the medium to enhance the production of penicillin.[39] Owing to the fact that penicillin is produced as a secondary metabolite, (ie after the mould has stopped growing), the fermentation time is relatively slow -about 200 hours. The penicillin is then isolated from the spent medium by filtration and crystallisation.[40]

The removal of a desired product from its medium following fermentation is known as "down stream processing". This process is linked to fermentation technology and is itself a key component of modern biotechnology.

One of the recent developments in fermentation technology has been the introduction of "open" fermenters, which allow continuous fermentation as opposed to batch fermentation. In continuous fermentation fresh medium is constantly fed into the fermenter and products are constantly removed. Although this may appear more efficient ,it does require sophisticated chemical engineering skills in order to ensure that the conditions in the vessel are those required for optimum product production and that the reaction mixture does not become contaminated by undesirable microbes.

There are two major recent uses of fermentation technology which it is felt deserve special mention. They are the "Gasohol Programme" in Brazil, and "Pruteen Production" by ICI in Britain.

The Brazilian National Alcohol Programme (known as the gasohol programme) was introduced to Brazil in 1975 following the massive increase in oil prices during the 1970's.[41] It is the largest single biotechnology programme in the world. Brazil grows large quantities of sugar cane, and this is fermented to alcohol by yeast . All Brazilian cars now run on either pure (95%) alcohol or on an alcohol-petrol mixture,[42] thus reducing the need for Brazil to import expensive oil. Developments in fermenter design have reduced the fermentation time from twenty-four hours to six and the yield of product has risen by ten percent during the last ten years.[43] There are now (1986) over 400 distilleries producing 2 500 000 000 gallons of alcohol per year in Brazil. It is hoped that by the year AD 2000 the programme will enable the country's entire energy needs to be supplied.[44]

During the 1970's, several large industrial companies investigated the possibility of using microbes to convert cheap organic materials into protein. It was hoped that this protein known as "single cell protein" (SCP), could replace imported protein rich soya-bean and fish-meal supplements for animal feed. BP and Shell were particularly interested in using hydrocarbons as substrates; however, this proved not to be viable due to the associated health risks.[45] One large scale process which did survive and which went on the market in 1980 was the production of the SCP "Pruteen", a substitute for soya-bean, developed at Billingham by ICI.[46] Pruteen is produced by growing the bacterium Methylophilus methylotrophus in an environment where it is fed with methanol, air ,ammonia and inorganic nutrients including phosphorus and calcium.[47] It is produced by continuous fermentation in a fermenter which is the largest in the world , fifty metres high and seven metres in diameter. The fermenter is kept under sterile conditions and is constantly stirred by a continuous flow of air bubbles from the bottom (known as air-lift fermentation).[48] During the fermentation, the cell concentration is kept at three per cent.[49] The SCP is removed from the fermenter continuously and is purified by centrifugation and drying. The fermenter can produce 50 000 tonnes of dry product per year.[50] The Pruteen contains seventy per cent protein and is rich in the amino acids lysine and methionine and is therefore a valuable end product. However, at present (1986), it costs twice as much as soya-bean so that its production is now run intermittently.[51]

ICI produce another form of protein in conjunction with Rank Hovis MacDougall; it is Myco-Protein, produced by the fungus Fusarium graminearum. This too is produced by continuous fermentation using glucose, obtained from maize starch, as a substrate. The product has been approved for use in human foods and came on the market in 1984, following extensive clinical trials.[52]

Enzyme Technology

The Spinks Report states:-

> We consider that the development and application of new industrial enzymes constitutes a major growth point in biotechnology.[53]

Although Pasteur had shown that yeast is responsible for alcoholic fermentation, he postulated in 1860 that this fermentation is inextricably linked with the life of the yeast cell.[54] It was therefore a major landmark in the history of Enzyme Technology when, in 1897, Eduard Buchner demonstrated that in fact a cell-free extract from yeast (ie the enzymes) could also carry out this fermentation.[55]

However, it was not until 1926 that the first enzyme (urease from jack bean) was isolated in pure crystalline form. Today nearly 2 000 different enzymes have been identified, of which 200 have been isolated and purified.[56]

Enzymes are a group of proteins synthesised by all living cells to function as catalysts for the many thousands of biochemical reactions which occur inside the cell. In order to review the current use of enzymes by industry one needs to appreciate their properties which are as follows:-

1 Enzymes are highly specific in their action, ie one particular enzyme will catalyse one particular reaction. This specificity of enzymes makes them particularly good at recognising substrate molecules even when the substrate is present in a mixture,and even when the concentration of substrate may be very low..
2 Enzymes have optimum conditions of pH and temperature for functioning. Most enzymes operate best under moderate conditions of temperature and pH.

3 Enzyme activity is destroyed (denatured) by high temperatures eg above 60°C. (An exception being the enzymes produced by thermophilic bacteria which work best at high temperatures.)

4 Enzymes have high powers of catalysis. For example the enzyme Beta-amylase converts 18 000 molecules of substrate (starch) to product(maltose) every second. [57]

5 Enzymes can be reused after they have catalysed a reaction.

The first enzyme to be marketed in the West was takadiastase in 1896. This enzyme was a crude mixture of hydrolytic enzymes ,made by growing the fungus Aspergillus oryzae on wheat bran.[58] Since this, enzyme production has become a multi-million pound industry. [59]

(A thorough and comprehensive list of the enzymes now in current use by industry is given in John Smith's book Biotechnology [60].)

Until about 1965 world wide use of enzymes was relatively low; the massive increase,fifteen fold, which occurred during the next five years,[61] was due to the introduction of bacterial enzymes into detergents. These are now known as "biological detergents". Most protein stains are notoriously difficult to clean and required very high temperature washes(eg 85-95°C.),which are energy expensive. The bacterial enzymes digest protein stains readily and can survive temperatures of up to 65°C. This makes them ideally suited for use in moderate temperature washes.[62]

As a result of the vast increase in oil prices during the 1970's ,and the need to conserve fossil fuel energy resources, (including oil), the Chemical Industry is now keen to develop economically feasible, enzyme-catalysed reactions to replace the traditional energy-demanding inorganically-catalysed reactions. (Seventy per cent of current industrial chemical processes involve catalysts and these are mostly inorganic catalysts. [63])

Perhaps the most potentially useful development in Enzyme Technology to have been made in recent years (1960-1980) is the introduction of immobilized enzymes. This is the physical, or chemical entrapment of enzymes or cells onto surfaces or inside fibres, gels or plastic particles. The four main methods of immobilisation are:-[64, 65]

1 Adsorption of the enzyme onto a surface eg alumina.
2 Covalent binding of the enzyme to fibres eg cellulose.
3 Entrapment of the enzyme within a lattice of polyacrilamide fibres.
4 Encapsulation of the enzyme inside a semi-permeable membrane to form micro-capsules (diameter 10μm-100μm).

The advantages of immobilized enzymes are:-[65,66]

1 The same enzyme can be used repeatedly since it is not lost at the end of the production batch.
2 The enzyme does not pollute the end product, thus facilitating the recovery of the product (downstream processing).
3 Increased thermostability of the enzyme often accompanies immobilization.
4 Immobilized enzymes can be used in a non-aqueous environment. (This is often required during the production of pharmaceuticals.)
5 Continuous (open) fermentation systems can more easily be designed when immobilized enzymes are used.
6 No wastage of energy is employed in the production of biomass.

The first immobilized enzyme to be used industrially was the enzyme aminoacylase in 1969 by the Japanese Company Taviake Seiyaku.[67] This enzyme is used to convert D aminoacids into their sterioisomer L form. Introduction of the enzyme in its immobilized form reduced production costs by forty per cent.[68] L amino acids are important as food and animal feed supplements and as ingredients in medical preparations. In addition, they have been incorporated into several cosmetic preparations, eg face cream and shampoo.[69]

Since 1969, other immobilized enzymes have been introduced to industrial process. For example, seventy per cent of the world's semi-synthetic penicillins are produced using the immobilized enzyme penicillin acylase. This method is employed by Beecham Pharmaceuticals in Britain.[70]

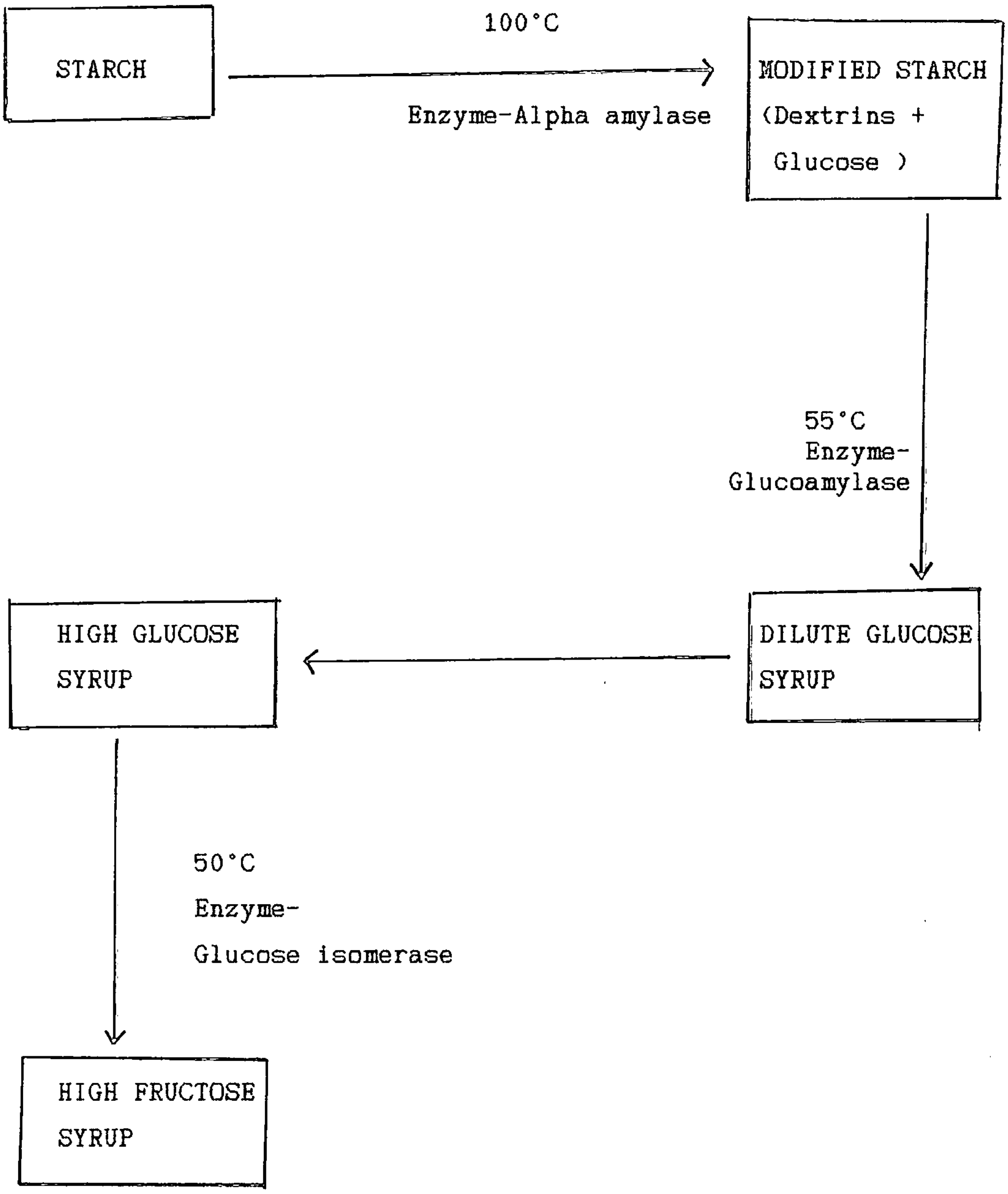
The sugar industry is a major consumer of enzymes, which it uses to hydrolyse starch into partially hydrolysed starch syrups (dextrins), glucose, and fructose. The process is shown in Diagram 1. Three enzymes needed in the process are:-[71]

1 Alpha-amylase - obtained from the bacterium Bacillus licheniformis.
2 Glucoamylase - obtained from the fungus Aspergillus.
3 Glucose isomerase - obtained from various microorganisms.

It should be noted that the enzyme glucoamylase is used in immobilized form , which enables a higher temperature to be reached in the reactor vessel.

DIAGRAM 1

Diagram to show the Enzyme Catalysed Hydrolysis of Starch into Fructose



Dextrins are needed as thickening agents and stabilisers (in frozen mousses, ice cream, etc) and glucose is used as a sweetener (in a wide range of products, eg soft drinks, cake mixes, confectioneries, chutney etc). Fructose, which is much sweeter than sucrose (the sugar obtained from sugar beet), is used to produce High Fructose Syrups (HFS).

High Fructose Syrups, consisting of ninety percent fructose and ten percent glucose, are now used in many soft drinks, confectioneries, sweet foods etc in the United States. It is thought that HFS will replace sucrose as the principle sweetener in the future.[72] HFS production in Europe is limited by EEC regulations which seek to protect sugar cane/beet farmers.[73]

Immobilized enzymes have been used widely in the production of biosensors, which are highly sensitive analytical instruments designed for continuous re-use.[74] Biosensors are now used extensively in medical analysis and are beginning to be introduced for use in other fields, for example in quality control testing by the food industry.and in the testing of pollutant levels in the environment.[75]

Immobilized enzymes are used in the following types of biosensors:- the enzyme electrode, the enzyme analytical reactor and the diagnostic reagent strip.

An enzyme electrode is composed of an enzyme held in place behind a semi-permeable membrane and connected to a transducer. When the electrode is dipped into the test solution, the analyte (substrate for the enzyme) passes through the semi permeable membrane and is then converted to product by the enzyme. The presence of product is detected by the electrochemical transducer which generates an electrical signal in either amps or ohms. This process can be explained by the following equation:-

analyte ⟶ ENZYME ⟶ product ⟶ TRANSDUCER ⟶ signal

Enzyme electrodes are now being used routinely to test for certain diseases. For example, the disease artherosclerosis (hardening of the arteries), is a major problem in developed countries where it is responsible for about half of all deaths.[76] There is a definite link between blood cholesterol levels and artherosclerosis. As cholesterol levels build up, the passage of blood through the arteries becomes increasingly difficult and this can result in blood clots (thrombosis) and even in a heart attack. The old test for blood cholesterol levels, which was time consuming and not highly accurate, has now been replaced by a new quick and highly specific test involving an enzyme electrode. This electrode involves the use of two immobilized enzymes, cholesterol esterase and cholesterol oxidase.[77]

In busy analytical laboratories where hundreds of samples are tested each day, there is a strong demand for automated analaytical processes to test numerous routine samples. Immobilized enzymes are now being used in enzyme analytical reactors which can test numerous samples simultaneously. These are now standard equipment in most clinical biochemistry laboratories.[78]

The third type of biosensor which uses immobilized enzymes is the diagnostic test strip.[79] These are small (8cm x1cm) thin, plastic strips with a pad at one end which contains immobilized enzyme and colour reagents. They can be used at home or in the doctor's surgery. The first diagnostic strip to be marketed was one which tests for glucose in urine samples. This simple test is quick (results are produced in 15 seconds) and quantitative, the pad turning a particular colour depending on the level of glucose present. In Britain, two per cent of the population suffer from diabetes mellitus,[80] (a condition which results in a higher than normal level of glucose in both the blood and urine).This test is now used in the diagnosis of diabetes mellitus, and in the subsequent monitoring of diabetes patients once they are being treated with the hormone insulin. which controls blood glucose levels.

A technique known as enzyme immunoassay (EIA) is now being used extensively in medical analysis. This technique is used to detect the presence and level of various antigens in body fluids, eg the hormones thyroxine, insulin, progesterone, oestrogen, and various bacterial exotoxins and serum proteins. The pregnancy test which detects the presence of the hormone human chorionic gonadotrophin (HCG) is also an enzyme immunoassay.[81]

Many of the biotechnology companies (eg Cetus and Hybritech) established in the late 1970's and early 1980's, marketed diagnostic kits in order to fund themselves while carrying out expensive research into genetically engineered products.[82] The latter were hoped to become high income producers. The Swiss biotechnology company Biogen, partly (8%) British owned, followed the American example and also concentrated on marketing diagnostic kits initially. It produces a kit in conjunction with the Japanese Green Cross to detect hepatitis B antigen in donor blood samples [83]

The British company Celltech, which was established by the National Enterprise Board, following the proposals made in the _Spinks Report_,[84] released its first diagnostic kit in 1981.[85] This kit tests for alpha-interferon levels in the blood. Two years later it produced a blood typing kit in conjunction with Boots.[86]

It should be noted that Celltech has a unique agreement with the Medical Research Council (MRC) in that it has first claim to develop and market any research carried out in an MRC laboratory related to Recombinant DNA technology and Monoclonal Antibodies. The aim of Celltech is to provide a link between universities and industry ,by providing the development needed to convert an idea from research into a marketable product.[87]

Enzyme technology has therefore developed substantially over the last fifty years due to man's increasing knowledge of enzyme specificity and enzyme action. The present writer feels that enzyme technology coupled with recombinant DNA technology are the basis for modern biotechnology, and that these will be the major growth areas in terms of the scope of biotechnology in the future.

Recombinant DNA Technology

Recombinant DNA Technology is perhaps better known as Genetic Engineering. It can be defined as "the manipulation of genes under highly controllable conditions."[88] For many people Genetic Engineering is synonymous with the term biotechnology.[89]

The phrase Genetic Engineering is relatively new, being introduced in the early 1970's to describe the novel research techniques then being discovered. However, man has in fact been involved with genetic manipulation for centuries, through selective breeding programmes used to isolate and cultivate animals and crops with improved characteristics.

Genetic Engineering has developed as a result of increasing knowledge about the genetic code. All cells whether they are eukaryotic (possessing a nucleus) or prokaryotic (without a nucleus) contain genetic material in the form of one or more chromosomes. Chromosomes are made up of a chemical called deoxyribonucleic acid (DNA). Hershey and Chase's experiments in 1952 showed that DNA was the inherited material passed on from one generation to the next.[90] A major breakthrough came the following year (1953) when Watson and Crick proposed a three-dimensional model for the DNA molecule.[91] It was found to be a double helix consisting of two parallel chains linked together by bonds between internally situated bases. It was later shown that the order of these bases (four types in total) along the DNA chain is of vital importance in determining which protein the DNA molecule codes for. A length of DNA which codes for the production of a specific (protein) product (eg a hormone, or an enzyme) is known as a gene.

The technique of Genetic Engineering was first performed in 1973 by Stanley Cohen and Herbert Boyer.[92] It is basically the isolation of a specific gene from an organism and its subsequent replication, thus enabling multiple copies of the gene to be produced. This technique also enables large quantities of the gene's product (eg a hormone) to be produced quickly and relatively cheaply. The process can be divided into the following stages:-[93](Illustrated in Diagram 2)

Stage One-Isolation of the required gene.

Special enzymes called Restriction Endonucleases are used to cut the gene out of the chromosome. These enzymes are capable of recognising different base sequences in the DNA molecule and of cutting the DNA at these points. This cutting (splicing) technique usually results in a staggered break across the two DNA strands leaving the isolated gene with its own characteristic "sticky ends".

Stage Two-Uptake of the isolated gene by a vector.

The isolated gene cannot be transfered to a recipient cell directly. It must first be taken up by a vector (carrier), which acts as an agent for carrying the gene across the recipient cell boundary. The choice of vector employed depends upon the choice of recipient cell. The two types of vector used are:- plasmids (small circular pieces of DNA found in many bacteria) and bacteriophages (viruses which infect bacteria).

In order to insert the isolated gene into the vector, the vector's DNA must first be cut using the same enzymes as were used in Step One. This ensures that the cut vector DNA will have the same type of "sticky ends " as the isolated gene. The sticky ends therefore chemically recognise each other and so the isolated gene inserts itself automatically into the vector DNA.

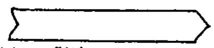
DIAGRAM 2

Diagram to show a Simplified Version of Genetic Engineering

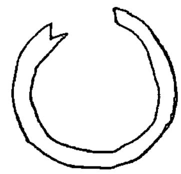
STAGE ONE-Isolation of the gene

isolated gene carrying desirable information

sticky end-

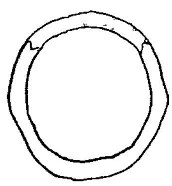


(created by cutting DNA
with restriction endonucleases).



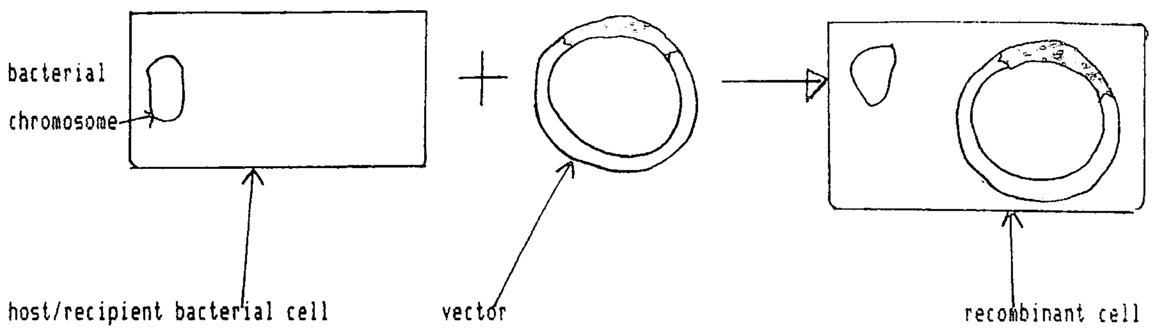
plasmid-
(circular piece of DNA, cut open with restriction endonucleases to allow insertion of the isolated gene)

STAGE TWO-Uptake of gene by a vector



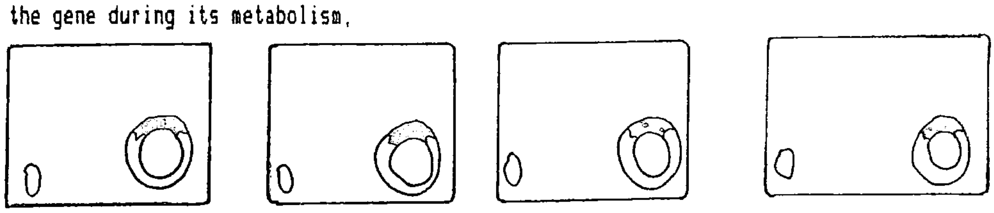
Sticky ends of plasmid/vector and isolated gene bind chemically, enabling gene to be inserted into the plasmid and transported with it,into a bacterium.

STAGE THREE- Transfer of gene to host cell.



STAGE FOUR-Harvesting of the recombinant cells

The bacterium/recombinant cell reproduces asexually to produce a clone of identical cells all containing copies of the plasmid and isolated gene. Each cell in the clone produces the product of the gene during its metabolism.



Clone of bacteria all making the product of the "isolated" gene.

Stage Three-

Transfer of the isolated gene to a recipient cell.

The vector, carrying the required gene, is then mixed with the recipient cell, usually a bacterium, though current research is being made on the use of yeast and plant cells as recipients. Only a certain proportion of recipient cells spontaneously take up the vector and with it the required gene. (They are now known as recombinant cells.) These recombinant cells are then isolated using various techniques. Sometimes the vector carries with it an easily recognisable label, eg antibiotic resistance to aid isolation of the recombinant cells.

Stage Four- Harvesting of the recombinant cells.

The recombinant cells are then put into a large vessel and provided with the necessary nutrients for growth. As the cells grow and multiply in numbers , numerous copies of the required gene are produced, in addition to which large quantities of the gene-product are also produced.

Initially most genetic engineering research concentrated on medically useful products, due to the high demand for both novel products and for a cheaper means of producing some existing products. Genetically engineered products of use in medicine include:-[94]

1 Hormones. eg insulin, somatostatin/growth hormone, thyroid stimulating hormone, calcitonin.
2 Viral and bacterial vaccines. eg the American company Cetus was the first (1982) to market a bacterial vaccine to combat infectious diarrhoea in calves and piglets.[95]
3 Blood clotting factors eg Factor V111.

4 Enzymes used in enzyme replacement therapy eg in the treatment of cystic fibrosis.
5 Enzymes used in diagnostic kits.
6 Antiviral agents eg interferon.

Genetically engineered insulin, called Humulin, was first produced in September 1979 by two American companies Genetech and Eli Lilly.[96] It took between ten and twelve years to research and develop at a cost of $100 million.[97] Despite this initial high cost, the companies are very optimistic about future marketing of genetically engineered insulin. Clinical trials have found it to vary less in quality than its traditional competitor (bovine insulin) and it appears to be free of the side effects which five per cent of patients taking bovine insulin experienced.[98] The world market for insulin is estimated at £100 million per year[99] and it is, therefore, economically attractive for biotechnology companies to invest in genetically engineered products which are in high demand and which have the potential of yielding good long-term financial rewards, despite the initial high cost of their research and development.

In Britain one in four thousand people suffer from the disease Haemophilia A.[100] These patients lack the blood clotting factor, Factor VIII. At present, haemophiliacs are treated by being given donated blood plasma, which is first tested to ensure that it is free from both the Hepatitis B virus and the HTLV-III virus (AIDS virus). It is thought probable that in the future genetically engineered Factor VIII may become available for haemophiliacs.[101].

Interferon is probably the best publicised genetically engineered product. Interferon was first discovered in 1957, and, since then a whole range of interferons have been discovered.[102] The main types are α, β and γ interferons.

Interferons are glycoproteins which most vertebrate animal cells produce in response to invasion by a virus. Interferon renders other cells resistant to viral invasion. The use of interferon as an anti viral agent was of great interest as viral infections are particularly difficult to treat, antibiotics being ineffective. The discovery of oncogenic (cancer causing) viruses in the 1960's caused speculation that interferon could also be used as an anti-cancer drug.[103]

However, until it became possible to apply genetic engineering to interferon, only very small amounts of impure interferon were obtained from human white blood cells at very high costs ($500 per patient per day), thus limiting its clinical use.[104] It was the discovery of two biotechnological techniques (genetic engineering and monoclonal antibody production), which occured in the mid 1970's, that led to the theoretical possibility of producing large volumes of pure interferon inexpensively for use in clinical trials.[105]

As a result of these advances in technology many of the biotechnology companies became involved in interferon research and development during the late 1970s. They supported the high cost of interferon research by developing and marketing diagnostic kits, which were relatively cheap to develop and did not require the extensive testing associated with human drug marketing. Japanese companies (eg Toray) became particularly interested in making cheap interferon, as cancer is the leading cause of death in Japan.[106] Anticancer drug sales in Japan are in excess of $500 million per year.[107] Toray are making genetically engineered β interferon for use in treating brain tumors.[108] Another Japanese company, Suntory, are producing genetically engineered γ interferon in connection with the American company Schering Plough.[109] γ interferon is effective over a wider range of cancers than β interferon and therefore promises to attract a larger market. It is interesting to note that Suntory hired over a hundred researchers, mostly from abroad, to establish its biotechnology scheme.[110]

Genetic engineering research involving plant cells has lagged behind research into the genetic engineering of medicinal products, which involves mainly animal and bacterial cells. One explanation for this is the shortage of suitable vectors into which isolated genes can be incorporated prior to transfer to the host cell.[111] Currently (1986) research is being done involving a bacterium A. tumefaciens, which infects plant cells and causes crown gall disease. The bacterium inserts a plasmid (small piece of genetic material) into the plant cells, which respond by dividing rapidly to form a tumour. All the tumour cells contain copies of the bacterial plasmid. Current research is concerned with using this plasmid to carrry isolated genes, eg nitrogen-fixing genes into plant cells (eg cereals).[112] As ten per cent of the world's oil supply is used to make nitrogenous fertilisers [113], it is of great economic interest to develop crop strains which can synthesise their own nitrogenous compounds, thus eleviating the use of nitrogenous fertilizers. Genetic engineering makes this theoretically possible.

Plant cells are capable of producing a range of useful products, including, medically useful compounds eg opiates, antileukemic and antitumour agents, alkaloids and steriods, and non-medicinal products such as perfumes, flavours and sweeteners.[114] It is theoretically possible that the genes for these products could be isolated, inserted into host cells and vast quantities of both the host cell plus its product cultured by fermentation technology.

Most genetically engineered products at present use the bacterium _E.coli_ as the recipient host cell. _E.coli_ synthesises the gene product within the cell membrane and therefore makes product recovery slightly more difficult. The use of different bacterial host cells, eg _B.subtilis_, is now being investigated, as _B.subtilis_ exports certain cell products from the cell thus facilitating product recovery.[115] Research into the use of yeast cells as recipient host cells is also currently being undertaken. [116]

The _Spinks Report_, in the present writer's opinion, is correct in stating:-

> Genetic engineering has the potential to extend the scope and power of every branch of biotechnology, no doubt beyond limits currently conceived.[117]

Cell Hybridisation

Somatic cell hybridisation is the fusion of the contents (protoplasts) of two cells of different species. The technique enables genetic material which would not normally combine in nature, to do so under controlled conditions. The resultant cell is called a hybrid and, as this technique involves somatic (non-gamete producing) cells, it is called somatic cell hybridisation.[118]

Hybrid cells are produced by treating the parental cells with forty per cent polyethylene glycol, which stimulates cell fusion. The resultant hybrid cells can then be grown up in fermenters to yield large quantities of identical hybrid cells and their gene products.

Probably the most significant example of somatic cell hybridisation is the production of monoclonal antibodies. This process was discovered in 1975 by Dr Caesar Milstein, working at the Molecular Biology Laboratory of the Medical

Research Council at Cambridge.[119] It is a process by which large quantities of highly specific antibodies (chemicals which recognise and neutralise specific antigens/germs) can be produced in vitro relatively cheaply.

Monoclonal antibody production involves the fusion of processed spleen plasma cells with myeloma cells. This process is outlined in Diagram 3. A processed spleen plasma cell is one which has been directed (by an antigen) to synthesise a specific antibody /immunoglobulin. A myeloma cell comes from a malignant tumour and characteristically divides at a faster rate than normal, non-tumour cells. Thus the resultant hybrid-myeloma (hybridoma) cell is immortal and produces a specific antibody . Isolated hybridoma cells are grown up on nutrient agar plates to form a clone of identical cells, which can then be grown up in fermenters to produce large quantities of antibody.[120]

Uses of monoclonal antibodies:-[121,122]

1 To target drugs, especially anticancer drugs, in the body. These drugs have been called 'magic bullets'. An antibody is attached to the drug which matches the antigens on the surface of the particular type of tissue cells to be treated. When introduced to the body the antibodies will direct the drug to the target organ due to the specificity in the match between antigens and antibodies.
2 To produce better quality vaccines (composed of antibodies) than can be achieved using conventional (animal produced) techniques.
3 As treatment following organ transplants ,when patients are immunosuppressed and need to be given ready-made antibodies.
4 To produce pure antibodies for use in diagnostic kits, eg to test blood plasma for the Hepatitis B virus.
5 To produce pure antibody needed for the purification and production of certain antigens, eg interferon.

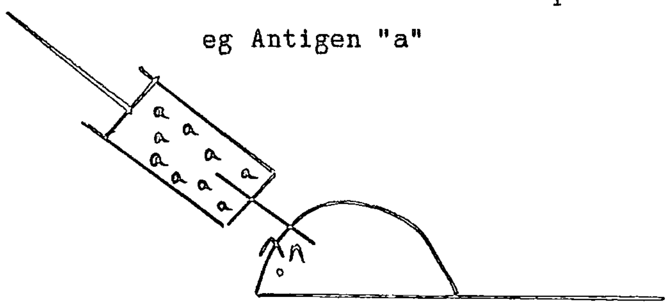
DIAGRAM 3

Diagram to show Monoclonal Antibody Production

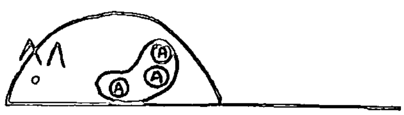
Antigen Type "a"

Immunise mouse with a particular antigen

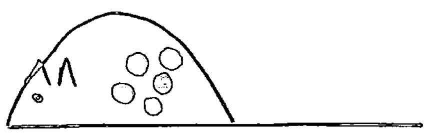
eg Antigen "a"



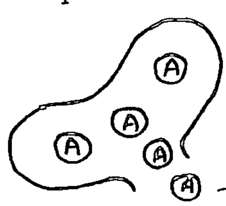
The immune system of the mouse responds by its spleen producing plasma cells which synthesise Antibody A.



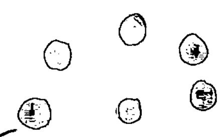
Removal of plasma cells from mouse's spleen.



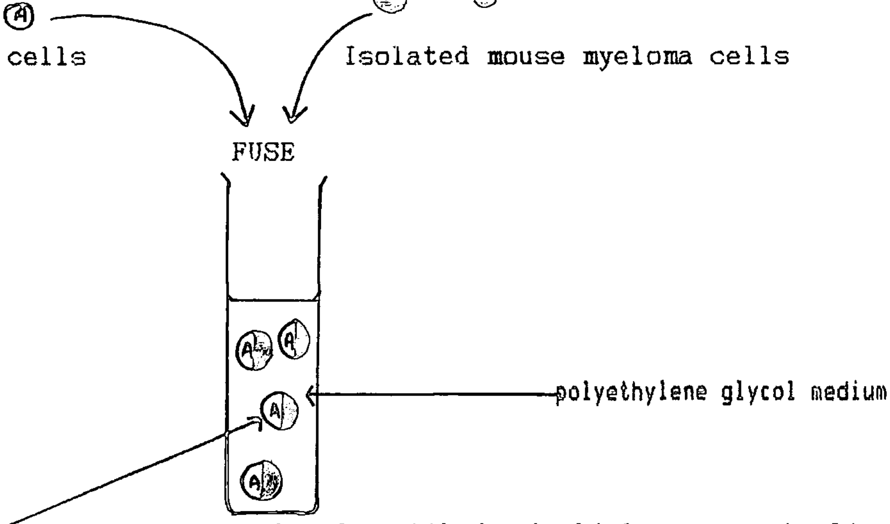
Mouse with cancer, containing myeloma cells.



Isolated spleen cells



Isolated mouse myeloma cells



Hybridoma cells producing monoclonal antibody A.which can neutralise antigen "a".

Plant Tissue Culture

Plant tissue culture and plant cell hybridisation are complementary techniques. Plant cells are totipotent, ie they have the ability to regenerate whole plants from single cells. Thus hybrid cells can be induced to grow into entire new plants using tissue culture techniques.

Tissue culture involves isolating either root, stem or leaf cells from a plant, and placing them in a medium to stimulate cell division and the formation of an undifferentiated mass of cells known as a callus. Callus cells are then removed to fresh media where they are stimulated to grow and generate roots, shoots and leaves. Identical plantlets can therefore be produced on a large scale economically.[123]

Unilever is involved in cloning oil palms which have an above average oil yield. The oil is used for margarine manufacture.[124] Similarly, Shell is researching ways of propagating forest trees by cloning particularly attractive mature parental trees.[125]

Waste Treatment Technology

Waste can be defined as any material or energy form that cannot be economically used, recovered or recycled.[126] Waste disposal technology is the largest single application of microorganisms by man.[127] Its success depends upon the enormous metabolic diversity of microbes. These are used to dispose of sewage, farm waste, effluent from the food industry and industrial pollutants such as, for example, organic chemicals and oil spills.

The aim of all waste treatment systems (biotreaters) is to minimise health hazards and to reduce the amount of oxidizable organic compounds present in the waste, thus producing a final effluent which can be discharged without adverse effects into the environment.[128]

Biotreatment of waste originated in man's use of cess pits and septic tanks. These primitive biotreaters made use of naturally occurring microorganisms to digest the waste material, and convert it into non-toxic products. Sewage treatment plants form the largest of all the biotechnological industries.[129] A modern sewage plant is "essentially a highly efficient form of traditional cess pit, scaled up to cope with the enormous and diverse demands of an industrial urban society."[130] It involves the controlled use of both aerobic microbes (eg Bacillus and Vorticella)and anaerobic (eg Methanobacterium) microorganisms to convert organic compounds in the waste to simple non-toxic substances, eg carbon dioxide, methane, and water.[131]

As a result of the advances and expansion of modern industrial processes and agricultural practices, the amount of waste produced and the diversity of waste products has increased with time. As stricter effluent controls have been introduced by Governments following public awareness of environmental pollution, industries have been encouraged to seek to avoid wastes which give rise to serious disposal problems and to look for new methods of treating effluent waste.[132]

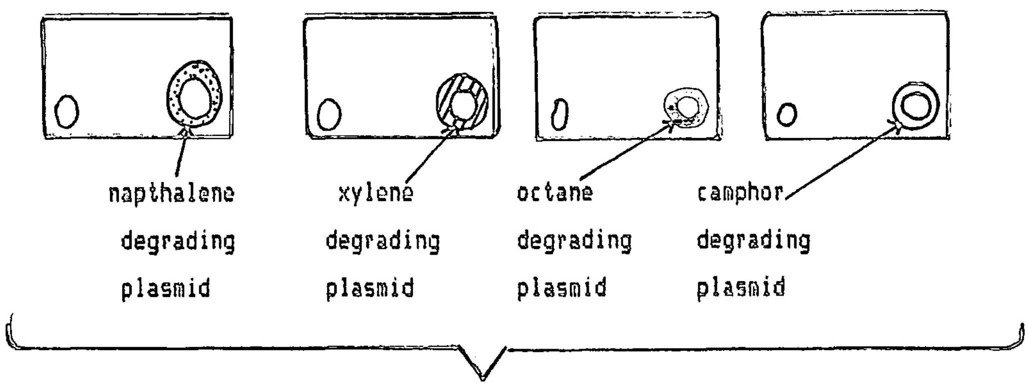
Plastic is a good example of a modern waste which causes long-term disposal problems, owing to its resistance to natural decomposition. However, ICI have now produced a biodegradable thermoplastic-polyhydroxybutyrate, (its trade name is "Biopol") which decomposes at a faster rate than conventional plastics, making it a desirable new packaging material.[133] As Biopol decomposes to form a substance which is a normal mammalian metabolite, it has great potential uses in medicine, eg for sutures, reabsorbable bone plates and microcapsules for controlled drug release. ICI produced Biopol is synthesised by the bacterium Alacaligenes eutrophus which is grown up in fermenters using glucose as a substrate. The ICI plant at Billingham produces 1 000 tonnes of the plastic each year.[134]

Pesticides and herbicides provide further examples of modern wastes which are seriously damaging the environment. Many of the pesticides and herbicides used do not spontaneously decompose and become incorporated into food chains, thus affecting the balance of natural ecosystems. Research into producing (by genetic engineering) new strains of microbes capable of breaking down the complex organic molecules in pesticides and herbicides is being undertaken. British scientists have produced a bacterium capable of detoxifying the pesticide Dalapon.[135]

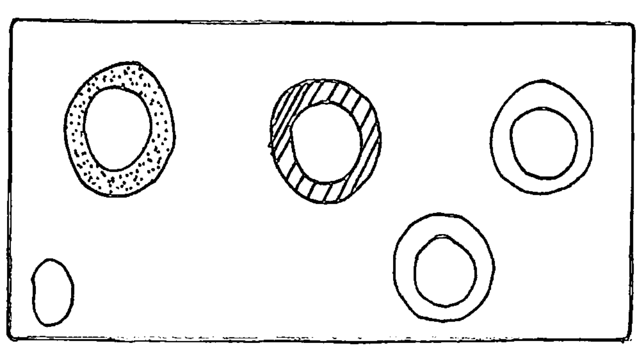
DIAGRAM 4

<u>Diagram to show the Synthesis of a "Superbug" which is Capable of Degrading a wide range of Hydrocarbons.</u>

Naturally occurring strains of <u>Psuedomonad</u> bacteria are shown below:-.
(Each bacterium contains a plasmid giving it the ability to degrade a specific hydrocarbon.)



All the plasmids are combined using cell hybridisation and genetic engineering techniques into one cell forming a "Superbug", shown below.



Synthetic "Superbug" capable of degrading the following hydrocarbons:-napthalene, xylene, octane, and camphor.

Cyanides are used extensively in industrial processes, eg the hardening of iron and steel, electroplating, the manufacture of synthetic dyes, plastics and fibres.[136] The effluent from these industries must be free from the highly toxic cyanides before being discharged into water supplies. ICI, in association with the University of Kent, have produced a product to control cyanide levels in effluents. It involves passing the effluent through a series of vessels which contain the immobilised (fungal) enzyme cyanide hydratase; this enzyme removes the cyanide, allowing cyanide-free effluent to be discharged from the final vessel.[137]

Oil spills form another major modern waste disposal problem. Oil is composed of hydrocarbons which certain species of bacteria in the Genus Pseudomonas can digest. Each species can only degrade a limited range of hydrocarbons. American scientists have created a "superbug" which is capable of degrading a wide range of hydrocarbons eg napthalene, xylene, octane, and camphor. This bacterium has been produced using genetic engineering and cell hybridisation techniques, as shown in Diagram 4, and is expected to, be of significant value in the treatment of oil spills.[138]

Another development in waste treatment technology is to the linking of waste disposal with the production of single cell protein (SCP).[139] In order to achieve this the waste material must be a suitable substrate for the growth of microorganisms. Carbohydrate wastes containing cellulose or starch make particularly good substrates for SCP production.The Symba Process in Sweden uses the starchy waste from a potato processing plant as a substrate for growing yeast cells, which are used as food for chickens, pigs and calves.[140] Similarly in Finland, the Pekilo Plant produces fungal protein using carbohydrate waste such as molasses, cheese whey, sulphite liquor and wood hydrolysates.[141]

The food industry produces much sugar-rich waste. In Britain Bassett's sweet factory near Sheffield has coupled a fermenter to its plant. Yeast converts sugar- rich waste into alcohol and carbon dioxide, which is then bottled and sold as a profit making side-line.[142]

Unfortunately, until recently it has not been possible to utilise the vast amounts of lignocellulose waste produced by the agriculture and forestry industries. However, Swedish scientists have patented a mutant of the wood rotting fungus, Sporotrichum pulverulentum, which is capable of selectively utilising the lignin and leaving the cellulose undamaged. The delignified cellulose then becomes a worthwhile food source for ruminant (cellulose digesting) cattle.[143]

It can be seen from these examples that the Spinks Report is fully justified in stating "biotechnology presents substantial opportunities in the treatment of wastes".[144]

Biotechnological processes and products are therefore very much part of life in the twentieth century and it is believed that "industries based on this new discipline [biotechnology] are poised on the threshold of a rapid expansion".[145] Many British companies, including several well known ones, are involved in producing products using biotechnological processes. For example Imperial Chemical Industries (ICI) produce Pruteen, Rank Hovis McDougall produce Mycoprotein, and Tate and Lyle produce Xanthum Gum used as a thickener in the food industry and the fungal pesticide Vertalec.[146] The Spinks Report is fully justified in stating:-

> "If there is to be a national gain from biotechnology, local authorities, teachers, parents and pupils must be informed of its significance".[147]

It is therefore essential that school pupils are made aware of the scope of biotechnology for two reasons; first to illustrate ways in which scientific knowledge is used by industry and secondly to stimulate interest in this field as a possible future career.

CHAPTER ONE

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CHAPTER TWO

The Development of Biotechnology at British Universities since 1980.

The Spinks Report (1980) states:-

> that expertise must be built up in universities, and that this will best be done by expanding the research and teaching capacity in a limited number of centres of excellence and ensuring their close interaction with industry.[1]

The Government, research councils, universities and industry have acknowledged the need 1) to expand the research and teaching of biotechnology at universities and 2) to promote better liaison between universities and industry.

Two main steps which have been taken since the Spinks Report and which have helped to implement the recommendations above are as follows:

1 Increased funding for biotechnology at British universities.

Before 1981, support for biotechnology came through the existing subject committee boards of the research councils ie the Science Research Council (SRC), the Agricultural Research Council (ARC), the Medical Research Council (MRC), and the National Environment Research Council (NERC). The main areas of biotechnology which were supported were basic fermentation studies, enzyme and protein technology, waste treatment studies and recombinant DNA studies. There was little support for applied biology that was specifically orientated towards the production of industrial products or processes.[2] The Spinks Report recommends that, in order to ensure the support for projects spanning the divide between the research councils, a Joint Committee for Biotechnology consisting of representatives from each research council should be established.[3] (As biotechnology is a multi-disciplinary subject, the Spinks Report regards this step as necessary for the successful development of biotechnology.)

In 1981, the Science and Engineering Council (SERC) established the Biotechnology Directorate. The Directorate acts under the guidance of a Management Committee which includes industrialists eg Dr E Dart, (Head of ICI Corporate Bioscience and Colloids Laboratory), academic scientists, eg Professor G Holt, (Polytechnic of Central London) and a Government representative , Dr R Coleman (Laboratory of the Government Chemist).[4] The Committee develops and implements the strategy for the support of research and training in certain areas of biotechnology.
(Support for applications of biotechnology in agriculture, medicine and environmental studies is funded by the ARC, MRC, and NERC respectively [5].) The Directorate is jointly funded by the Engineering and Science Boards. Its budget has risen, from £1 million in 1981/1982 [6], to a projected £3.8 million for 1986/1987.[7] The Directorate funds biotechnology research through:-

a) Research Studentships, which are three-year Ph.D. courses.
b) Cooperative Awards in Science and Engineering (CASE Awards). These are three-year courses jointly devised, supervised and funded by an academic department and a collaborating body. For instance , Cambridge University's Biotechnology Centre has received a grant for £29,392 (to which ICI has contributed) for research into the use of triazine dyes in the separation of blood proteins.[8]
c) Advanced Course Studentships. These are one-year postgraduate courses. Thirty studentships are supported each year.

The Directorate has defined " priorty areas" of biotechnology which it feels deserve special support. This has been done bearing in mind the findings of the Institute of Manpower Studies report, "Enabling Manpower for Biotechnology" , which envisaged a possible shortage of senior biotechnologists in microbial physiology, biochemical engineering and bioelectronics.[9]

The Directorate's "priority areas", which now receive special support, are: [10]

a) Process engineering, which includes both fermentation technology and "down-stream" processing.
b) Microbial physiology.
c) Large-scale growth of both plant and animal cells. For example, the Wolfson Institute for Biotechnology at Sheffield University has received support for research into opiate- and antitumour-agent production by large-scale cell growth.
d) Plant genetics and plant biochemistry. This is considered a particularly important area of research, because of noted shortage of plant biochemists. The Directorate, in conjuction with the ARC and the Department of Trade and Industry's (DTI) Biochemistry Unit, has pinpointed three main areas of plant biotechnology which need support.
   (i)The use of vectors in plant genetic manipulation.
   (ii)The biochemistry of seed development.
   (iii)Plant pathogenicity and symbiosis.
e) Recombinant DNA Technology. In particular research on gene expression in mammalian cells is to be encouraged.
f) Biocatalysis ie the use of enzymes, immobilised cells or immobilised enzymes, to catalyse reactions. The Directorate is particularly interested in supporting protein engineering. This is the use of genetic engineering techniques to transform bacteria, so that they synthesise proteins which have improved characteristics.

g) Biosensors and bioelectronics. The Directorate's support in this field has doubled during 1985 .[11] Professor B Hartley (Imperial College, London) sees this as a "booming area" of biotechnology. He says "biosensors are the vital link in the automation of chemical production factories".[12]

h) Waste treatment and biodegradation.

Apart from the increase in funding for biotechnology research, the University Grants Committee (UGC) responded to the proposal made in the Spinks Report that new teaching posts should be established in biotechnology. The report suggested that twenty posts should be created between 1980 and 1985.[13] In 1983, the UGC earmarked an annual grant of £850,000 for this purpose.[14]

The Spinks Report showed concern over the exodus, mainly to the United States, of a significant number (approximately 250) of senior biotechnologists from the United Kingdom during the late 1970's.[15] A Manpower Studies report commissioned by the Biotechnology Directorate , entitled "The Biotechnology Brain Drain", shows that the main reasons for this exodus were the paucity of suitable job opportunities , poor management, and a lack of commitment to biotechnology in the United Kingdom.[16] It is the present writer's opinion that both the increase in funding now available for biotechnology and a formalised strategy for biotechnology research which have helped to rectify the situation which led to this exodus. The amount of money now invested in biotechnology research in the United Kingdom is comparable to that in Japan; however, it is less than investment in France or West Germany, and considerably less than investment in the United States.[17] Whilst acknowledging this increase in funds, the Biotechnology Directorate feels that the funds are "inadequate to meet future needs".[18] Dr R Coleman, the Government Chemist, who has special responsibility for the support of Biotechnology on behalf of the DTI, believes that there is no shortage of money available for biotechnology, his view is the need to ensure that, "modest amounts of cash are dispensed judiciously to selected activities."[19] It is the present writer's opinion that universities will need to look to industry for further substantial increases in biotechnology funding.

2 Increased official links between British universities and industry.

The Spinks Report notes that, in 1980, British industry lagged behind other world competitors in its use of academic consultants. Cooperation between industry and British universities was particulary poor in the field of biological sciences.[20] By contrast, in Japan, where biotechnology is now flourishing, "there is no official or conceptual division between basic and applied research ....[and]...there is a continual exchange of skills and services between universities and industry."[21]

Since 1980, liaison between industry and British universities has increased, as a result of encouragement from certain bodies, and in particular, the SERC Biotechnology Directorate. The Directorate, apart from encouraging an increase in CASE Awards (jointly funded and supervised by industry), from three in 1981 to twenty-eight in 1984,[22] has also helped to fund and establish several "Biotechnology Clubs". These clubs involve a variety of private industrial companies subscribing to the organisation with additional funding from the Biotechnology Directorate. Each club is associated with one (or more) universities and the research carried out is of interest to the supporting companies.The first and most publicised "club" to be established was the "Biocentre" at Leicester University.

The Biocentre at Leicester University.

This was opened in September 1982, through funding by Leicester University ,the Wolfson Foundation, SERC and five British Companies (Dalgety Spillers, Gallaher, John Brown Engineers and Constructors, Whitbread, and Distillers). Each company promised £1.5 million to support the running costs of the Centre for the first five years.[23] SERC's Biotechnology Directorate provided a grant of £183,000 to cover the initial cost of equipment.[24] The Centre is run by a Management Committee composed of representatives from Leicester University and from the supporting companies. The committee decides which types of research will be funded and whether the research will be part of its "core research" or will be carried out as "contract research". Professor B Holland, of the Department of Genetics, who helped establish the centre, envisages that the centre will have approximately one hundred staff and an annual budget of £7 million by 1986.[25] The primary objective of the centre is:-

> to develop as a centre of excellence in molecular genetics, with the emphasis initially on the genetic systems of yeasts and higher plants.[26]

In 1985, the Biocentre appointed a new Director to oversee its work, Professor I J Higgins (Professor of Biotechnology at Cranfield Institute of Technology). He acts as joint director of both the Leicester Biocentre and Cranfield's Biotechnology Centre.[27] It is hoped that this association will encourage the exchange of knowledge between Leicester(in the field of genetic manipulation), and Cranfield (in the field of fermentation technology and downstream processing).[28]

Since the opening of the Leicester Biocentre, other clubs have been established at Sheffield, Cambridge and Surrey Universities. In addition, the Institute for Biotechnological Studies, which has no particular geographical location, was established in 1983, through the collaboration of the University of Kent, the Polytechnic of Central London, and University College London.[29] This association enables all three bodies to pool their resources and expertise. The Institute is funded by a consortium of seven companies (including Glaxo, Shell Research, and May and Baker) and a grant from the specially created DTI's Biotechnology Unit. The Institute aims to investigate the extended use of biocatalysts under controlled conditions.[30] In 1985 SERC established its Protein Engineering Club. This is funded by four British Companies (Celltech, Glaxo, ICI, and RTZ/J E Sturge) and the Biotechnology Directorate. The Club's Programme Manager, is Dr R Freedman (Senior Lecturer in Biochemistry at the University of Kent). His role is to coordinate the overall research being undertaken by research groups at the following universities:-Bristol, Leeds, Oxford, York, and Birkbeck College and Imperial College, London. The programme includes investigating commercially interesting enzymes, such as those used in antibiotic production, in biological cleaning agents and in the manufacture of sweeteners.[31]

Apart from the increased liaison between universities and industry which has occurred at postgraduate level as a result of the the rise in the number of CASE studentships and the introduction of "club" activities. Undergraduate courses too have increased the amount of industrial contact offered to students. In particular, The Royal Society report, Biotechnology and Education, supports sandwich courses, where students spend a period of time (usually a year) working in industry.[32] In order to encourage sandwich courses, the Department of Trade and Industry's (DTI) Biotechnology Unit gives financial support to companies which take on students from sandwich courses.[33] Three of the biotechnology-based undergraduate degree courses reviewed later in this chapter offer a sandwich option. They are at Kent[34], Reading[35] and Warwick[36] Universities. The report Biotechnology and

Education recommends that biotechnology should be taught by academic staff with a good understanding and experience of industrial biological processing.[37] Several of the undergraduate biotechnology-based degree courses, reviewed later in this chapter (eg at Leeds and Strathclyde Universities[38,39]) include lectures given by visiting industrialists and visits to local industrial plants.

In view of all the developments which have occurred since 1980 to promote liaison between universities and industry, it could be felt that the criticism made by Mr Durham, (Chairman of Unilever, a company involved in biotechnology research) that, "suspicion of and apathy towards industry still [1984] runs very deep throughout the education system",[40] would be untenable when applied to biotechnology and the universities.

Rapid growth in biotechnology has occurred in universities following the *Spinks Report*, chiefly through increased funding and improved industrial links, and this has enabled universities to improve the training available to potential professional biotechnologists.

Prior to 1980, in order to become a professional biotechnologist, the only route available was to take an undergraduate degree in one of the following disciplines: microbiology, genetics, biochemistry, chemistry, chemical engineering, biochemical engineering, food engineering, civil engineering or control engineering. This was often followed by postgraduate training in biochemical engineering, chemical engineering or brewing science.[41] Since 1980, new courses have been introduced, both at postgraduate and undergraduate levels, designed specifically to meet the needs of a multi-disciplinary subject such as biotechnology. Postgraduate and undergraduate courses will be reviewed separately.

Postgraduate training for biotechnologists.

Three-year Ph D research projects are available in a variety of areas in biotechnology and are funded either through the various research councils mentioned earlier ie MRC, ARC, NERC, SRC, or through the Biotechnology Directorate. The latter supports research in the "priority areas" of biotechnology already mentioned.

In addition, the Directorate funds one-year M Sc courses. Any course must first meet the approval of the Directorate, ie it must provide suitable training for a potential biotechnologist. The Directorate share the view of The Royal Society report Biotechnology and Education, that there is a need only for a small number of advanced courses, and that such courses should not be general courses in biotechnology per se, but should be more specialised and combine practical scientific techniques with industrial project work.[42]

The Directorate requires that these courses should contain a compulsory module of chemical engineering principles and that whereas some should convert chemical engineers into biotechnologists, others should be orientated towards specialised aspects of biotechnology. The following courses have gained support from the Directorate:[43]

1 Birmingham University.-M Sc BiochemicalEngineering/ Biotechnology.
2 University College,London.-M Sc Biochemical Engineering.
3 University College,London.-M Sc Applied Molecular Biology and Biotechnology.
4 University of Manchester,Institute of Science and Technology.-M Sc Bioreactor Systems.

Each M Sc course gains acceptance for an initial three-year period, followed by annual reviews. Continual acceptance is related to the number of graduates who have obtained employment in British industry. (In 1984, eleven of the twelve students who had completed the M Sc in Biochemical Engineering at University College London gained employment in British companies.[44])

The Directorate provides a maximum of thirty Advanced Course Studentships each year. This number is regarded as sufficient to meet the current employment needs of the biotechnology industry.[45] (Both The Royal Society report, Biotechnology and Education[46] and the Manpower Studies report, "Enabling Manpower for Biotechnology"[47], estimate that approximately one hundred biotechnologists will be required each year. (This includes both postgraduate and undergraduate students.)

Undergraduate degree courses available at British universities for potential biotechnologists.

One of the most significant developments to occur since 1980 has been the introduction of undergraduate degree courses specifically entitled "Biotechnology". Although the Spinks Report foresaw the introduction of such courses, it nevertheless recognised that opinion was very divided about their introduction.[48] Indeed, the report Biotechnology and Education states, "we do not see such a necessity for general undergraduate courses in biotechnology."[49] Support for such degree courses is still (1986) very divided.

Professor I J Higgins, Director of the Biotechnology Centre at Cranfield Institute of Technology and the Leicester University Biocentre, states:-

> I personally believe, along with many others, that biotechnology should be taught primarily at postgraduate level, but that appropriate undergraduate courses should contain an element of the subject.[50]

Dr. J. Brown, Admissions Tutor for the Department of Biological Sciences at Warwick University states that:-

> The University Grants Committee have in fact officially disapproved of the launching of the so-called Biotechnology degrees since at degree level no one course can embrace all the disciplines which underpin the biotechnology industry.[51]

The first Biotechnology degree course was introduced at Queen Elizabeth College, London in 1981.[52] (Queen Elizabeth College has since [1985] been incorporated into King's College London). By 1985, an applicant interested in studying biotechnology at a British university would find ten universities listed under the heading "Biotechnology" in the Index of the current UCCA Handbook for that year.[53] These universities and the biotechnology-based courses then available are shown in Table 1. It should be noted that the course titles vary considerably, only four being specifically entitled "Biotechnology".

TABLE I

Undergraduate Degree Courses in Biotechnology available for study commencing October 1985 at British Universities.

(These courses appear under the heading "Biotechnology" in the Index of the UCCA Handbook October 1985 Entry.)

University	Course Title	UCCA Number
The Queen's University of Belfast	B.Sc. Biotechnology	J800 Biot.
Birmingham	B.Sc. Biochemistry with Biotechnology	C7J8 Bioch/Biot.
	B.Sc. Biological Sciences (allowing specialisation in Biotechnology.)	C100 Biol. Sci.
Kent at Canterbury	B.Sc. Microbiology (allowing specialisation in Biotechnology.)	C500 Microbiol.
Leeds	B.Sc. Biotechnology	C624 Biotech.
Imperial College, London	B.Sc. Biotechnology	J800 Biotech.
King's College London	B.Sc. Biotechnology	J800 Biotech.
University College London	B.Sc. Biochemical Engineering	H870 Biochem.Eng.
Reading	B.Sc. Biotechnology	J800 Biotech.
Strathclyde	B.Sc. Applied Microbiology	C510 App.Microb.
	B.Sc. Technology and Business Studies (Technology option in Biotechnology)	HN19 TSB.
Warwick	B.Sc. Microbiology and Microbial Technology (Suitable for applicants interested in biotechnology.)	CC59 Micro.Virol.

In 1981, The Royal Society in Biotechnology and Education was concerned that courses might be introduced entitled "Biotechnology" at centres which had had no previous biotechnological experience and that those courses might not adequately fulfil the requirements of biotechnology.[54] In order to assess the extent to which the degree courses in the UCCA list (Table 1) provide a suitable framework of study for potential professional biotechnologists, a review of their course content is necessary. Information on course content has been taken from the relevant university prospectus. The course content has been compared with the training specifications laid down in Biotechnology and Education, which states:-

> Practising biotechnologists need to be fully conversant with the physical science principles behind process engineering; sensitive to the constraints imposed by the biological system adopted and must be numerate.[55]

To achieve this, the report suggests that irrespective of the route taken by a student to a career in biotechnology, their education must have included elements of the following subjects:- mathematics, microbiology, genetics, and biochemistry.[56]

Comparison of course content of the degree courses in the UCCA list reveals that the Technology and Business Studies degree course at Strathclyde University, even though it has an option in biotechnology, should be classified separately from the others in this list. Unlike the others, it is not a science-based degree course. It provides its students with a background knowledge of science in addition to training them in accountancy, marketing, and economics. The course, therefore enables students to acquire a good insight into the commercial aspects of the biotechnology industry. The Admissions Tutor for this course states that it was introduced "to provide biotechnology based industries with widely educated generalists who could "speak the language of biotechnologists".[57] It is intended that graduates from this course will enter management training; the course does not aim to produce biotechnology-scientists ie not bench scientists.

In contrast, all the other degree courses in the UCCA list are science-based courses. However, one of these, in the present writer's opinion does not appear to contain sufficient microbiology/genetics/biochemistry content to qualify as providing a suitable framework of study for potential biotechnologists. This is the Biological Sciences degree course at Birmingham University. It is a broad-based biological science course which promotes biotechnology awareness. (It should be noted that there are many other degree courses, both at universities and polytechnics, which help to promote biotechnology awareness. Indeed, forty such courses were noted in 1981 in Biotechnology and Education, and it is probable that the number has increased since then).[58]

The remaining ten degree courses from the UCCA list shall be referred to collectively as "biotechnology-based" degree courses in this thesis, irrespective of the individual course titles. Information from the relevant university prospectuses suggest that these courses are intended to provide a suitable training for future biotechnology-scientists.

The Biotechnology degree course at The Queen's University of Belfast was withdrawn before October 1985. Professor P F D'Arcy, the Dean of the Science Faculty there, states that "a Diploma/M.Sc. Course in Biotechnology is being offered in preference to an undergraduate course, but a Biotechnology undergraduate course might be introduced in the future."[59] It would be of interest to investigate the reasoning behind this decision.

Introduction of the biotechnology-based degree courses.

Of the nine biotechnology-based degree courses available for study in October 1985, it is those which have the word "biotechnology" in their title which give the impression of being new courses.(ie introduced since 1980.) All four Biotechnology degree courses (Leeds, King's College and Imperial College, London and Reading Universities) have evolved at universities where biotechnology was developing naturally, in departments of biology, biochemistry, microbiology, and chemical engineering. For example, the course at Reading was introduced to complement the course in Food Technology, while that at Leeds evolved in response to a perceived specific need from industry.[60] In fact, although the Biotechnology degree course at Imperial College, London was first registered as such in 1985, Dr P G Mantle, the Admissions Tutor, points out that, "we in effect have been teaching biotechnology for the last twenty years."[61] It is, therefore, apparent that these courses have certainly not merely been introduced following an upsurge of enthusiasm,- an anxiety expressed in the Spinks Report[62]

Course content of the biotechnology-based degree courses.

Although all nine courses are science-based and have several common features, each course has its own particular blend of subjects available for study in the final year. These reflect the research interests of the particular university.

The Biochemical Engineering degree course at University College London has a completely different overall emphasis from the other nine, as it has a much higher engineering component. The course was introduced in 1972, in response to a perceived need to train engineers who were familiar with aspects of both biochemistry and engineering.[63] The Institution of Chemical Engineers and the Council of

Engineering Institutions accredited the course in 1978. Professor P Dunnill, at University College, views this professional qualification as an important aid in later career development.[64] He regards biochemical engineering as the common factor which links together the wide diversity in the study of biological product production. He says the principles of biochemical engineering apply to the production of antibiotics, spirits, enzymes, silage, and waste water treatment.[65] In 1985, the course admitted fifteen students, though Dr M Hoare, the Admissions Tutor, envisages this number as increasing to twenty in future years.[66] The Spinks Report (1980) notes:-

> an increasing shortage of adequately trained biochemical engineers.....Few university departments specialise in producing chemical engineers with any experience of handling biological processes and materials.[67]

In 1985, there were still only two universities offering Biochemical Engineering degree courses. (University College London, and Swansea University.[68]) However, in 1986, Surrey University is offering a four year MEng degree course in Process Engineering.[69]

The course at University College is composed of units. In the first year, students study biochemistry, engineering fundamentals, computing and mathematics. The second year includes lectures from industrialists and further courses in mathematics, process engineering, and biochemistry. The third year includes lectures on molecular biology, genetics, and chemical engineering. Lectures are complemented by practical studies, which include pilot plant experiments. A complete week is spent in the pilot plant in the third year. This enables students to gain first hand experience of all the stages in a large scale process. A major project is undertaken by small teams, a) to design a plant producing some biological product and b) to assess its economic feasibility. In recent years, plants have been designed to produce penicillin, protein hydrolysates, fructose enriched glucose, and human serum albumen.

University College offers an optional fourth-year course. This provides additional experience in biochemical process design and product evaluation to students wishing to continue their studies. The selection of students for this course is not based on academic ability, but on their future career choices.

All the other biotechnology-based degree courses have a high biological-science content rather than engineering content. All are three-year courses, except the course at Strathclyde University which, like other Scottish degree courses, is a four-year course for students who enter from a background of the Scottish Certificate of Education at Higher Level. Applicants offering Advanced Levels at entry proceed directly into the second year of the course. The Biotechnology degree course at Reading University is also a four-year course, with students spenting their third year working in a biotechnology-based industry.

All these degree courses provide in their first year an introduction to subjects such as biochemistry and microbiology and courses in physical and organic chemistry and mathematics. Thus students, from a variety of Science Advanced Level backgrounds are all given the opportunity to cover the necessary foundation upon which the more specialised subjects studied in years two, and three can be built. At most of these universities, the first year course is common to a number of different degree disciplines, thus allowing a certain amount of transfer between disciplines up to the end of the first year. For example, at Leeds University the first year course in Biotechnology is closely related to the degree courses in Biochemistry, Genetics and Microbiology. At Imperial College, London, there is a common first year course for all Life Sciences students, including Biotechnology degree course students.

The second year of the biotechnology-based courses includes more specialised aspects of biochemistry and microbiology; for example, courses in enzymology, microbial genetics, molecular biology, bioenergetics and microbial physiology. There are some variations within this core of topics; for example, chemistry is studied in the second year at Warwick University, while Kent University offers a computing course and Leeds University includes a course on plant design and product recovery in the second year. The Biotechnology degree course at King's College London has an optional course on plant biochemistry available in the second year. This appears to be the only biotechnology-based degree course to include a course on plant biotechnology. (A degree course entitled Plant Biochemistry has been introduced at King's College London for October 1986.)[70] In the second year of the Biotechnology degree course at Reading University, there are courses on industrial management and principles of chemical engineering, in addition to the other core subjects.

It is in the third year that variations in course emphasis between the different biotechnology-based degree courses becomes more apparent. Most of these courses in their final (third) year offer a core of the following topics:- microbial genetics, genetic engineering, applied protein chemistry, industrial biochemistry, applied biotechnology, and fermentation technology. At Leeds University the third year includes courses in the manipulation of plant cells, immobilised enzymes and immobilised cells, the use of structural data in drug design , photochemical energy conversion, and photosynthetic biomass production. The Biotechology course at King's College London has courses in food processing and biotechnology diagnostics in its final year. Reading University continues its course on industrial management into its final (fourth) year. At Warwick University, students in Microbiology and Microbial Technology attend a series of lectures ,given by visiting industrialists on the economics and ethics of the biotechnology industry.

This course includes visits to local biotechnology-based industries.

Assessment of the biotechnology-based degree courses.

The specifications laid down in Biotechnology and Education[71] (previously mentioned on page 56) have been taken as a means of assessment when reviewing the extent to which the biotechnology-based degree courses provide a suitable framework of study for future professional biotechnologists. Judging from information in the relevant prospectuses, all these courses appear to provide a good grounding in microbiology, biochemistry, and mathematics. (A requirement expressed in Biotechnology and Education.)[72] The precise balance between these subjects varies slightly at the different universities. For example, the Biochemistry and Biotechnology course at Birmingham University and the Biotechnology course at Imperial College, London, have a high biochemistry input. In contrast the courses at Kent, Reading, and Warwick Universities appear to have a higher content of microbiology.

In addition, The Royal Society in Biotechnology and Education, specified that, "practising biotechnologists should be familiar with the principles of process engineering."[73] The Biochemical Engineering course at University College London, fulfills this requirement in addition to giving students an insight into biochemistry and developing their mathematical ability. The other biotechnology-based degree courses also include an introduction to engineering principles, though to a lesser extent than the course at University College London. This is achieved through studying the production of various biotechnological products. For example, at Birmingham University there are lectures on fermentation technology given in the final year of the Biochemistry with

Biotechnology degree course. Similarly, at Kent University the Microbiology course contains lectures on industrial fermentations and on applications of biological catalysts. In the final year of the Microbial Technology degree course at Warwick University, there are lectures on the techniques and problems of growing microorganisms on an industrial scale. Most of these courses on engineering principles occur in the final year of the courses; however, both Reading and Leeds Universities have seen fit to introduce courses on chemical engineering principles and plant design/ product recovery, respectively, in the second year.

Furthermore, The Royal Society looked to both higher education and industry to tackle the problem of ensuring adequate industrial and commercial appreciation in students destined for biotechnology. In Biotechnology and Education, The Royal Society recommended that this can be achieved through the following:-[74]

1 An increase in the number of sandwich courses.
2 The appointment of staff with first-hand knowledge of industrial biological processing.
3 Lectures being given by visiting industrialists.
4 Visits being made to local biotechnology companies.

In respect of these recommendations, while Reading University's Biotechnology degree course is the only one to include a whole compulsory year spent working in industry for all its students, all the other biotechnology-based courses do contain industrial links, demonstrated mainly through lectures being given by visiting industrialists.

Kent and Warwick Universities do offer a sandwich option to a small percentage of their students. Industrial experience is also encouraged at both King's College and University College London, where students are expected to spend their summer vacations working in industry. The Government cutbacks in expenditure which have occurred since 1981, have reduced the availability of sandwich courses in all subjects.[75] Thus, although it is educationally desirable to increase the number of sandwich course options available in biotechnology-based degree courses, this measure is not feasible at present owing to financial constraints. Bearing this factor in mind, all the biotechnology-based degree courses do provide students with an insight into the biotechnology industry. The course at Reading University stands apart as it is unique in offering a course in industrial management in both the second and final year.

The Royal Society [76] feared that the new courses specifically entitled Biotechnology might not provide students with sufficient skills and expertise to enter careers in production and development. It is difficult to assess if this is so without surveying the opinion of industry. However, the course content of all these biotechnology-based degree courses, appears to provide potential professional biotechnologists with all the requirements specified by The Royal Society. In particular, the courses entitled Biotechnology do not appear significantly diluted or different from the other biotechnology-based degree courses.

The Biotechnology degree course title controversy.

The main difference between the biotechnology-based degree courses appears to reside in their title, rather than in their content. In 1981, The Royal Society feared that popular demand might encourage existing courses to change their name in order to appear more attractive, irrespective of their course content.[77] In fact, Dr W F R Pover, the Admissions Tutor at Birmingham University, states that, "when other universities named courses with biotechnology in their titles we followed."[78] Dr P G Mantle, Admissions Tutor at Imperial College, London, states that the Biotechnology degree course there is synonymous with a degree in Biochemistry. He says that, "undergraduate Biotechnology courses have been launched more for political expediency than for academic need." [79]

It is most unfortunate that the degree course title Biotechnology has evoked such strong criticism, which, in the present writer's opinion, is ill-founded and may have a detrimental effect on these courses. Both academics and industrialists appear reluctant to acknowledge these courses. Professor J Smith, (Department of Bioscience at Strathclyde University) is strongly opposed to undergraduate courses in Biotechnology. He states that, "most so-called Biotechnology courses are Applied Microbiology plus a little engineering and some Business Studies." [80] Dr K Hardy, Head of the Microbiology and Cell Biology Division of Biogen, the Swiss biotechnology company, shares this view. He says, "I am not sure that a sound Biotechnology course could differ much from one in Microbiology, except in name."[81] The present writer thinks that although this may be true, if the course content meets the needs of professional biotechnologists, the course should be given recognition, irrespective of its title.

It is particularly disappointing if ignorance of course content deters industrialists from employing Biotechnology degree course graduates. Dr J H Hay, Research Manager of the Food Group Research Department of the Distillers Company, (a company supporting the Leicester University Biocentre), states:-

> It is our view that graduates with a first degree in Microbiology, Biochemistry, or Chemical Engineering, and a higher degree in Biotechnology eg M.Sc. , would probably be looked upon with more favour by prospective employers than graduates with a first degree in the, as yet evolving subject of biotechnology.[82]

This reluctance by industry to acknowledge Biotechnology degree courses has in turn influenced student opinion. Dr P G Mantle, states that at Imperial College, London, "some of our students would prefer to graduate in Biochemistry rather than Biotechnology."[83] Although it is beyond the scope of this thesis, it would be of interest to compare the employment prospects of Biotechnology graduates with other biotechnology-based degree course graduates over several years.

It was suggested in 1981 in Biotechnology and Education[84] that a system of accreditation should be introduced in the United Kingdom in order to give formal recognition to courses providing an adequate basis for entry into biotechnology careers. The present writer regards this measure as now (1986) essential. Unless the Biotechnology degree courses available at universities are recognised as worthy by both academics and industry, they will be undervalued, and may ironically contribute little to the development of biotechnology.

CHAPTER TWO

ENDNOTES

I. Spinks Report, p. 25.

2. Science and Engineering Research Council (hereafter referred to as SERC) Biotechnology Directorate, Report for the Year Ended 31 August 1982, Swindon 1982, p. 3.

3. Spinks Report, p. 37.

4. SERC Biotechnology Directorate, Biobulletin:The Newsletter ofSERC's Biotechnology Directorate, Vol.1. No.1., Swindon 1984, p. 3.

5. Idem., Directory of research in biotechnology, Swindon 1982, p .1.

6. Idem., Report for Year Ended 31 August 1982, p .3.

7. Idem., Biobulletin, Vol.2. No.1., Swindon 1984, p.7.

8. Idem., Biobulletin, Vol.1. No.2., Swindon 1984, p.6.

9. Institute of Manpower Studies, Enabling Manpower for Biotechnology, quoted in SERC Biotechnology Directorate, Biobulletin, Vol.1. No.1., Swindon 1984, p. 5.

10. SERC Biotechnology Directorate, Biobulletin, Vol.1. No.2., Swindon 1984, p. 3.

11. Idem., Biobulletin, Vol.2. No.1., Swindon 1985, p. 7.

12. British Broadcasting Company Radio 4, Science Now, Jan.27, 1986.

13. Spinks Report, p. 41.

14. Jon Turney, "University scramble for new talent", The Times Higher Educational Supplement, London, Jan.21, 1983.

15. Spinks Report, p .23.

16. Institute of Manpower Studies, The Biotechnology Brain Drain, quoted in SERC BIotechnology Directorate, Biobulletin, Vol.1. No.1., Swindon 1984, p. 5.

17. Ronald Coleman, "The elements of a possible Boom", New Scientist, Feb.9, 1984, p. 29.

18. SERC Biotechnology Directorate, Biobulletin, Vol.2. No.1., Swindon 1985, p. 7.

19. David Fishlock, "No shortage of Financial Support", The Financial Times, London, May 3, 1983, p. 28.

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CHAPTER THREE

The Expectations of University Admission Tutors when Selecting Applicants for Biotechnology-based Degree Courses

A questionnaire entitled "Biotechnology Courses at British Universities" was sent to the Admissions Tutor of every biotechnology-based degree course available for study commencing October, 1985. (These are shown in Table 2) The questionnaire aimed to investigate the entry requirements for these courses, the selection proceedure and the expectations of Admissions Tutors when selecting applicants. In addition, Admission Tutors were asked to comment on the present Advanced Level background of candidates, specifying where necessary how this could be improved to fit the needs of their course.

The Questionnaire "Biotechnology Courses at British Universities."

This questionnaire shall be referred to in both this text and end notes as the "Questionnaire". A copy of the "Questionnaire" which was sent to Admissions Tutors is shown in Appendix One, at the back of this thesis. (Note:-The working title of this thesis at the time of sending the "Questionnaire" was "Biotechnology and its Place at Ordinary and Advanced Level in the School Science Curriculum").

The "Questionnaire" was divided into two parts. Part One dealt with factual information relating to the particular undergraduate degree course. For example, when and why it was introduced, the number of places on the course for 1985 entry, the total number of applicants, entry requirements and selection proceedure before conditional offers are made.

TABLE 2

To show the Admissions Tutors of Biochemistry-based Degree Courses who replied to the questionnaire 'Biotechnology Courses at British Universities' (July 1985)

University	Biotechnology-based degree course title and UCCA code	Admissions Tutor
Birmingham	B Sc Biochemistry with Biotechnology (J800 Biot)	Dr W F R Pover
Kent at Canterbury	B Sc Microbiology (C758 Bioch/Biot)	Dr R B Freedman
Leeds	B Sc Biotechnology (C624 Biotech)	Dr I W Halliburton
Imperial College, London	B Sc Biotechnology (J800 Biotech)	Dr P G Mantle
King's College London	B Sc Biotechnology (J800 Biotech)	Dr M Bazin
University College London	B Sc Biochemical Engineering (H870 Biochem Eng)	Dr M Hoare
Reading	B Sc Biotechnology (J800 Biotech)	Prof D L Pyle
Strathclyde	B Sc Applied Microbiology (C510 App Microbiol)	Prof J Smith
Warwick	B Sc Microbiology and Microbial Technology (C59 Micro Virol)	Dr J Brown

This section included a question ("Questionnaire" Part One, Question 13) which asked which qualities universities regarded as important when selecting candidates, either at interview or from the UCCA report. Part Two of the "Questionnaire" asked for the views and opinions of Admission Tutors as to whether the present Advanced Level background of the majority of candidates could be improved and, if so, how. Particular reference was made to Advanced Level Biology courses. This part of the "Questionnaire" included free response as well as structured questions.

The response to the "Questionnaire" was good. All the universities which received a copy replied. (Shown in Table 2.) The majority of the replies received contained very detailed and full answers to many of the questions, and several supplied additional information.

In view of the lengthy responses and the willingness on the part of Admissions Tutors to supply information, it was felt that universities valued this opportunity to discuss these issues and to give their opinions. Especially valued was the chance to say how the Advanced Level background of students could be improved. Professor D Pyle, from Reading University, expressed particular interest in the "Questionnaire", stating that, "I look forward to seeing the results of your work - it should be very useful to all of us".[1]

Although 100% of the universities which received a "Questionnaire "replied, the sample size is so small (nine universities) that this precludes any valid statistical analysis being carried out on the data received. However, the data do reveal certain trends in the views of Admissions Tutors.

Analysis of the replies to the "Questionnaire" is based according to the type of question asked, depending on whether it is factual or opinion seeking.

All the information in this chapter has been taken from the replies to the "Questionnaire". Only specific quotations have been given references in the end notes, though all the replies are listed in the bibliography.

Entry requirements and selection procedures for biotechnology-based degree course applicants.

Table 3 shows the number of places available on the biotechnology-based degree courses commencing in October 1985, the total number of applicants and the ratio of male:female applicants. Although the number of places varies slightly from one university to another, the average number of places is eighteen. Most Admissions Tutors do not expect this number to increase in the near future, although those at King's College London[2], University College London[3], and Reading University[4] envisage a slight increase in places over the next few years. Despite the introduction of some new biotechnology-based degree courses (King's College London, Leeds and Reading Universities) since 1980, when the Spinks Report noted a shortage of adequately trained biochemical engineers and individuals skilled in microbial genetics and molecular biology[5], the small number of graduates produced in Britain who are qualified to enter the fast developing field of biotechnology is still (1986) of major concern. Professor B S Hartley, Director of Imperial College's, Centre for Biotechnology, and a member of the Spinks Report Committee on a recent radio programme (1.2.86.) expressed deep concern that, in comparison to other countries, the United Kingdom was producing far fewer graduates who could enter the biotechnology industry than for example Japan which produces ten times as many as the United Kingdom.[6] This concern is not shared by SERC's Biotechnology Directorate, who consider that a sufficient number of graduates is being trained to meet industrial needs.[7] However, as no substantial increase in the number of places on the biotechnology-based degree courses is envisaged, this situation will remain unchanged for the foreseeable future.

Competition for places on the biotechnology-based degree courses also varies, as is shown in Table 3. Although the number of applicants for the different courses differ, (280 for Strathclyde University's course, in contrast to 64 for Reading University's course), it appears that the longer established courses, for example at Strathclyde and Kent Universities, have a greater number of applicants than some of the more recently introduced courses for example at Reading University. It would be of interest to know whether this difference will continue in subsequent years, and also whether there will be a difference in the number of applicants for degree courses specifically entitled "Biotechnology" as opposed to the other biotechnology-based degree courses.

All the universities required that candidates took three Advanced Levels, with Chemistry Advanced Level being regarded as essential. The other two Advanced Levels were chosen from Physics, Biology and Mathematics. (Shown in Table 4)

Strathclyde University in the main receives applications from Scottish applicants offering Scottish Highers, five being the required number for entry. English, Chemistry, and Mathematics are essential and either Physics or Biology. Candidates offering Advanced Levels when applying to Strathclyde University are expected to have Advanced Level Chemistry and Advanced Level Mathematics.

TABLE 3

To show the number of applicants for Biotechnology-based Degree Courses at British Universities, commencing in October 1985

University	B Sc Course Title	Total Number of Applicants	Number of Places Available	Ratio of Applicants: Places	Ratio of Male:Femal Applicants
Birmingham	Biochemistry with Biotechnology	74	20	4:1	2:1
Kent at Canterbury	Microbiology	168	20	8:1	1:1
Leeds	Biotechnology	110	10	11:1	3:1
Imperial College, London	Biotechnology	87	10	9:1	Data not received
King's College London	Biotechnology	Data not received	20	-	-
University College London	Biochemical Engineering	100	15	7:1	3:2
Reading	Biotechnology	64	20	3:1	2:1
Strathclyde	Applied Microbiology	280	18	15:1	1:1
Warwick	Microbiology and Microbial Technology	Data not received	30	-	-

NOTE: Source of data - Replies from University Admissions Tutors to the Questionnaire 'Biotechnology Courses at British Universities'

TABLE 4

To show the Entry Requirements for a Biotechnology-based Degree Course at a British University (Courses commencing October 1985)

University (B Sc Course title)	Preferred 'A' level subjects Number	Subjects	Essential 'A' level subject	Acceptable alternatives to 'A' level Biology
Birmingham (Biochemistry with Biotechnology)	3	Chemistry plus 2 from Maths/Biology/ Physics	Chemistry	Botany, Human Biology, Zoology
Kent at Canterbury (Microbiology)	3	Chemistry plus 2 from Biology/Maths/ Physics	Chemistry	Botany, Zoology
Leeds (Biotechnology)	3	Chemistry plus 2 from Maths or Science based	Chemistry	Botany, Human Biology, Zoology
Imperial College, London (Biotechnology)	3	Chemistry plus 2 from Biology/Maths/Physics	Chemistry	Botany, Human Biology, Zoology
King's College London (Biotechnology)	3	Maths, Physics Chemistry	Chemistry	Botany, Social Biology, Human Biology Environmental Science
University College London (Biochemical Engineering)	3	3 from Physics/Maths/ Chemistry/Biology	Chemistry	None
Reading (Biotechnology)	3	3 from Physics/Maths/ Chemistry/Biology	Chemistry	Human Biology Environmental Science
Strathclyde (Applied Microbiology)	5 Scottish Highers	English/Chemistry/ Maths/Biology/Physics or 'A' level Chemistry and Maths (B Grade)	Not applicable	Not applicable
Warwick (Microbiology and Microbial Technology)	3	3 from Physics/Maths/ Chemistry/Biology	Chemistry	Botany, Human Biology, Env Sci, Zoology

NOTE: Source of Information - Replies to Questionnaire 'Biotechnology at British Universities'

TABLE 5

To show Selection Procedure at British Universities offering Biotechnology-based Degree Courses

University (Course Title)	Majority of Candidates Interviewed	Percentage of Candidates Interviewed	Average Offer ('A' level grades)
Birmingham (Biochemistry with Biotechnology)	Yes	76-100%	B-B-C
Kent at Canterbury (Microbiology)	No	51-75%	B-C-C
Leeds (Biotechnology)	No	26-50%	B-C-C
Imperial College, London (Biotechnology)	No	1-25%	B-C-C or B-B-C (B in Chemistry)
King's College London (Biotechnology)	Yes	76-100%	B-C-C
University College London (Biochemical Engineering)	Yes	76-100%	C-C-C or B-C-C
Reading (Biotechnology)	No	1-25%	Minimum offer: C-D-D
Strathclyde (Applied Microbiology)	No	1-25%	Highers: Chem and Maths B 2 other Bs, 1 C
Warwick (Microbiology and Microbial Technology)	Yes	51-75%	B-C-C or C-C-C

NOTE:

1 Source of Information - Replies to the Questionnaire 'Biotechnology Courses at British Universities' (July 1985).

2 Abbreviations Used:

A = Advanced
Chem = Chemistry
Maths = Mathematics

The conditional offers made to successful applicants vary only slightly from one university to another, as is shown in Table 5. The average offer is B-C-C at Advanced Level.

For the courses overall, almost 100% of applicants applied through UCCA. However, at Kent University, 10% of applicants applied directly.[8]

Although the majority of universities showed no particular preference as to whether candidates entered university directly after school, or had spent time in Industry, Dr W Pover, the Admissions Tutor at Birmingham University states a strong preference for candidates to enter university directly from school. He says :-

> the so called maturing process enables students to forget the chemistry they need for the course, to become less malleable and slower to learn the mass of factual material we have to present in the first two years.[9]

By contrast, Professor J Smith at Strathclyde University[10] favours candidates who have spent time in industry, because of their maturity. Dr M Hoare Admissions Tutor at University College London[11] is also in favour of candidates having either industrial experience or pursuing an activity between school and university.

The replies to the "Questionnaire" showed that the method of selecting applicants also varied between universities. Birmingham, Kent, King's College London, University College London, and Warwick Universities interviewed the majority of their applicants before making conditional offers. However, Imperial College, London, and Reading Universities rarely interviewed applicants but used the UCCA Form, which includes a headmaster's report, as their sole source of information.

Qualities which Admissions Tutors regard as important in biotechnology-based degree course applicants.

In Part One, Question 13 of the "Questionnaire" , Admissions Tutors were asked to select from a list of suggested qualities the ones which they regarded as important when selecting applicants, either at the interview or from the the UCCA report. Table 6 shows the replies to this question. Admissions Tutors were given the opportunity of specifying any additional qualities which they regarded as being important but which were not shown in the list.

All but one of the replies gave no additional qualities, which suggests that the list included most, if not all, the qualities which were looked for in candidates. The exception, however, was University College London, which required applicants to have "an awareness of engineering and the importance of ultimately achieving a professional status for practise in industry".[12] This was not surprising as the Biochemical Engineering degree course at University College has industrial recognition. The main trends which emerge from the replies are as follows:-

1 Candidates were expected to have high/average Advanced Level grades predicted.
2 A responsible attitude to work was seen as important by the majority of universities.
3 Candidates were expected to be able to assess experimental results critically.
4 The ability to communicate scientific issues verbally was seen as important by all the universities. This was interesting, as it even included those universities who do not interview the majority of their applicants. eg Reading and Strathclyde Universities.
5 The majority of universities expected candidates to have some knowledge of what biotechnology involves, both factual knowledge and some idea of industrial involvement in

biotechnology. Birmingham University regarded this as being very important.

Only four out of the nine universities regarded good manual dexterity as a favourable quality and, in fact, Leeds University did not mention this at all. In view of the fact that biotechnology-based degree courses include practical work using microbiological techniques (including recombinant DNA techniques), the present writer is surprised that not more universities specified this skill.

Similarly surprising were the replies that "an awareness of current world events" was not seen as necessary by Leeds University and King's College London. As biotechnology is such a broadly based subject, linked to many different kinds of industries, and is being developed world-wide, it was expected that all universities would require candidates to be aquainted with a variety of topics.

TABLE 6

Table to show which Qualities Admissions Tutors regarded as important when Selecting Applicants for Biotechnology-based Degree Courses

Quality	Degree of Importance			
	Very Important	Favourable	Indifferent	Not Required
a High 'A' level grades predicted	B K L KC S	I UC R		
b Average 'A' level grades predicted	R	B K UC S	I	KC
c Positions of responsibility held	B I UC R S		L KC	
d Candidate able to relate well to other students	UC	L I R S	B	KC
e Candidate able to relate well to staff		B L I UC R S	K	KC
f Candidate having a responsible attitude to work	B K I UC R	L S		KC
g Candidate has good manual dexterity		B I KC S	K UC R	L
h Candidate can assess experimental results critically	K KC	B L I UC R S		
i Ability to relate socially in a positive manner to the interviewer	UC	B L I R S	KC	
j Awareness of world current events		B I UC S	R	L KC
k Interested in a wide range of scientific issues	K	B I KC UC R S		L
l Ability to communicate scientific issues verbally	B UC R S	K L I KC		
m Familiar with factual knowledge from 'A' level courses	S	K UC	B I KC	

Table 6 continued.

Table to show which Qualities Admissions Tutors regarded as important when Selecting Applicants for Biotechnology-based Degree Courses

Quality	Degree of Importance			
	Very Important	Favourable	Indifferent	Not Required
n Familiar with factual knowledge of what Biotechnology involves	B	I KC UC R S	K	
o Awareness of the industrial involvement in Biotechnology	B	B K I KC UC R S		

NOTE:

1 Source of Information - Replies to the Questionnaire 'Biotechnology Courses at British Universities' (July 1985).

2 Abbreviations Used -

A = Advanced
B = Birmingham University
K = Kent University
L = Leeds University
I = Imperial College, London
KC = King's College London
R = Reading University
S = Strathclyde University
UC = University College London
W = Warwick University

Views of Admissions Tutors' on the contribution made by present Advanced Level Science Courses towards preparing students for following a biotechnology-based degree course.

Admissions Tutors were asked to state how important different Advanced Level Science courses were in providing a basis for studying their university's course. ("Questionnaire" Part Two, Question 1.) Table 7 shows the replies to this question. The following main points arise from the replies:-

1 The acquisition of "essential factual information ".
All the universities regarded Advanced Level Chemistry as providing the essential factual information upon which their course could be built. This was not surprising as this is the only Advanced Level which is an essential requirement for entry at all the universities. Advanced Level Biology, Physics, and Mathematics were all seen to provide some factual information useful to the course; however, opinion was divided on the extent to which these Advanced Levels contributed useful information.

2 The acquisition of " sound scientific reasoning skills". This includes the ability to assess experimental results critically.
Advanced Level Mathematics was regarded almost universally as being of very great value in developing sound scientific/reasoning skills. In general Advanced Level Biology, Physics and Chemistry were regarded as being of lesser value. However. it was slightly surprising that none of the universities specified Advanced level Mathematics as an entry requirement.

3 Training in " good manual dexterity ".
Chemistry, Biology and Physics Advanced Levels were regarded as developing " good manual dexterity" to varying extents. However, this was not of prior concern to Admissions Tutors when selecting applicants.

4 Development of "accurate observational skills".

Advanced Level Chemistry and Biology were regarded as being of considerable value in developing accurate observational skills; this was particularly so for Advanced Level Biology, suggesting that Biology is still regarded as chiefly a descriptive science, a point noted in Biotechnology and Education.[13]

5 Ability to cope with the mathematical content of the degree course.

All the universities regarded Advanced Level Mathematics as being of considerable value in enabling candidates to cope adequately wilh the mathematical content of the course. This again supports the argument that Advanced Level Mathematics should be made an entry requirement. By contrast, Advanced Level Biology was seen by four out of the eight universities as being of no value in preparation for the mathematical content of the course. Advanced Level Chemistry and Physics were thought to contain some mathematical content.

In summary, the Admissions Tutors felt that Advanced Level Chemistry provides a large corpus of factual information upon which the biotechnology-based degree courses can be built. Whilst Advanced Level Mathematics provides not only mathematical skills of direct use to these courses, but also develops sound reasoning skills, a valued feature.

TABLE 7

To show Admissions Tutors' Views on the Contribution made by Present 'A' Level Science Courses towards Preparing Students for Studying a Biotechnology-based Degree Course at University

	'A' level	0 (of no value)	1 (of some comparatively small value)	2 (of considerable value)	3 (of very great value)
a In providing the essential factual information upon which your course can be built	Chemistry				KC K IC
	Biology		L B KC	R K IC	UC S R LB
	Physics		L B KC K	R IC	UC S
	Maths		KC K	R B IC	UC S L
b In developing the sound scientific/ logical reasoning skills required for your course	Chemistry		KC	R K	IC UC S L B
	Biology		L KC K	R B	UC S IC
	Physics		L KC	R K	UC S B IC
	Maths			R	KC K IC UC S L B
c In developing good manual dexterity	Chemistry		UC R B	S L KC	K IC
	Biology		UC R B KC	S L	K IC
	Physics		UC R B KC	S L	IC
	Maths	IC UC B KC K	R	S	
d In developing accurate observational skills	Chemistry		KC	B UC S R L	K IC
	Biology			B KC UC R L	S R IC
	Physics		L KC	B S R K	UC IC
	Maths	L B KC K	IC	S R	UC
e In ensuring the candidate is able to cope with the mathematical content of the course	Chemistry	UC	L KC K IC	S R B	
	Biology	UC L KC K	B IC	S R	
	Physics		L B IC	UC KC K	S R
	Maths			B IC	KC K UC S R L

NOTE:

1 Source of Information - Replies to the Questionnaire 'Biotechnology Courses at British Universities' (July 1985).

2 Abbreviations Used - A = Advanced, Maths = Mathematics
B = Birmingham University, K = Kent University, L = Leeds University, IC = Imperial College, London,
KC = King's College London, R = Reading University,
S = Strathclyde University, UC = University College, London, W = Warwick University

The Advanced Level background of the majority of biotechnology-based degree course candidates.

The universities expect all candidates for biotechnology-based degree courses to have taken Advanced Level Chemistry, and two other Science Advanced Levels generally chosen from Biology, Physics and Mathematics.

In response to the question , "Do you feel the present Advanced Level background of the majority of candidates could be improved?", six out of the nine universities replied "yes". The responses to this question are shown in Table 8. The replies revealed certain distinct trends. For example, five out of the six universities requested that candidates should be more conversant with applied mathematics. University College London especially stated that all candidates not taking Advanced Level Mathematics should be required to take "OA" Level Mathematics.

Both Reading and Kent Universities expressed a wish for a broader sixth-form curriculum. With the introduction of Advanced Supplementary (AS) Levels in 1989, this may become possible. "AS" Levels will be discussed in more detail in Chapter Five.

University College London, wished that Biology courses in general contained a " greater content of biochemistry of high rigour".

Birmingham University wished that candidates were more familiar with applied mathematics involving biochemical examples. Since seven out of the nine universities wished to see Advanced Level Biology courses becoming more physico-chemically orientated, it is possible that an increase in the biochemical content of most Advanced Level Biology courses would help fulfil several of these requirements. This measure would provide an area in the syllabus into which some applied mathematical examples could be introduced. It would also rectify the situation noted by several of the universities that Advanced Level Biology courses provided little if any mathematical content upon which their degree courses could be built.

Leeds University wished that candidates had better English. The ability to "communicate scientific issues verbally" was regarded as an important quality when selecting applicants. As none of the present Advanced Level Science courses tests articulation, and written examinations contain an almost negligible proportion of marks for expression, it would appear difficult for universities to assess these qualities in an applicant unless this is done at interview. (Leeds University does not interview the majority of of its applicants'[4].) Improvement in the standard of written and oral English may be achieved through the broadening of the sixth-form curriculum after the introduction of "AS" Levels.

Imperial College, London wished that candidates had a more "consistent understanding of the fundamental principles of chemistry, biology and physics". Gaps in the fundamental knowledge in candidates might be due either to differences between the syllabuses of the various Examination Boards, or due to variation in the teaching of the syllabus. Although this point was raised by only one university , it is felt that this comment is very significant and would warrant further investigation. It may be that other university Science Departments would support this request to standardise the content taught in Science Advanced Level courses. The introduction of a core syllabus common to all Examination Boards should alleviate this problem.

TABLE 8

To show the Views of Admissions Tutors of Biotechnology-based Degree Courses at British Universities as to whether the Advanced Level Background of Candidates could be improved, and if so, how?

University and B Sc Course Title	Replies to the above question	Suggestions made as to how the 'A' level background could be improved
Birmingham (Biochemistry with Biotechnology)	Yes	a More Applied Mathematics especially using Biochemical examples b More practical work in schools
Kent at Canterbury (Microbiology)	Yes	A broader Sixth Form syllabus
Leeds (Biotechnology)	Yes	Better English and Mathematics
Imperial College, London (Biotechnology)	Yes	a By providing consistent understanding of the fundamental principles of Chemistry, Biology & Physics b More Applied Mathematics
King's College London (Biotechnology)	Yes	More Applied Mathematics
University College London (Biochemical Engineering)	Yes	a By ensuring Biology courses contain a greater content of Biochemistry of high rigour b By ensuring that all candidates not taking 'A' level Maths are required to take 'OA' level Mathematics
Reading (Biotechnology)	No	Short of a wider 'A' level spectrum spectrum which would be beneficial
Strathclyde (Applied Microbiology)	No opinion	-
Warwick (Microbiology and Microbial Technology)	No opinion	-

NOTE:

1 Source of Information - Replies to Questionnaire 'Biotechnology Courses at British Universities' (July 1985).
2 Abbreviations Used - A = Advanced, OA = Ordinary Advanced

Admissions Tutors' views on the biotechnology content of present Advanced Level Science courses.

The universities appeared to lack consensus as to whether or not they would like to see an increase in the amount of biotechnology in Advanced Level Science courses. Table 9 shows the replies to this question. Those universities which did want to see an increase in the biotechnology content of Advanced Level Science courses wished this to be done on the theoretical rather than practical side, and wished the increase to be made in Biology, Physics and Chemistry Advanced Level courses. In particular, it was the universities offering degree courses specifically entitled "Biotechnology " which favoured such an increase.

Three universities (Leeds, King's College London, and Reading) wished to see an increase in the biotechnology content of Advanced Level Biology courses. Irrespective of whether universities would like to see an increase in the biotechnology being taught at Advanced Level, all universities were asked how they would like to see the biotechnology content of Advanced Level Biology courses represented in the syllabus. Six out of the nine universities wanted it as an optional topic, while two wanted it as part of a common core which all students would take.

TABLE 9

The Extent to which Biotechnology should be present in the Sixth Form Science Curriculum in the opinion of Admissions Tutors of Biotechnology-based Degree Courses

	In favour of an increased amount of Biotechnology in the 'A' level syllabuses			Favouring inclusion of Biotechnology in 'A' level Biology syllabus as			In favour of an 'AS' level in Biotechnolog
University	Chem	Biol	Phy	Common Core	Optional Topic	No Pref	
Birmingham	x	x	x	-	-	-	No
Kent at Canterbury	-	-	-				-
Leeds	x		x				-
Imperial College, London	x	x	x				No
King's College, London							Yes
University College, London		x					No
Reading							No
Strathclyde	-	-	-				No
Warwick	-	-	-				No

NOTE:

1 Source of Information - Replies to the Questionnaire 'Biotechnology at British Universities' (July 1985)

2 Abbreviations Used - A = Advanced, AS = Advanced Supplementary, Biol = Biology, Chem = Chemistry, Phy = Physics

TABLE 10

To show which Biotechnological Topics Admissions Tutors would like included in 'A' level Biology Syllabuses

Topic	To be included					Indifferent	Not to be included	
	5	4	3	2	1	0	-1	-2
a Diversity of bacteria (including useful and harmful)	UC	L	B R IC IC KC		S			
b Structure, size and reproduction of viruses	UC		B IC R	L	S			
c Growth of bacteria eg yeast in liquid media	UC	KC	B IC R		S	L		
d Principles of traditional fermentations eg beer	UC	L	B KC	R S	IC			
e Fundamental principles of genetic engineering	UC	KC	R	L S IC				B
f Examples of industrial genetically engineered products in UK		L	KC	R	S IC	UC		B
g Fundamental principles of monoclonal antibody production			KC	R	S L IC			B UC
h Involvement in UK of industry in antibody production			KC	R	S IC	L		B UC

TABLE 10 (continued)

Topic	To be included					Indifferent	Not to be included	
	5	4	3	2	1	0	-1	-2
i Concept of single cell protein		L	R KC		S B IC			UC
j Tissue culture techniques in general			KC	R	S	L	IC	B UC
k Degradation of waste products by bacteria		L UC R KC		S	IC			B
l Industrial use of enzymes		UC R	KC L		IC S			B

NOTE:

Source of information: Replies to the questionnaire 'Biotechnology Courses at British Universities'. (July 1985)

Abbreviations Used: A = Advanced; B = University of Birmingham; IC = Imperial College, London; K = University of Kent at Canterbury; KC = King's College, London; L = Leeds University; R = Reading University; S = Strathclyde University; UC = University College London; W = Warwick University

The biotechnology topics which Admissions Tutors would like to see present in Advanced Level Biology courses.

The report "Biotechnology and Education" states that elements of biotechnology should be present in all biology courses in order to ensure adequate biotechnological awareness.[15] It was therefore of interest to ask Admissions Tutors of biotechnology-based degree courses which aspects they would like to see included.

A list of twelve different biotechnology topics was given, and Admissions Tutors were asked to state whether they would want each topic to be included in a syllabus. ("Questionnaire" Part Two, Question 8.) In order to gauge the strength of their opinion, they were asked to indicate the importance of a topic's inclusion by circling the appropriate number on an eight point scale, 5 representing inclusion being very important, 0 representing indifference in opinion and -2 representing that the topic should not be included.

The replies (shown in Table 10) reveal certain trends. For example, the majority of universities which replied to this question seven out of the nine), were in favour of including most of the twelve topics. All the universities were in favour of including topics a, b, c, and d. These topics could be classified as "traditional biotechnology". Similarly, topic k, (Degradation of waste products by bacteria) could also be classified as "traditional biotechnology"; and the majority of the universities (the exception being Birmingham University) wished this topic also to be present in Advanced Level Biology syllabuses.

In contrast to these more traditional topics, the list included some more recently discovered techniques, which could be thought of as "new biotechnology" eg genetic engineering, monoclonal antibody production, single cell protein production, tissue culture techniques, and the industrial use of enzymes. The response to the inclusion of these topics varied. In general, most universities thought these should be present in Biology syllabuses. In particular, there was strong support for the inclusion of "fundamental principles of genetic engineering", especially from University College London, and King's College London. They both expressed a wish that this would be part of a common core, and therefore studied by all Advanced Level Biology students, whether or not they continued to study a biotechnology-based science at university.

It was interesting that although University College London wanted the principles of genetic engineering to be taught at Advanced Level, it was less insistent that their application also be taught. This was also the case with several other universities, eg Imperial College, London, Reading and Strathclyde. By contrast, Leeds University strongly supported the inclusion of examples rather than the teaching of principles alone.

In general, most universities wanted the inclusion of monoclonal antibody production, though this was less well favoured than the inclusion of genetic engineering principles. There was much less support for the inclusion of tissue culture techniques into the syllabuses, with the majority of universities feeling indifferent to or definitely not wanting its inclusion.

By contrast, six out of the seven universities favoured inclusion of "the use of industrial enzymes". These included University College London, and King's College London, which wanted this topic to be part of a common core.

It should be noted that the reply from Birmingham University differed in many respects from the other replies. Although Birmingham wished to see the inclusion of many of the "traditional topics", in general they were strongly opposed to the inclusion of any of the "new biotechnology" topics. Out of the universities which offer degree courses entitled Biotechnology (ie Imperial College, London, King's College London, Leeds and Reading Universities), all except Imperial College, London, strongly supported the inclusion of most of the "new biotechnology" topics. Reading and Leeds Universities wanted these to be part of an optional topic in an Advanced Level Biology syllabus. Imperial College, London, stated that it would like these topics to be included as an optional part of the syllabus, but it was less committed to this measure than Leeds and Reading Universities. The difference in opinions may be linked to the fact that the course at Imperial College, London, although entitled "Biotechnology", in fact contains a high proportion of biochemistry, whereas the courses at Leeds, Reading and King's College London are specifically committed to the teaching of biotechnology.

University College London, strongly supported the inclusion of "traditional biotechnology" topics into Advanced Level Biology syllabuses as part of a common core. It also favoured the inclusion of some "new biotechnology" topics eg "the industrial use of enzymes" and "the principles of genetic engineering". As University College had stated that it did not wish to see an increase in the biotechnology content of Advanced Level Biology syllabuses, one assumes that University College believe these topics to be represented in current Advanced Level Biology syllabuses.

To summarise, the topics which received a good measure of support from most Admissions Tutors for representation in Advanced Level Biology syllabuses are:-

1 Diversity of bacteria (including useful and harmful).
2 Structure, size and reproduction of viruses.
3 Growth of bacteria in liquid media.
4 Principles of traditional fermentations, eg beer.
5 Fundamental principles of genetic engineering, and a few examples of products.
6 Degradation of waste products by bacteria.
7 Industrial use of enzymes.

The present writer feels that universities do not want Advanced Level syllabuses to become too specialised through the inclusion of many examples of modern biotechnology. However they do want schools to cover the basic principles of traditional biotechnology. There may also be a tendency for universities to want to introduce new biotechnology themselves to students; instead of the introduction coming from teachers, who may not be specialised in the field. The present writer feels strongly that teachers of Advanced Level Biology should be able to incorporate aspects of modern biotechnology into their teaching in a manner which is appropriate to their students' abilities.

CHAPTER THREE

ENDNOTES

1. MS., Reply to "Questionnaire", Professor D L Pyle, Department of Food Technology, University of Reading, Jan. 14, 1986.

2. MS., Reply to "Questionnaire", Dr M Bazin, Faculty of Biological Sciences, King's College London, University of London, July 1985.

3. MS., Reply to "Questionnaire", Dr M Hoare, Department of Chemical and Biochemical Engineering, University College, University of London, Aug. 1985.

4. MS., Reply to "Questionnaire", Professor D L Pyle.

5. <u>Spinks Report</u>, p. 25.

6. British Broadcasting Corporation, Radio 4, <u>Science Now</u>, Jan.27, 1986.

7. SERC Biotechnology Directorate, <u>Biobulletin</u>, Vol.I. No.I., Swindon 1984, p.5.

8. MS., Reply to "Questionnaire", Dr R B Freedman, Faculty of Natural Sciences, University of Kent at Canterbury, Aug. 1985.

9. MS., Reply to "Questionnaire", Dr W F R Pover, Faculty of Science and Engineering, University of Birmingham, July 1985.

10. MS., Reply to "Questionnaire", Professor J Smith, Department of Bioscience and Biotechnology, University of Strathclyde, July 1985.

11. MS., Reply to "Questionnaire", Dr M Hoare.

12. <u>Ibid.</u>

13. <u>Biotechnology and Education</u>, p. 11.

14. MS., Reply to "Questionnaire", Dr I W Halliburton, Department of Microbiology, Leeds University, July 1985.

15. <u>Biotechnology and Education</u>, p. 10.

CHAPTER FOUR

The Biotechnology content of current (1986) Advanced Level and Ordinary Level Science syllabuses, and the Correlation between Syllabus Content and University Expectations

The Department of Education and Science states in "The School Curriculum" (1981), that "examination syllabuses are not intended to be teaching syllabuses".[1] However, "The Finniston Report" notes that :-

> The tenor and content of what is taught to children in schools is to a large extent established by the examination syllabi for the main curriculum subjects.[2]

Therefore, even if not intended, there appears to be a definite link between syllabuc content and what is taught.

The Royal Society report Biotechnology and Education in 1981 recommended that, in order to ensure that biotechnological awareness was part of the science curriculum, the following two criteria should be implemented:-

> (i) that elements of biotechnology were always included as one aspect of biology and
> (ii) that some reference to process engineering with biological materials was one criterion for an acceptable chemistry syllabus.[3]

In order to assess to what extent biotechnology is being taught in present (1986) Advanced Level and Ordinary Level Science courses, a review of all present science syllabuses with a biological/chemical content was undertaken.

TABLE 11

To show GCE Ordinary Level Course Syllabuses (1986) with a Chemistry and/or Biology content, which have been reviewed for their Biotechnology content

Examination Board	Course Title	Pages in Published Syllabus	Code of Course (if present)
Joint Matriculation Board	Chemistry	373-380	
	Biology	426-430	
	Rural Biology (Agriculture)	453-455	
	Rural Biology (Horticulture)	455-456	
	Physical Science	486-490	
	Science	490-497	
	Technical Science	497-503	
	Environmental Science	503-509	
Northern Ireland General Certificate of Education Examinations Board	General Science	146-152	
	Chemistry	195-202	
	Biology	211-214	
	Human Biology	231-236	
Oxford & Cambridge Schools Examination Board	Chemistry	234-238	5620
	Physics with Chemistry	239-242	5630
	Combined Science (Course I and II)	243-262	5640/41
	General Science	263-268	5660
	Biology	269-275	5680
Scottish Examining Board	Agricultural Science	31-32	
	Horticultural Science	33-34	
	Anatomy, Physiology and Health	36-40	
	Biology	44-54	
	Chemistry	74-81	
	Engineering	88-93	
Southern Universities' Joint Board for School Examinations	General Science	65-67	5003
	Human Biology	67-69	5099
	Biology	70-74	5093
	Chemistry	85-87	5073
The Associated Examining Board	Biology	319-325	006
	Chemistry	334-345	014
	Environmental Science	363-367	078
	General Science	371-380	032
	Human Biology	393-399	043
	Engineering Science	507-509	059

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TABLE 11 (continued)

Examination Board	Course Title	Pages in Published Syllabus	Code of Course (if present)
University of Cambridge Local Examinations Syndicate	Chemistry	6-16	5070
	Environmental Science	7-16	5015
	Science (Physics/Chem)	19-30	5124
	Science (Physics/Biol)	19-34	5125
	Science (Chem/Biology)	19-34	5126
	Science & Integrated Science	19-34	5127/28
	Combined Science	19-34	5129
	Agricultural Science	7-13	5033
	Biology	33-40	5090
	Human & Social Biology	59-68	5098
University of London	Biology	83-89	040
	Botany	103-107	060
	Human Biology	113-118	320
	Chemistry	133-147	081
	Engineering Science	233-238	150
	Environmental Studies	267-270	135
	Integrated Science	497-504	200
	Physics with Chemistry	505-524	551
University of Oxford Delegacy of Local Examinations	Environmental Studies	40-41	2875
	Chemistry	57-59	5855
	Chemistry	59-63	5856
	Botany	79	5860
	Biology	79-84	5862
	Human Biology	84-87	5863
	Biology with Physics	91-93	5856
	Chemistry with Biology	92-95	5869
	General Science	96-99	5871
	General Science (pre-nursing syllabus)	99-103	5872
	Agricultural Science	103-105	5873
Welsh Joint Education Committee	Biology I (Common Syllabus GCE/CSE existing syllabus)	8-10	0102
	Biology II (Common Syllabus GCE/CSE revised syllabus)	11-17	0102
	Human Biology	18-19	0127
	Rural Biology	22-23	0143
	Chemistry	34-37	0105
	Physical Science	57-59	0141
	General Science	60-63	0117
	Engineering Science	74-75	0113

The biotechnology content of Ordinary Level Science courses

All the 1986 Ordinary Level Science syllabuses which have a biological and/or chemical content and which were reviewed are shown in Table 11. There is a wide range of Science courses available at this level. They can be classified as :-

1 Single-discipline Science courses, eg physics, chemistry and biology.
2 Combined (united) Science courses which, in the main, lead to one Ordinary Level certificate and are composed of elements of two science disciplines, eg physics and chemistry or chemistry and biology.
3 General Science courses which lead to one Ordinary Level certificate but contain elements of all three scientific disciplines.

In the main, because of the entry requirements of universities, pupils applying for biotechnology-based degree courses will have studied Single-discipline Science courses at Ordinary Level. The majority will have taken all three science Ordinary Levels as separate subjects ie physics, chemistry and biology. (A few candidates may have taken Physical Science Ordinary Level and a Biological Science Ordinary Level only). The study of General Science courses only at Ordinary Level, does not meet the entry requirements of the university biotechnology-based degree courses. These Ordinary Level qualifications are therefore not suitable for future potential biotechnology-based degree course applicants. In any case, they are generally taken by students wishing to continue their science education up to Ordinary Level, but not beyond.

Perhaps the most significant finding while reviewing the Ordinary Level syllabuses is that the word "biotechnology" itself does not appear. These syllabuses were all published in 1984, three years after the recommendations made in Biotechnology and Education.[4] However, although no direct reference as such is made to biotechnology, every Ordinary Level syllabus contains examples which could be classified as biotechnology or, as is more often the case, the syllabus contains topics which could be extended (by the teacher) to incorporate biotechnological examples.

For example, most Chemistry syllabuses include work on "nitrogen" and refer to "nitrogenous fertilizers". This topic could be extended to include the nitrogen cycle and to reveal the importance of chemical reactions carried out by microorganisms. The introduction of biotechnology into a syllabus through the extention of existing topics relies entirely on the teacher's interpretation of the syllabus and his/her willingness and competence to recognise where biotechnology can be introduced.

It was found that General Science courses were much better designed to facilitate the incorporation of some biotechnology than were the other Ordinary Level courses. This was so for two reasons. First, these courses are designed in an integrated style, mixing together biological, physical and chemical topics, and thus facilitating the inclusion of a multidisciplinary subject such as biotechnology. Secondly, all these syllabuses were very clearly written, with precise instructions, thus ensuring no misinterpretation of the syllabus. Such clearly written syllabuses help to ensure uniformity in what is taught.

Clarity of expression in these General Science syllabuses may stem from the fact that teachers involved in these courses will in the main have specialised in one science only during their education and training, and Examination Boards have recognised a need, when writing these syllabuses, for greater detail than is usual in most Single Science syllabuses.

Most General Science syllabuses include reference to both the harmful and useful activities of microorganisms, and therefore provide students with a more balanced view of microbes than is found in some Single Science syllabuses, .eg Northern Ireland Examination Board's Ordinary Level Biology syllabus.[5]

The London Board Integrated Science course is worthy of special mention, as it has made a very positive effort to include a wide range of biotechnological processes in its syllabus, as shown below:-

> Section 2. The Behaviour of Matter.
> ....The role of catalysts in Industry (eg Haber process). Enzymes as biological catalysts. The importance of a correct range of acidity and temperature for the functioning of enzymes......
> Chemical reactions brought about by a) microorganisms, in breaking down of large molecules of waste matter to simpler ones, eg sewage treatment, compost, b) alcoholic fermentation in wine and beer making, c) yoghurt making. The production of antibiotics as illustrated by penicillin.
> The microorganism should be considered as a bag of enzymes, some of the enzymes being kept inside the bag and others released from it. [6]

This section uses the applications of science as a vehicle for introducing the underlying scientific principles, eg the use of biotechnological examples to illustrate the properties of enzymes and their use to man.

In contrast, to the General Science courses the Combined Science courses contain fewer biotechnological examples. In particular the courses entitled Physical Science or Physics with Chemistry or Science (Physics, Chemistry) have no biotechnology content. These courses are not written in an integrated manner but contain two distinct sections of chemistry and physics. This format in a syllabus does not facilitate the insertion of transdisciplinary material.

In addition, in order to constitute one Ordinary Level certificate, each of the two sections has a much reduced content, which would be subsequently difficult to extend to include some biotechnology.

Most of the Single Science Ordinary Level Biology and Chemistry courses include areas of the syllabus which could be readily modified to include biotechnological examples. However, in general, there are only a few examples of biotechnology actually cited. Such examples tend to be found in Biological Science rather than in Chemistry syllabuses. It is particularly disappointing that, although many Chemistry syllabuses express the desire to show how "chemists seek ways of converting natural raw materials into desirable and useful products"[7] they often fail to include any biotechnological examples. The Scottish Examination Board states in its Ordinary Level Chemistry syllabus that pupils should "gain some appreciation of the part science has to play in the world economy".[8] The development of the biotechnology industry is coupled to world economy. For example, the production of gasohol (an alcohol substitute for petrol) in Brasil, Pruteen (biomass) production in the United Kingdom and the developing use of enzymes as industrial catalysts are all processes which have been developed for economic reasons and which could be used to illustrate the role of science in today's world economy.

Furthermore, it is disappointing that none of the chemistry syllabuses or those entitled Engineering Science [9,10,11], include any reference to "process engineering with biological materials" , a recommendation made in Biotechnology and Education.[12]

It is the microbiology content of most Single Science Ordinary Level Biology syllabuses which provide an area of the syllabus where biotechnology is either already present, or could be introduced. The microbiology content of the different syllabuses varies considerably. For some it may "amount to as little as 5-10% of the total biology syllabus content."[13] In others, for example the Human Biology Ordinary Level syllabus of the London Board,[14] there is an entire section (approximately a third of the syllabus) entitled "Man's Place in Nature", which is chiefly microbiology and includes man's use of microbes.

Most "pure" Biology syllabuses include reference to microorganisms under sections on "The Range of Living Organisms" ; generally, a bacterium, a fungus and a virus are studied. The bacterium and virus are often cited in conjunction with the spread of disease and the spoilage of food, without any reference to their positive uses to man. Although some Boards refer to the role of fungi as decomposers , none of the "pure" Biology syllabuses refers to antibiotic production by fungi, or to man's use of fungi as food. Pupils studying a "pure" Biology Ordinary Level course may acquire an unbalanced view of microorganisms, unless the opportunities which are available in syllabuses to reveal the usefulness of microbes are identified and explored.

The London Board Ordinary Level Biology syllabus does state the need for "candidates to recognise the social and economic implications of biology."[15] According to the Spinks Report's definition of biotechnology, (the application of biological organisms, systems or processes to manufacturing industry"[16], biotechnology should be part of any biology syllabus if it is to fulfil the aim stated by the London Board.

In contrast, to the "pure" Biology syllabuses, Human Biology syllabuses in general have a larger section on microbiology, often located under sections on "Environmental Health". Several of these syllabuses, whilst concentrating on the harmful effects of bacteria, also include examples of useful bacteria used in sewage treatment, and in antibiotic production. The University of Oxford syllabus[17] specifies that a practical demonstration to show the antibiotic action on bacteria should be included, as does the revised Biology GCE/CSE syllabus of the Welsh Joint Education Committee.[18] This is particularly significant, as few syllabuses (an exception being the Scottish Examination Board) give details of any practical work which should be included. Without clear indication in syllabuses that practical microbiology is intended as part of the course, much of the biotechnology which is present will be done theoretically. The London Board's Human Biology syllabus[19] even specifies that a visit to a water and a sewage works is an integral part of the course.

Most Botany Ordinary Level syllabuses contain no biotechnology, although the London Board syllabus states that:-

> The importance of bacteria to man should include useful activities as well as a simple treatment of pathogenic examples. [20]

Regrettably, this invitation to introduce some biotechnology does not present itself in any of the Environmental Science or Agricultural Science syllabuses. These concentrate rather on microbial diseases in cattle and plants and fail to mention the use of tissue culture techniques as a means of propagation or the use of microbial insecticides.

To conclude this review of Ordinary Level Science syllabuses, it is the General Science courses which at present contain the most biotechnology. Single Science Biology and Chemistry Ordinary Level courses contain very few, if any, examples of biotechnology, but areas of the syllabus could easily be extended or modified to incorporate more biotechnology. Thus, candidates applying to study a biotechnology-based degree course, having studied three separate sciences at Ordinary Level, will, in general, have had very little opportunity to meet any biotechnology during their Ordinary Level courses.

Criticism of the current Ordinary Level Science syllabuses

It should be realised that it is while studying science courses between the ages of fourteen and eighteen that students ought to have the opportunity to be made aware of biotechnology and the possible career opportunities it offers.

Current (1976-1986) Ordinary Level Science syllabuses have been criticised for being overloaded with content, promoting the learning and recall of facts at the expense of the understanding and application of concepts, [21] and for failing to incorporate more recent concepts and technological developments. [22]

Therefore, if biotechnology is to be represented in Ordinary Level Science courses, examination boards must ensure that it is clearly specified in syllabuses. The Biotechnology Subcommittee of the Association for Science Education (ASE) has recently stated that:-

> ....perhaps examination boards should give more guidance to teachers as to how examples of elements of biotechnology could fit into or be developed from typical cores of any biology, chemistry, or science syllabus. [23]

The Royal Society report Biotechnology and Education, notes that "average teachers will need support to persuade and help them to teach towards the interests of biotechnology".[24] Indeed, the ASE Biotechnology Subcommittee has endorsed this statement, and has suggested ways in which aspects of biotechnology could be effectively introduced into the cores of most existing science courses for fourteen to eighteen year olds, by ensuring that existing and proposed syllabus topics, from different subject areas, are exploited to the full.[25]

It is thought that these suggestions made by the ASE Biotechnology Subcommittee could be of great value to many teachers when planning the incorporation of biotechnology into future science courses, particularly to teachers who have not specialised in microbiology or biotechnology and who may find it difficult to spot the opportunities available for its introduction. In fact, the ASE Biotechnology Subcommittee has said that:-

> to be totally realistic (however), only if questions related to biotechnology are included on examination papers will reference be made to biotechnology in many of our schools. [26]

Future 16+ Science syllabuses and their biotechnology content

School Science syllabuses are being reformed at the time of writing this thesis and it should be noted that, at present, the Examination Groups are preparing the General Certificate of Secondary Education (GCSE) syllabuses for approval by the Secondary Education Council. Therefore, in order to predict the biotechnology content of future GCSE Science courses the National Criteria for Science, Chemistry, Physics, and Biology, upon which the syllabuses are based have been reviewed.

In the National Criteria for Science it states that courses should enable students to appreciate the applications of science in everyday life. To ensure that this is implemented it proposes that:-

> at least 15 percent of the total marks are to be allocated to assessment(s) relating to technological applications and social and economic and environmental issues, which should pervade all parts of the examination, the greatest emphasis being given to technological applications. [27]

This measure encourages the incorporation of the new technologies, eg biotechnology, in future science courses. The Chemistry GCSE courses are to be composed of a core of material representing a minimum of sixty six percent of the total marks. [28] This core includes a section entitled "Social, economic, environmental and technological applications of chemistry".[29] The section includes several areas where biotechnological examples could be introduced, eg making the most of the world's resources, pollution control, food supply and energy resources.

Future GCSE Biology courses are similarly composed of a core of material, comprising a minimum of sixty-six percent of the course.[30] The National Criteria state that the content of the core must be:-

> related, as appropriate to the personal, social, economic and technological implications of the subject matter. Due attention must be paid to these matters in any assessment scheme.[31]

This suggests that future GCSE Biology courses will all include some biotechnology. It would therefore appear that future GCSE courses in Biology and Chemistry will contain more biotechnology than the present Ordinary Level Single Science syllabuses.

The biotechnology content of Advanced Level Biology courses

As the majority of Biotechnology-based degree course applicants will have had little, or no, opportunity to become acquainted with biotechnology during their Ordinary Level courses, it is of interest to review current (1986) Advanced Level Science syllabuses for their biotechnology content. The report Biotechnology and Education [32] states that despite the expansion of Advanced Level syllabuses in Physics, Chemistry. and Biology, many syllabuses do not emphasise current areas of research eg biotechnology. The report recognises that:-

> due to the regrettable barrier to engineering which exists in the UK , approaches to encourage some pupils into biotechnology may have to come mostly through biology and chemistry. [33]

However, the report foresaw a particular problem with school biology, as it has "stemmed largely from a descriptive science with the emphasis on structure rather than on the processes carried out by living organisms." [34] It is the present writer's opinion that this view of modern biology courses (especially at Advanced Level) is out-dated and biotechnology can be successfully introduced to modern biology courses.

The report Biotechnology and Education states that:-

> At present (1981) new and significant scientific and commercial developments in microbiology, biochemistry, antibiotic production, genetic engineering, etc may readily escape pupils' attention. It remains possible to pass A-Level biology without learning anything of microbiology and its applications. [35]

In view of this last statement it was decided when reviewing syllabuses for their biotechnology content to concentrate on Advanced Level Biology courses, and to compare their biotechnology content with the expectations and wishes of Admissions Tutors of the Biotechnology-based degree courses.

Table 12 lists all the Advanced Level Biological Science courses which are available for study in the United Kingdom, with examinations being held in June 1986, and which are reviewed. This includes the Scottish Examination Board's Higher Grade Certificate in Biology.

The most surprising finding was that out of the twenty different syllabuses (all written three years after the report Biotechnology and Education) the word biotechnology appears only twice- in Cambridge Examination Board's Biology [36] and Social Biology[37] Advanced Level syllabuses.

Several of the Examination Boards (Cambridge, Northern Ireland, Oxford and Cambridge, and Southern Universities Joint Board) have incorporated the GCE Examining Board's agreed "common core" into their Advanced Level Biology syllabuses. This core comprises approximately sixty percent of the course, and is designed to be "a suitable preparation for university and polytechnic courses in Biology". [38]

Although there is no direct reference to biotechnology in the core, it does state that "many topics in the syllabus have significance for the social, environmental and economic implications of Biology" [39], and that these applied aspects should be referred to throughout the teaching of the syllabus. In addition, it states that these implications, including technological applications of modern biology, should be tested in any form of assessment. [40] This implies that aspects of biotechnology should be present in the teaching of any syllabus which has adopted this common core.

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TABLE 12

To show Advanced Level Courses Syllabuses (1986) in Biological Science, which have been reviewed for their Biotechnology content

Examination Board	Course Title	Pages in Published Syllabus	Code of Course (if present)
Joint Matriculation Board	Biology	430-448	
Northern Ireland General Certificate of Education Examinations Board	Biology	222-236	
Oxford & Cambridge Schools Examination Board	Botany	100-107	9860
	Zoology	108-121	9285
	Biology	122-132	9672
Southern Universities Joint Board for School Examinations	Biology	74-83	9267
The Associated Examining Board	Biology	325-333	607/677
	Human Biology	399-410	642
University of Cambridge Local Examinations Syndicate	Biology	83-103	9260
	Social Biology	104-122	9265
	Zoology	123-135	9285
	Botany	136-148	9860
University of London	Biology	94-102	040
	Botany	107-112	060
	Zoology	123-132	650
University of Oxford Delegacy of Local Examinations	Botany	230-237	9860
	Zoology	237-248	9285
	Biology	248-254	9862
Welsh Joint Education Committee	Biology	2-7	0006
Scottish Examining Board *	Agricultural Science	32-33	
	Horticultural Science	34-35	
	Anatomy, Physiology & Health	36-40	
	Biology	54-64	

* The Scottish Examining Board Courses are 'Higher Grade' courses, not Advanced Level courses

The majority of the syllabuses (irrespective of whether they have adopted the common core) are composed of compulsory material only. However, two Advanced Level Biology syllabuses (Joint Matriculation Board[41], and Welsh Joint Education Committee[42]) do offer optional topics in addition to the main material. Both these courses include options which contain a significant amount of biotechnology. Option 5 of the Welsh Joint Education Committee's Advanced Level Biology syllabus is entitled "Medical and Industrial Biology" which occupies six weeks teaching time, and which includes examples of both harmful and useful microorganisms. It is slightly disappointing that this clearly written syllabus does not include some more recent examples of biotechnology, eg insulin production by bacteria, interferon production, or bacterial proteolytic enzyme production for use in washing powders.

The Joint Matriculation Board Advanced Level Biology syllabus offers, out of a choice of nine options, one entitled "Microorganisms". This option occupies approximately twenty percent of the total syllabus teaching time. (This is substantially more than any other syllabus gives to the study of microbiology.) This option includes man's use of microbes, with the emphasis being on the more traditional forms of biotechnology. However, this Board allows Centres to submit their own options for the Board's approval so that it is theoretically possible for a teacher with a keen interest in biotechnology to submit an option which contains some more recent biotechnology. It should be noted that, although these options enable pupils who study them a greater opportunity to become familiar with some biotechnology or applied microbiology than is afforded by other Boards, pupils who have not studied these options have very little opportunity to become acquainted with any biotechnology in the remaining compulsory material. This problem has been noted in Biotechnology and Education, which favoured the incorporation of some biotechnology as an examinable and compulsory element of Advanced Level courses,[43] thus ensuring general awareness of biotechnology.

This view is in contrast to the wishes of most of the Biotechnology-based degree course Admissions Tutors. Six out of the eight who replied, wished biotechnology to be present as an optional topic in Advanced Level Biology courses. (Table 9 in Chapter Three shows their responses.) This was felt to be a surprising preference, as the incorporation of biotechnology as purely an optional topic automatically reduces the number of Advanced Level Biology students who will be made aware of biotechnology, unless a significant number of teachers choose such options.

At present, the only Board to include a significant amount of biotechnology in its core (compulsory) material is the Southern Universities Joint Board Advanced Level Biology syllabus.[44] It contains a fully comprehensible section entitled "Applications of Biology". This section is particularly well balanced, including traditional forms of biotechnology, eg the production of fermented milk products and of beverages and the treatment of sewage, as well as some recent biotechnology. (eg microbes as food including single cell protein, with named examples of bacteria, yeasts, microfungi, algae, and fat-forming fungi.) The use of biological alternatives to fossil fuels is also mentioned, as is the biological treatment of industrial and agricultural waste which could lead to useful end-products. This syllabus therefore gives all students the opportunity to study not only the pathogenic nature of microbes, but also their uses in today's society.

In general, most other syllabuses refer to microbes throughout their syllabus under a variety of topic headings. Some of these references can be classified as biotechnology though they are mainly examples of traditional biotechnology eg antibiotic production. (Antibiotic production is present in the following Advanced Level syllabuses :-Human Biology [45] [Associated Examining Board], Zoology[46] [Cambridge Board], and Biology[47] [Oxford and Cambridge Board]).

Most Biological Science syllabuses include a brief study of microbes under the section on "diversity of organisms". This generally includes a comparison of prokaryotic and eukaryotic cell structure and a short review of bacterial nutrition and reproduction. While this is an example of microbiology, it cannot be classified as biotechnology as it does not include man's use of microbes. However, Cambridge Board's Biology syllabus has extended this section, as follows:-

> Kingdom Monera - a brief review of bacteria with reference to their various modes of nutrition and applications in biotechnology. [48]

Cambridge Board therefore assumes that the reader understands the term biotechnology, and is familiar with examples which can be given. No indication is given of the depth to which applications in biotechnology should be studied.

The majority of Advanced Level Botany syllabuses under the section on "diversity of organisms" include a more detailed study of fungi, than is found in Biology syllabuses. It is disappointing that it is only the London Board syllabus which has used this opportunity of including some biotechnology. It states that the following should be studied:-

> the economic importance of fungi in causing decay ......the nutrition of yeast......and its value to the fermentation industries. [49]

Thus, in general, most Advanced Level Biological Science syllabuses have a very small percentage of microbiology (an exception being the Southern Universities Joint Board Biology syllabus) and an even smaller percentage of biotechnology. That which is present is concealed within the syllabus, and where specific examples are given they are of a traditional nature. In the two cases where the word biotechnology appears, it is used loosely and without guidance, suggesting that it it has been inserted in order to demonstrate knowledge that the word exists rather than to promote understanding of the processes involved.

It is therefore essential that if some biotechnology is to be part of all Advanced Level Biology courses, syllabuses must be written giving clear instructions of their intent to teachers. This should include examples of practical work. None of the Advanced Level Biology syllabuses gave details of practical work to be undertaken in the area of biotechnology.

In addition, the report Biotechnology and Education noted that "practical work in the field of modern genetics and genetic engineering was almost non-existent at schools".[50] It suggested that experiments with yeast and non pathogenic bacteria could be done to demonstrate the principles of genetic engineering.[51] Dr W F R Pover, Admissions Tutor for the Biochemistry with Biotechnology degree course at Birmingham University[52], expressed concern over the reduction in the time allocated to practical work in Advanced Level Science subjects. He says that this has caused a reduction in the manual dexterity and observational skills of students to a worrying extent. This supports the need for Advanced Level Biology syllabuses to give more attention to the detail of their practical work instructions, including those used to illustrate biotechnology.

Correlation between the biotechnology content of Advanced Level Biology syllabuses and the expectations of University Admissions Tutors.

In the "Questionnaire" sent to Admissions Tutors of the universities offering Biotechnology-based degree courses, Admissions Tutors were asked to state whether in their experience they had noticed an Advanced Level Biology Board syllabus which offered a better background for entry to a Biotechnology-based degree course. (Questionnaire Part Two, Question 6.) It was interesting to note that, out of the nine replies six said "no", one said "don't know", and two did not comment. This was a slightly surprising response in view of the widely differing amounts of biotechnology in various syllabuses, possibly indicating a lack of acquaintance with Advanced Level syllabus content.

With respect to the topics which universities wished to see present in Advanced Level Biology courses (shown in Table 10, Chapter Three) the following was discovered:-

1 Some of the topics which universities wanted, are already present in most Advanced Level Biology syllabuses.
For example:-

a) Most universities had strongly supported the inclusion of both the harmful and useful effects of bacteria. All Advanced Level Biology syllabuses do include reference to the diversity of bacteria; however, emphasis was given in most syllabuses to the harmful effects of bacteria. ie spread of disease.

b) Most universities wanted Advanced Level Biology syllabuses to include reference to the structure, size and reproduction of viruses. Present syllabuses do include this.

2 But there appears to be a mis-match in the wishes of universites and what current Advanced Level Biology syllabuses offer with respect to certain topics.

For example :-

a) Although most universities wished that syllabuses included the growth of microorganisms in liquid media eg yeast; only a few Advanced Level Biology syllabuses included this, an example being Cambridge Board's Biology syllabus.[53]

b) Similarly, the majority of universities wanted Advanced Level Biology syllabuses to include the principles of traditional fermentations eg beer production. However, only a few Advanced Level Biology syllabuses include this. An example being Southern Universities Joint Board syllabus.[54]

c) The majority of universities wished fundamental principles of genetic engineering to be present on Advanced Level Biology syllabuses; however, this is not included on the majority of syllabuses.

CHAPTER FOUR

ENDNOTES

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CHAPTER FIVE

How Universities' Requirements may be Better Matched in the Future by the Proposed Changes in the School Science Curriculum.

Before considering whether the proposed changes in the school science curriculum will enable biotechnology-based degree course applicants to be better prepared than at present, one should address the following question.

Should some aspects of biotechnology be present in the secondary school science curriculum?

The present writer thinks it should and there are two reasons for its inclusion. First, there is the need to ensure pupil awareness of biotechnology. The Spinks Report notes that:-

> If there is to be a substantial national gain from biotechnology, local authorities, teachers, parents and pupils must be informed of its significance.[1]

Indeed, the Royal Society Report "The Public Understanding of Science" has indicated a "strong prima facie case for the existence of a link between public understanding of science and national prosperity."[2] The Royal Society notes that new technologies such as biotechnology, have developed from the underlying science.(ie microbiology, biochemistry and chemical engineering) The successful exploitation of these new technologies:-

> ....requires those responsible for the nation's industries, as well as a supportive government, to be aware of science and technology, [and] to recognise their full potential value.[3]

In addition, sucessful exploitation also depends critically on the availability of adequately trained and skilled scientific and technological manpower. Thus, inclusion of some biotechnology in the school curriculum is essential if the future generation is to become aware of the new technologies eg biotechnology, and in order to stimulate interest in the subject and to encourage a proportion of pupils into careers in biotechnology.

The second reason for including some biotechnology into the school science curriculum as it would help to implement some of the national curricular objectives. (Listed on page 130) Biotechnology can be used as an educational vehicle for promoting the following :-

1 Biotechnology can help to demonstrate the relevance of studying science to pupils; in particular, it can be used to illustrate the relationship between science and industry. It has been stated that science teaching in schools should not be presented as something divorced from industrial considerations.[4] Indeed, the Government has stated that "more emphasis needs to be given to science and technology"[5] which will allow pupils to understand and develop positive attitudes towards industry. The Department of Education and Science states that one of the main factors which appears to turn pupils away from science is that "many examination syllabuses especially at ordinary level are overloaded and out of date".[6] By including examples of UK industries which are involved in biotechnology, pupils can be made aware of the importance of science in their present and future lives. The industrial involvement of biotechnology, can be demonstrated by including visits to local industries and by inviting industrialists into school to give talks. The development of school-industrial liaison has been supported by the Government[7] the Royal Society[8] and the ASE Biotechnology Subcommittee.[9]

2 The products of the biotechnology industry include many to which most school pupils can relate, eg dairy products, and fermented products including beer, wine, vinegar, and antibiotics. Pupils of all ages throughout secondary school are familiar with these products. Sewage treatment

and water purification are biotechnological processes which are again of relevance to all school pupils. The relevance of biotechnology to all pupils , enables it to be introduced into the science curriculum at any age , as long as it is approached in a manner suitable to the age and ability of the pupils.

3 Biotechnology is a multidisciplinary subject, and thus provides pupils with an opportunity to see the inter-relationship between the different science disciplines ie physics, chemistry, and biology.

4 Biotechnology provides a means by which aspects of microbiology, biochemistry, engineering and economics can be introduced into a science course. It can also be used to include some business awareness in science courses.

5 Effective science teaching should give pupils the opportunity to carry out practical work and to test their own ideas.[10] Biotechnology lends itself readily to practical investigation , which the Royal Society in Biotechnology and Education notes can be carried out cheaply and safely in the school situation.[11]

6 Finally, if Advanced Level courses are to "reflect the current situation in biological sciences"[12], (an aim of the Cambridge Board Advanced Level Biology syllabus), then this in itself, is grounds for introducing biotechnology into the sixth-form science curriculum.

In connection with the future development of biotechnology, the school science curriculum needs to fulfil two different functions. First, it has to provide awareness in biotechnology to all pupils. Secondly, it has to ensure that a certain proportion of pupils will become interested enough in biotechnology to become future biotechnologists. For this latter group of students the science curriculum should provide adequate skills and knowledge needed for their future training.

Criticism of the present school science curriculum.

In 1982, the Assessment of Performance Unit (APU) published a report, entitled "Science in Schools: Age 15". This report yielded significant findings with respect to the subject choices made in years four and five by pupils in the United Kingdom. It shows the following:-[13]

1 A higher percentage of boys (14%) than girls (9%) study all three separate sciences (physics, chemistry, and biology) in years four and five.
2 Where only one science is studied, girls show a marked preference for biology, (33% in contrast to 7% boys) whilst the reverse is seen in the case of physics (18% boys : 3% girls).
3 Few pupils study a general science course.
4 Approximately ten percent of pupils study no science at all after the age of thirteen.

The findings of the APU Report were assessed by the Secondary Science Curriculum Review (SSCR). (The SSCR, established in 1981, consists of a body of representatives from the Association for Science Education, the Department of Education and Science, the Health Education Council, the Northern Ireland Council for Education Development, the Schools Council, Examining Boards and the standing Conference on University Entrance.) The SSCR came to the following conclusion:-

> Given the very low take-up of general and integrated science courses and the small proportion of boys and girls taking all three sciences, approximately 73% of boys and 81% of girls are failing to study a broad range of subject content in years four and five.[14]

Thus, although the number of students taking and passing Ordinary Level and Advanced Level Science courses has increased since the mid 1970's,[15] the School Curriculum in the early 1980's appeared not to encourage the majority of pupils to study a broad and balanced science course up to the age of sixteen years. In addition, it perhaps failed to provide genuinely equal curricular opportunities in science for girls as well as boys. The Department of Education and Science in "The School Curriculum" notes a shortage (particularly girls) of able scientists and engineers,[16] a probable result of the science curriculum of the early 1980's.

In the interests of biotechnology, the school science curriculum needs to promote general biotechnology awareness and also provide a suitable background for the training of future biotechnologists. The report Biotechnology and Education states that:-

> the overriding educational need for all is a broadly-based schooling with a balanced curriculum of science and other subjects and a balanced appreciation of the equally important roles of physical science and biology and of science, technology and engineering in industrial development.[17]

The report favours a broad based science education up to the age of sixteen. In particular, it recognised the benefits of studying a combined or integrated science course in preparation for studying a transdisciplinary subject such as biotechnology.[18] (A similar finding had been reported in "The Finniston Report" which reviewed the training of engineering students, another transdisciplinary subject.[19])

It has been found that the most common pattern of study at present (1986) is for pupils to follow a combined science course in the first two years of secondary school, followed by separation into the separate science courses (ie physics, chemistry and biology) in the third year. This forms the background upon which fourth and fifth year course choices (ie Ordinary Level and Certificate of Secondary Education) are made at the end of the third year.[20]

The present writer has found that General Science courses contain more examples of biotechnology than the present Single Science Ordinary Level courses. However, despite favouring General Science courses for pupils up to the age of sixteen, the report Biotechnology and Education notes that their establishment in schools might have major resource implications and, in particular, the availability of teachers able to teach both physical and biological sciences. [21]
In view of this, the report supported the continuation of the Single Science courses, made up of a core of material and containing a fringe of transdisciplinary material.[22]

The main criticism of the present sixth form science curriculum, made in Biotechnology and Education is that few students in general study all four sciences, ie physics, chemistry, biology and mathematics. It particularly favoured the Scottish system where students are able to study a range of subjects (Highers) up to the age of seventeen.[23] It states that:-

> such a broadly based educational system has much to recommend it as far as biotechnology is concerned, especially as the school curriculum goes hand-in hand with a 4-year degree course at university.[24]

Professor D L Pyle, of Reading University had, in his reply to the "Questionnaire", expressed concern that most of his students were deficient in at least one of the following subject areas:-biology, chemistry, physics or mathematics.[25]
As a means of broadening the sixth form curriculum of biotechnology based degree course candidates , Reading,[26] Kent[27], and not surprisingly Strathclyde [28] Universities were in favour of the Scottish system.

Changes in the school science curriculum

In order to ensure all pupils have the opportunity of studying a broad and balanced science course up to the age of sixteen[2], changes are being made to both the form of the science curriculum and to the course provision.

The changes are in line with the Government's set of national objectives specified in the recent (1985) document "Better Schools".[29] These objectives are the basis of the curricular policies of the Secretaries of State, the Local Education Authorities and the schools, thus ensuring that implementation of curricular objectives at each level will have a common aim. The national objectives are as follows:-[30]

1 The curriculum in both primary and secondary schools should be broad. It should introduce pupils to a wide range of areas of experience, knowledge and skills.
2 The curriculum should provide equal opportunities for both sexes.
3 The curriculum should be balanced.
4 The curriculum should be relevant; all subjects should be taught in such a way as to relate to the pupils' own experience and to show their applications and continuing value in adult life.
5 The government favours local initiatives which bring together schools and employers in shared activities.
6 Both subject matter and the manner in which it is taught should match the abilities and aptitudes of the pupils.

The Department of Education and Science published a Statement of Policy entitled "Science 5-16". In its introduction, it states that:-

> Science should have a place in the education of all pupils of compulsory school age, whether or not they are likely to follow a career in science or technology. [31]

The SSCR[32] and the Royal Society[33] support this DES statement and this policy is now known as "Science for All". In order to implement this policy within the framework of the national curricular objectives, the following proportion of the timetable is to be allocated to science teaching.[34]

First two years	- ten percent of total curriculum time.
Third year	- about fifteen percent of total curriculum time.
Fourth and fifth years	-about twenty percent of total curriculum time.

If Science is to occupy only twenty percent of the timetable, ie eight periods a week, so that all students in years four and five are afforded a balanced overall curriculum; radical changes will have to be made in the provision of courses as students could not adequately study all three separate sciences in this time allocation. [35]

The Government is aware that these changes will take time to come into effect and that many schools will continue to teach all three separate sciences, especially to average and more able pupils for some time to come. However, it proposes that simply pruning of the factual content of existing courses to provide more room for investigative, applied, and problem-solving aspects is an inadequate measure. In order to teach a balanced science course in the time available, the development of physical science and biological science courses or integrated science courses provides a more favourable way forward. [36]

In addition, the Government wants science courses to provide "an understanding of science and its significance which goes beyond the acquisition of scientific knowledge alone" and for courses to incorporate "more recent concepts and technological developments".[37]

Courses in years four and five, apart from providing all pupils with a basic understanding in science , have also to provide a suitable background for Advanced Level study in science. The Government states that it is :-

> committed to the retention of Advanced Levels, as they not only have an educational value in their own right but also play an important role in the selection for higher education.[38]

However, the Royal Society, in "The Public Understanding of Science" criticises the sixth-form curriculum as being "appallingly narrow". It states that:-

> the depth of specialisation entailed by the current [1985] A-Level system is totally unnecessary, often engendering wasteful repetition of subjects in the first year of a degree course.[39]

This Report favours a revised system, allowing a broader range of subjects to be taken to a lower standard.

The Government has already taken one step to broaden the sixth form curriculum. In May 1984, the Secretaries of State published a consultative paper proposing the introduction of Advanced Supplementary (AS) Levels. [40] These would be taken simultaneously with Advanced Level courses; they would be of Advanced Level standard, but would occupy only half the time of an Advanced Level course. The paper proposed that students at present taking:-[41]

1 Four A Levels would take three A Levels and two AS Levels.
2 Three A Levels would take two A Levels and and two or three AS Levels , or three A Levels and one AS Level.
3 Two A Levels would take two A Levels and one AS Level.

The Advanced Supplementary Levels studied would either complement or contrast with the Advanced Levels being taken. The introduction of AS Levels has been strongly supported by the universities and employers' organisations. [42] The former have shown a willingness to give full recognition to AS Levels in thier admissions' policies. However, in general, schools and colleges have shown divided opinion over the introduction of AS Levels, due to concern over syllabus design and the insertion of AS Levels into the sixth form timetable.[43] The Government has decided to go ahead with their introduction. AS Level syllabuses are now (1986) being prepared by the GCE Boards and the Secondary Examination Council; the first AS Level examinations will be held in 1989.[44]

The effect of the future science curriculum changes on biotechnology-based degree course applicants.

Since the report Biotechnology and Education was written in (1981), GCSE courses are to be introduced. Their content is based on the national curricular objectives mentioned earlier, and it is likely that future science courses will contain more transdisciplinary material than at present. As the content of GCSE courses will differ from the present Ordinary Level courses, this will have an effect on the content and teaching style of science courses in years one, two and three. These, in turn, may become more applied and include some biotechnology.

It is also probable that General Science courses will be developed at the expense of Single Science courses. The future science curriculum for eleven to sixteen year olds would appear to support the recommendations in Biotechnology and Education[45] , and therefore to encourage biotechnology awareness.

Apart from the changes in course content, pupils are to be encouraged to study a balanced science course up to the age of sixteen. This will give a larger proportion of pupils the opportunity to meet aspects of biotechnology than is the case at present. It can also be argued that it is more important to ensure awareness in biotechnology between the ages of thirteen to sixteen than it is at sixth form level on the basis that it is during this time that pupils make preliminary career choices and select their Advanced Level subjects. Indeed some pupils will complete their schooling at sixteen.

The changes being made to promote a balanced science curriculum for both sexes should ensure that more girls study science up to the age of sixteen. As a result, the number of girls studying Advanced Level Sciences should also increase. This may in turn raise the proportion of girls applying to study a biotechnology-based degree course. In 1985 the ratio of male: female applicants was as high as three : one at Leeds University. (Table 3, Chapter Three)

The introduction of AS Levels will allow more sixth form students to study all four science subjects. However, although studying all four science subjects may alleviate the problem noted by Professor Pyle [46](ie that students were deficient in at least one science subject); it is in itself narrowing their education to science subjects at the expense of a more rounded curriculum, composed of both Arts and Science subjects.

The higher education bodies attach particular importance to the early development of an AS Level in Mathematics with practical applications.[47] This has significance for biotechnology based degree course candidates, as it would help to fulfil some of the suggestions made by the universities in connection with the improvement of the background of applicants. (The suggestions are shown in Table 8, Chapter Three.)

In addition, the introduction of AS Levels would enable some future biotechnologists to study some English during their sixth form studies. Leeds University expressed a wish that students had better English. (Table 8, Chapter Three) The Royal Society Report "The Public Understanding of Science" has also stated that " pupils should learn to write about science in good, clear English free from jargon".[48]

Replies to the "Questionnaire" showed that in principle, three out of the nine universities were in favour of the introduction of AS Levels. The others, were divided in opinion. Two were against their introduction (Birmingham and Strathclyde), while the rest were undecided. Although AS Levels may enable the sixth form background of biotechnology based degree course applicants to be improved, it is only when the syllabuses are available for inspection that their worth can be accurately assessed.

At present, sixth form science students have, in theory, the opportunity to encounter some biotechnology in both Biology and Chemistry Advanced Level courses. Whereas non-science sixth formers may have the opportunity to meet some biotechnology in their general studies courses, though the present writer suspects that, at present, there is little opportunity for this. The introduction of AS Levels into the sixth form curriculum will enable more students to study science, including Arts Advanced Level students. If some biotechnology were introduced into an AS Level course eg AS Level Biology or AS Level Chemistry, more students would be given the opportunity of becoming aware of biotechnology than at present in the sixth form. Indeed, Admissions Tutors to the Biotechnology based degree courses were asked in the "Questionnaire" (Part Two, Question 11) , if they would like to see the introduction of an AS Level in Biotechnology. Their replies are shown in Table Nine ,Chapter Three. Out of the seven replies, five said "No", and only King's College

London said "Yes". It would therefore appear that although an AS Level in Biotechnology would increase the opportunities to introduce biotechnology to sixth form students , such an innovation is not supported by the universities.

The place of biotechnology in the school science curriculum is perhaps best summarised by Dr P G Mantle, Admissions Tutor at Imperial College London. He states,

> While it is good to introduce biotechnology at school, as an illustration of the relevance of studying the biological and chemical sciences, its factual content should be rather superficial since there is a danger that attention is diverted from the more important business, that of teaching fundamental principles in biology, chemistry, maths and physics.
> In my view the sixth form course should be a blend of fundamental principles and enough non-examined illustrations of relevance to whet the appetite for further study. [49]

The present writer supports this statement and realises that it is important for teachers to maintain a balance between the basic principles taught and the use of applications. Without due care it is possible for a situation to arise where the basic principles are overshadowed by the applications.. However, it should be noted that applications can be a useful vehicle for introducing some (but not all) basic principles. There is also a danger that if sixth form courses classify applications/illustrations as non-examined material, these topics will become a "remainder factor" ie only being taught if the time and inclination allows.

The implications of incorporating some biotechnology into the secondary school science curriculum.

It has been noted that "the pace and pattern of improvements in the curriculum will depend above all on the energy, imagination and professional skill of the teachers".[50] At present (1986), the teaching of biotechnology in schools relies heavily upon the competence and willingness of teachers to spot syllabus areas where it can be introduced. However, if future science courses are to expand their sections on the applications of science, (which includes biotechnology), this step will impose demands on the teaching staff.

The education and training of many science teachers in one pure science only does not equip them well for teaching transdisciplinary material.[51] Biotechnology and Education notes that, "as few teachers are trained in both physical and life sciences and fewer are aware of the industrial potential of biology, they miss opportunities to suggest biotechnological examples".[52] It will therefore become increasingly important that teacher training is:- "designed to help teachers to teach more readily at the interface between subjects, between their pure and applied aspects, and between academic excitement and economic and social importance".[53]

As the future science curriculum between the ages of eleven and sixteen will probably favour the development of General Science courses, it will become of utmost importance that there is a teaching force available which is qualified to teach both physical and biological sciences. There has been a reported shortage of physics and to a lesser extent chemistry teachers.[54] This means that biology teachers will be increasingly relied upon to teach General Science courses. It is therefore particularly important that biology teachers have an adequate knowledge of mathematics and physics as well as chemistry, and that they are given opportunities to become more familiar with industrial and commercial aspects of science, for example biotechnology.

In "The Public Understanding of Science ", the Royal Society strongly supports that teachers should appreciate industry and commerce; it says this appreciation can only be gained from direct experience.[55] It recommends that science teachers have some industrial experience between finishing their first degree and starting teacher training, a view shared by the Government.[56]

It is not only the newly qualified teacher who needs the opportunity to gain industrial experience; indeed, the Secretary of State recognises that "professional development throughout a teacher's career ...... will need to account for advancing technology."[57] The Government[58] and the Royal Society[59] fully support the opportunities available for teachers to gain industrial experience for example through fellowships and secondments.

It is noted that "good teaching depends heavily on a reasonable match between the qualifications and experience of teachers and the subjects they teach".[60] Therefore in the interests of biotechnology, it is essential that science teachers are made aware of its significance, and are given the necessary support to introduce aspects of biotechnology into their teaching at all levels.

Recent research has shown that:-

> Teachers have a good idea of the scope of biotechnology and are quite willing to introduce aspects of it into the school curriculum but they feel constrained by lack of resources and a shortage of information.[61]

Indeed it has been noted that most text books make scant reference to biotechnology. References to microorganisms in the majority of text books are related to their potentially harmful effects rather than their beneficial uses.[62] It is to be hoped that new text books will become available which follow the line of the new examination syllabuses, and will include examples of the industrial uses of biological processes.

The present writer feels strongly that the inclusion of some aspects of biotechnology in the school science curriculum is of genuine benefit to school pupils of all ages. It is essential that pupils are given opportunities to see the relevance of studying the fundamental principles in any subject (science included). It is also important that pupils appreciate the interrelationship. between subjects, this can only be afforded through dealing with transdisciplinary material eg biotechnology. Economics which plays such a vital role in the world outside (and within)school should not be kept isolated from the pupils' experience. It is the present writer's belief that examples of biotechnology, if introduced carefully into the school science curriculum can help to achieve these objectives.

Incorporation of aspects of biotechnology into school syllabuses should ensure that more students, than at present, are made aware of its significance and that a small proportion will be sufficiently stimulated to study biotechnology further after leaving school. The proposed changes in the school science curriculum should mean that future applicants for biotechnology-based degree courses have a better background for entry than at present.

The future development of biotechnology in the school science curriculum looks promising, however its effectiveness relies heavily on the availability of resources, clearly written syllabuses and increased liaison with the biotechnology industry.

CHAPTER FIVE

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APPENDIX 1

UNIVERSITY:

COURSE:

ADMISSIONS TUTOR:

QUESTIONNAIRE - BIOTECHNOLOGY COURSES AT BRITISH UNIVERSITIES

PART ONE.

1. When was the ....degree Course introduced to ....University?

2. Why was this Course introduced?

3. How many places are available on the course per year?

   (i) Number of places for course starting Oct. '85 ________

   (ii) Any future increase/decrease in availability of places which your foresee:

4. For the course commencing October 1985.

	Male.	Female.
How many candidates applied:		
(a) Via UCCA	____	____
(b) direct	____	____
*(c) any other method	____	____

* If appropriate, please specify how:

ENTRY REQUIREMENTS FOR THE COURSE .

5. How many, and which are the preferred A Level subjects for entry to the course?

Number ....

Subjects...

....

6. Please specify any A Level subject(s) considered:

(a) essential for entry ....

(b) not acceptable...

7. Is an application acceptable from a candidate studying A Level Biology who has O Level Chemistry but is not studying A Level Chemistry?

YES/NO

8. If Biology A Level is acceptable, which of the following are recognised as suitable alternatives to A Level Biology?

A Level:	Zoology	Botany	Human Bioloby	Social Biology	Environmental Science
	☐	☐	☐	☐	☐

Please ✓ if acceptable

✗ if not acceptable

9. Do you accept the relevant TEC/ONC/OND exams instead of A levels?

TEC YES/NO

ONC YES/NO

OND YES/NO

SELECTION OF APPLICANTS

10. Is it the policy of your University to interview the majority of applicants before making a conditional offer?

YES/NO

11. What percentage of applicants were interviewed for the course starting in October '85

1 - 25   26 - 50   51 - 75   76 - 100

Tick appropriate section.

12. How do you select applicants for interview?

13. Which of the following qualities do you look for in an UCCA Report or at interview, and how important are they in selection.

PLEASE CIRCLE TO INDICATE DEGREE OF IMPORTANCE.

Qualities		Very Important	Favourable.	Indifferent	Not Required
a.	High A Level grades predicted	1	2	3	4
b.	Average A level grades predicted	1	2	3	4
c.	Positions of responsibility held	1	2	3	4
d.	Candidate able to relate well to other students	1	2	3	4
e.	Candidate able to relate well to staff	1	2	3	4
f.	Candidate having a responsible attitude to work	1	2	3	4
g.	Candidate has good manual dexterity	1	2	3	4
h.	Candidate can assess experimental results critically	1	2	3	4
i.	Ability to relate socially in a positive manner to the interviewer	1	2	3	4
j.	Awareness of world current events evident	1	2	3	4
k.	Interested in a wide range of scientific issues	1	2	3	4
l.	Ability to communicate scientific issues verbally	1	2	3	4
m.	Familiar with factual knowledge from A level courses	1	2	3	4
n.	Familiar with factual knowledge of what Biotechnology involves	1	2	3	4
o.	Aware of the industrial involvement in Biotechnology	1	2	3	4

14. Please specify any other qualities which you feel should be present to make a candidate successful:

15. What is an average offer given to a successful candidate?

16. Is any preference shown to candidates

(i)	coming direct from school	YES/NO
(ii)	deferred entry	YES/NO
(iii)	coming from Industry	YES/NO

17. If possible, please comment further if you answered yes to any of the above, indicating why they are given preference.

BIOTECHNOLOGY AND THE 6TH FORM CURRICULUM

To investigate:

1) Whether admissions tutors feel the present A level science syllabuses offer a suitable background for candidates entering Biotechnology.

2) The opinions of admissions tutors re. proposals for introducing/increasing Biotechnology in the 6th form curriculum.

Views on Present A level Science Subjects.

1. Please indicate (by ticking where appropriate) the importance to various aspects of your course of the present A level science subjects:-

		0 (of no value)	1 (of some - comparatively small - value)	2 (of considerable value)	3 (of very great value)
(a) In providing the essential factual information upon which your course can be built.	Chem.				
	Biol.				
	Phy.				
	Maths				
(b) In developing the sound scientific/logical reasoning skills required for your course.	Chem.				
	Biol.				
	Phy.				
	Maths				
(c) In developing good manual dexterity.	Chem.				
	Biol.				
	Phy.				
	Maths.				
(d) In developing accurate observational skills	Chem.				
	Biol.				
	Phy.				
	Maths.				
(e) In ensuring the candidate is able to cope adequately with the Mathematical content of the course	Chem.				
	Biol.				
	Phy.				
	Maths.				

2. Do you feel the present A level background of the majority of Biotechnological candidates could be improved? YES/NO

If yes, how?

3. In general, would you like to see an increase in the amount of Biotechnology present in the following A level syllabuses:

A level Chem.	A level Biol.	A level Physics.
YES/NO	YES/NO	YES/NO

4. If you answered yes to any of the above, would you like the increase to be theoretical and/or practical?

		Theoretical	Practical
A level	Chem	YES/NO	YES/NO
	Biol.	YES/NO	YES/NO
	Phys.	YES/NO	YES/NO

The following questions relate specifically to A level Biology Courses

5. In recent years Biology A level courses have become more experimental and physico-chemically orientated. Would you like to see this trend increase still further?

YES/NO

6. (a) The extent to which aspects of Biotechnology are included in present A level Biology syllabuses varies according to the examining Board. In your experience, have you noticed a particular A level Biology Board which offers a better background for entry to Biotechnology courses than others?

YES/NO

(b) If yes to 6 (a) please specify which and if possible give reasons as to why you find it better:

7. Would you like the inclusion of aspects of Biotechnology to be part of a common core of material taught during the A level Biology course or as an optional topic?

Preference:- Common core Optional topic No preference

Please tick where appropriate.

8. How important do you feel the following list of principles/concepts are regarding their inclusion into an A level syllabus? Please indicate the strength of your feeling by ringng the appropriate number, e.g. (-1)

Principle/Concept.	To be included					Indifferent	Not to be included	
(a) Diversity of bacteria (including useful and harmful)	5	4	3	2	1	0	- 1	-2
(b) Structure, size and reproduction of viruses	5	4	3	2	1	0	- 1	-2
(c) Growth of bacteria e.g. yeast in liquid media.	5	4	3	2	1	0	- 1	-2
(d) Principles of traditional fermentations,e.g. beer	5	4	3	2	1	0	- 1	-2
(e) Fundamental principles of Genetic Engineering	5	4	3	2	1	0	- 1	-2
(f) Examples of industrial Genetically engineered products in the U.K.	5	4	3	2	1	0	- 1	-2
(g) Fundamental principles of monoclonal antibody production	5	4	3	2	1	0	- 1	-2
(h) Involvement in U.K. of industry in antibody production	5	4	3	2	1	0	- 1	-2
(i) Concept of Single Cell protein	5	4	3	2	1	0	- 1	-2
(j) Tissue Culture Techniques in general	5	4	3	2	1	0	- 1	-2
(k) Degradation of waste products by bacteria	5	4	3	2	1	0	- 1	-2
(l) Industrial use of enzymes	5	4	3	2	1	0	- 1	-2

Future Proposals for study between 16 - 18

Please answer the following questions bearing in mind how the proposal will affect the background of future Biotechnology applicants.

9. Would candidates benefit from studying a broader general curriculum before entry to University, such as offered by the Scottish system?

YES/NO

10. Are you in favour of the introduction of AS (Advanced Supplementary) levels as proposed in May 1984 by the Secretaries for Education & Science in England and Wales?

YES/NO

10. continued...

Reason:

11. Would you like to see an AS level introduced in Biotechnology as a distinct subject in its own right?

YES/NO

12. Finally,

The Royal Society Report 'Biotechnology and Education' 1981 stated that:

'The more informed and competent Biology teachers are becoming aware of biotechnology and are, where possible, modifying their teaching accordingly'.

Do you agree?

YES/NO

Could you please justify your answer?

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