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Biology and Human Welfare
Case Studies in Teaching Applied Biology

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Preface

The Science and Technology Education document series has been initiated as part of Unesco's programme to encourage international exchange of ideas and information in science and technology education. The present volume, as part of the "Biology and Human Welfare" theme, was produced under the auspices of the Commission for Biological Education of the International Union of Biological Sciences (CBE-IUBS) under contract with Unesco. It was written by Mr. A.J. Pritchard of the Department of Education, The University, Southampton, United Kingdom. The opinions expressed in the following pages are those of the author and not necessarily those of Unesco.
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CHAPTER 1

BIOLOGY, HUMAN WELFARE AND EDUCATION

Science education in many parts of the world exists to serve the interests and perceived needs of the various national and scientific communities. These interests have changed over the last forty years. The 1950's in retrospect can be seen to have been the 'boom years' of science and technology. Technological optimism was rampant, it was felt by many that science and technology could 'solve all human problems', but very few people were concerned with exploring the social implications of laboratory work. Pierre Augers book 'Current Trends in Scientific Research' published by UNESCO in 1961 reflects the optimistic, and some would now say somewhat naive, ideas on science, technology and society of that period. Among such ideas were those that suggested that by putting much effort and funding into pure science then development would automatically follow and the human condition throughout the planet would benefit - disease would be conquered, food production develop to meet all peoples needs, everyone would be provided for in terms of clothing, warmth and material resources. By the mid 1970's the situation had changed dramatically, particularly in the industrialised world, science was seen by many as undesirable - Michel Batisse, Unesco's Deputy Assistant Director for Science wrote in 1980:

"Scientific research is under fire in many quarters of government and public opinion. There is a marked disenchantment, particularly in western industrialised countries, with the social and human benefits of science which, in common language, is generally but erroneously equated with technology. The threat of nuclear weapons, the pollution of the environment, the uncertainty of the supply of resources - all combined with inflation, unemployment and the tensions arising from rapid modifications of value systems - are seen as instances of failure of the conscious or unconscious dream that science and its proper application would solve the problems of mankind". (Batisse, 1980)

Unesco published in 1977 'The Scientific Enterprise' written by the then Assistant Director General for Science, Adriano Buzzati-Traverso which described the alarmist mood of the time when some environmentalists were pleading for a halt to development and even to science itself. This climate of opinion in the 1970's forced many people concerned with science, technology, education and development to take stock and think again about the meaning of development, the nature of science and the carrying capacity of our planet.

The 1980's seem to reflect a further phase of the relationship between science, technology and society, one in which the developing countries are attempting to build up their national capabilities in science and technology while the developed countries are displaying a more cautious attitude towards the roles of science and technology and the relationship between science, technology and development.
These issues and concerns have been reflected in science education throughout the world. At the school level particularly in the developed world, there have been changes of emphasis from a purely scientific enquiry approach to teaching in the 1960's through attempts also to embrace social decision making approaches in the 1970's and now more recently attempts to include a much more technological orientation to science teaching. At national and international levels a number of attempts have been set in motion to harness science teaching more explicitly to various perceived human needs. The Bangalore Conference of 1985 on Science and Technology Education and Future Human Needs, (organised by ICSU with help from UNESCO) represents perhaps the most ambitious attempt to stimulate thinking about the relevance of science education to the needs of the developing world.

In exploring the role of science teaching in helping meet human needs it is important to see science in relation to technology, society and development. It has been argued that in order to achieve a science education that responds effectively to human needs one should incorporate a much greater technological dimension. This has been argued very powerfully by Blum (1985) particularly in relation to the needs of rural dwellers in developing countries. There is a strong case for making our science teaching more relevant in the sense that people can be helped to draw upon science creatively in their daily lives, whether in their work or in managing their personal life. However in order to achieve this it is important to clarify the relations between science and technology. Much useful technology, particularly in the rural developing world, was not produced as a result of scientific research. Most traditional, indigenous technologies are not science but craft based, and, involving scientists and engineers in the process of adapting and improving such technologies is not proving easy. Even in the industrialised world technology and science based technology are very different activities. That is not to say that 'retrospective' scientific explanations of such technologies may not be very useful hooks on which to hang our science teaching (e.g. the action of yeast in bread making, the physics of the steam engine, etc). Equally it is important to recognise that a 'scientific' understanding of a craft based technology can expand its potential enormously. It is also highly likely that if we oriented our science teaching more towards the technologies most of our pupils will meet in their daily lives (and for many developing countries this would be those associated with local agriculture and community health) we would more quickly bring about improvements in their future conditions of life. Much of the technology that is valuable to us has been developed by a series of gradual improvements in design. However during this century and particularly in the last forty years new technologies have arisen as a result of laboratory based science. The sources of new technologies such as nuclear power, electronics, data-processing, biotechnology and industrialised agriculture, lie in physics, chemistry, mathematics, genetics and biology. An interesting feature of these new science based technologies is the speed and intensity by which their products affect society, the consequent social and environmental upheaval compared to craft based technologies, together with the reasons why resources were devoted to their development.
The Green Revolution which involved the application of innovatory high yielding varieties of rice, wheat and other major crops to developing countries, agriculture, is an interesting example of the influence of science-based technologies. The aim to increase food production was certainly achieved. In the developing world from the early 1960's exceptional productivity became the norm in several parts of tropical Asia and Latin America. India for example produced only around 50 million tonnes of cereals and related crops per year in the early 1950's, by 1970 this had increased to 108 million tonnes. The high yield crop varieties produce bigger harvests, and in some cases mature faster, so allowing more crops per year than traditional varieties. However they can only do this when they receive high rates of fertiliser application, pesticides and excellent irrigation. The seeds are hybrids so cannot be grown by the farmer himself. One of the unexpected results of the Green Revolution has been the tendency for larger farmers to increase their holdings at the expense of smaller farmers who, forced out of business, swelled the urban unemployed. A further consequence has been to tie developing countries more closely to the world agricultural economy. The environmental impact has involved the reduction in genetic resources with the loss of native varieties, changed soil structures and natural habitats.

Some aspects of the unexpected social and economic impact of the Green Revolution can be illustrated by reference to the Muda River area of Northern Malaysia. Here a 90 million dollar dam was constructed to allow irrigated paddies to produce two crops of high yield rice a year in place of traditional rice. By the early 1970's output had almost tripled. Previously Malaysia had only been 50% self-sufficient in rice, by 1974 it was 90% self-sufficient. However while average incomes for all categories of farmers increased, the wealthier categories increased their incomes by 150% while the poorer farmers only increased their incomes by 50%. After 1974 the harvests failed to expand further even with use of increased fertiliser. Costs of fertiliser increased with costs of oil and real incomes for all farmers fell, but especially those of the poor whose incomes in 1979 were lower in real terms than before the Green Revolution. The richer farmers finding themselves with disposable income started to buy up the land from the poorer farmers. The landscape meanwhile was transformed from a mixed one into a homogenised landscape. The landless resorted to slash and burn farming in Malaysia's forests.

The story of the Green Revolution seems to provide case histories to illustrate almost everyone's point of view. But it can be reasonably argued that the 'advanced' agriculture developed through the Green Revolution does not always suit the needs of the world's poor, represents major threats to maintaining the biosphere and can lead to biased research and development. It provides very interesting case studies for us to explore the inter-relationships of science, technology and society. In particular it raises questions of the importance of considering the cultural and political issues when classifying a problem as purely technical, if technical success is to have any meaning in the long run. Equally it illustrates how technical manipulation of the natural world on the grand scale we are now capable of, can lead to unforeseen consequences involving the depletion of natural resources and destabilisation of the biosphere. While in the short term we may satisfy our needs this may be at the
expense of endangering the future. Finally if we explore these issues further it suggests that science/applied science/development is a continuum and that to ignore one aspect of it is to imperil the others.

Zuckerman describing how science led to an understanding that splitting the atom could release vast amounts of energy, had this to say of the resulting arms race:

"From that moment technology assumed command a new future with its anxieties was shaped by technologists, not because they were concerned with any visionary picture of how the world should evolve, but because they were merely doing what they saw to be their job". (Zuckerman, 1982)

He is, in effect, suggesting that the development aspect of the continuum has until recently been ignored in this sphere by the general public. Clearly in many parts of the world today many people are aware that (a) we need to ask what technologies are actually wanted and how urgently and (b) scientific research policy involves choices which demand public participation. This latter can be illustrated by the case of Cambridge City Council, Harvard University and Massachusetts Institute of Technology in the U.S.A. in the mid-1970's. In 1976 Harvard University proposed building a special high-security laboratory in which to conduct experiments with recombinant DNA. Considerable alarm was expressed by the local people about the possibility of the escape of man-made viruses which may be highly virulent to man or other life forms. Although with hindsight the hazards first suggested were greatly exaggerated the case illustrates an important development in the science/technology/society relationship. The City Council set up a review board of eight citizens, all non-scientists, chosen to represent their local community. They eventually allowed construction to go ahead with stringent safety precautions and commented:

"Knowledge, whether for its own sake or for its potential benefits to humanity, cannot serve as a justification for introducing risks to the public unless an informed citizenry is willing to accept those risks. Decisions regarding the appropriate course between the risks and benefits of potentially dangerous scientific inquiry must not be adjudicated within the inner circles of the scientific establishment .......
We wish to express our sincere belief that a predominantly lay citizen group can face a technical scientific matter of general and deep public concern, educate itself appropriately to the task, and reach a fair decision".

Such a principle that lay people should now be involved in regulatory activity over certain kinds of research is one which clearly poses serious questions for science education. Firstly what science education is necessary, as a basis for future adults to be able to educate themselves appropriately for participation in such
decision making? Secondly, and just as importantly, what science education is appropriate for future scientists so that they may recognise the complexity of the impact of science on society, and the need for the participation of society in decisions which the scientific community may have expected in the past to take by themselves? These two questions are important for science education everywhere. They are particularly pertinent in the developing world if science and technology are to be harnessed more effectively to serving human needs. Herrera (1979) in discussing changing ideas of development commented,

"To devise a science policy to implement self-reliance is not an easy task. It is not simply to create technical solutions for certain problems; it is, above all, to incorporate in those solutions the specific characteristics of the society involved".

The science and technology must always be appropriate and this has considerable implications for research and development. Dr. H. B. G. Casimir (1979) addressing the U.N. Colloquium on science, technology and society commented that 'Science and technology cannot be applied to development. Science and technology are an essential part of development'. Both Casimir and Herrera recognise a changed view of science and development which does not denigrate science but reinterprets development goals, and sees the basic-needs model of development as being inevitably linked with public participation. This is implicit in the Introduction to the Programme of Action resulting from the 1979 U.N. Conference on Science and Technology for Development (UNCSTD) which states that 'the primary responsibility for the development of the developing countries rests upon these countries themselves.....', and in the subsequent emergence of the policy accepted equally by developed and developing countries of endogenous development of science and technology. Singer (1977) has argued that such science and technology will imply changes in research and development priorities where "...... high priority will have to be given in indigenous R and D to the needs of small farmers, rural and small-scale industries and the informal sector". The endogenous approach does not mean however that the necessary science and technology must always arise from within a country it is the process by which they are created or selected that must be endogenous. Equally it does not mean that 'appropriate' technology need be the only approach, the Chinese have, for instance, developed a successful two pronged approach in which high technology exists alongside appropriate technology. However, if a developing country is to make judgements and be free to develop its own technologies, rejuvenate its traditional practices or import a foreign technology with or without modification, it must have a science education policy aimed at developing an endogenous science. The implementation of such a policy takes us back to the two questions posed earlier viz - what science education for the decision making public, and what science education for the future national scientific community? In clarifying these questions it may be helpful to bear in mind João Frank da Costa's (Secretary General of UNCSTD) (1979) list of twelve 'musts for development' (Figure 1) together with the Lagos Plan of Action for the economic
FIGURE 1

THE TWELVE COMMANDMENTS OF DEVELOPMENT

(UNESCO COURIER NOVEMBER 1979)

1. Development must be total - not just limited to economic factors but expanded to include all social and cultural considerations.

2. Development must be original - hence development styles must be diverse and antique concepts of 'the gap' can be dispensed with.

3. Development must be self-determined.

4. Development must be self-generated - but self-reliance will usually be achieved by horizontal co-operation with other developing countries or triangular co-operation involving developed countries as well.

5. Development must be integrated - for example, the industrial and agricultural sectors must be developed jointly, together with the system for education and training.

6. Development must respect the integrity of the environment - both natural and cultural.

7. Development must be planned - the free play of economic forces does not lead to an equitable diffusion of scientific and technological potential.

8. Development must be directed towards a just and equitable social order - all sectors of the population must benefit equally from the applications of science and technology.

9. Development must be democratic - the goals of society are not all scientific and technological; science and technology must not be allowed to assume control.

10. Development must not insulate less-developed regions into 'reservations'.

11. Development must be innovative - depending neither on the importation of advanced or outdated technologies.

12. Development planning must be based on a realistic definition of national needs.
development of Africa during 1980 - 2000 (1981), (Figure 2) adopted by the Organisation for African Unity in April 1980.

FIGURE 2

THE NINE-POINT PLAN - LAGOS PLAN OF ACTION

1. Each African nation should create a national science and technology centre for development;

2. Improve science and technology education and training;

3. Provide an institutional base capable of inventing, innovating, and adapting technologies for African development patterns;

4. Improve local production capacities in such industries as steel making and aviation;

5. Develop cheap rural technologies;

6. Integrate research, development, and appropriate technologies with development goals for agriculture, industry, natural resources, energy, transport and communications, health, urban development, and the environment;

7. Mobilise additional national funds for science and technology;

In addition Africa should

8. Develop regional centres for science and technology;

9. And seek substantial international funds for the development of its scientific and technological base.

The harnessing of science and technology to human welfare clearly is dependent upon education and training in all countries. Over the past decade many developing countries have built up their education systems with huge University complexes and a considerable increase in the output of qualified personnel. However this has not always strengthened the scientific capabilities of these countries in terms of development related to human welfare. India, for example ranks third in the world in terms of the number of scientifically and technically trained personnel, but as S. Bhagavatam, the President of the Indian Institute of Science (1979) has commented:
"... instead of hastily concluding that we should increase the size of the scientific community in each of the developing countries, the issue should be looked at more critically ... while a large sized scientific community is at best a necessary requirement for development, it certainly cannot be a sufficient requirement ... it is not the size of the community that really matters, but the quality."

He is not here commenting on the ability and integrity of the scientific and technical community, more on the frequent lack of their integration in the development process. As was commented upon earlier in this chapter it has often been difficult to involve scientists and engineers in the process of improving indigenous technologies. It is the case that highly qualified people, although potentially a resource, can become a social and economic load, and even part of a brain drain to countries where the styles of research and development better fit their professional aspirations (F. F. Papa Blanco, 1979). The issue here is the view of science and technology that is implicit in the education and professionalisation of scientists and technologists. This should be of concern all countries developed or developing. An endogenous science/technology will contribute to enabling any country to promote its own development by helping in selecting policies from three possibilities:

- assessing and improving indigenous technologies
- assessing, adopting or adapting foreign technologies
- developing new technologies.

In order to do this a country needs (a) a scientific and technological community that is both familiar with science and technology worldwide and also the social and cultural requirements of their country; and (b) a public that has a growing understanding of the value, possibilities and limitations of science and technology, in relation to their own values and culture. The educational implications are great indeed and do not lie solely in the science part of the curriculum, but in the whole curriculum and throughout the education system. However there are particular issues here for science education. If we are to adjust our science curriculum appropriately, the above discussion suggests three inter-related aspects, an understanding of which would be useful to bear in mind in curriculum planning:

1. **Science and Development**

Science is a means of constructing reality, it is an immensely powerful means of imagining the world, perhaps the most powerful we have in terms of manipulating the environment, but it is not the sole arbiter of truth. We have to ask questions not only about science, but also about development,
what is development for? If development is viewed positively, and critically, then science can be effectively harnessed to the goals of development - the questions will not be seen as purely technical ones.

2. Science and Technology

Science and Technology are a continuum. There is a mutual interpenetration of science and technology in the contemporary world. This still has a habit of producing technologies which are not necessarily wanted. It is only by recognising that problems are not purely technical (that is we have to ask ourselves what development is for?) that we may find means of catalysing science into producing all the technologies that are badly needed.

3. Public Participation

Society has always, in some way or another, determined how much scientific activity there will be. However there is an increasing trend for society to want to play a role also in deciding what sort of science. This is part of the understanding of the implications of asking the question, 'What is development for?'. Both the public and the scientific communities need to be equipped to come to terms with this.

These three themes can help in clarifying questions about 'What is science education for?' and so help sharpen thinking about 'What constitutes appropriate curricula in science?'

We can further clarify the second question by also looking at current trends in scientific activity that are the breeding grounds of technical and social change. In this respect the life sciences are especially significant in that they are providing us with new knowledge about the value of life which is already being translated into practical action, and may indeed be more significant over the next decade than physics has been over the past few decades. Equally important has been the shift from reductionism to holistic thinking, particularly in the life sciences, which has focused attention on the world's natural systems such as soils, rivers and oceans, forests, savannahs and grasslands, and generated studies of the inter-relationships of such systems. Medicine and agriculture in particular are likely to be provided with the potential for dramatic changes from advances in the life sciences. (Figure 3, page 11.) At the molecular level the use of recombinant DNA technology, at the cellular level the use of tissue culture, at the community level the use of a greater understanding of biomass. The manipulation of biological systems to provide greater photosynthetic efficiency, the manipulation of all food plants so that they can produce their own nitrogen, and further development of integrated biological control systems are all potential developments that can dramatically affect global energy and material demands with considerable economic and social effects. The use of recombinant DNA technology in the
<table>
<thead>
<tr>
<th>Breakthrough</th>
<th>50 per cent probability date</th>
<th>90 per cent probability date</th>
</tr>
</thead>
<tbody>
<tr>
<td>new nitrogen-fixing plants</td>
<td>1985</td>
<td>1995</td>
</tr>
<tr>
<td>single-cell edible protein</td>
<td>1982</td>
<td>1987</td>
</tr>
<tr>
<td>plants resistant to predators</td>
<td>1990</td>
<td>2000</td>
</tr>
<tr>
<td>bacteria for use in waste treatment and pollution control</td>
<td>1984</td>
<td>1990</td>
</tr>
<tr>
<td>petrochemical substitutes</td>
<td>1988</td>
<td>1995</td>
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<tr>
<td>gene therapy for diseases such as sickle-cell anaemia</td>
<td>1993</td>
<td>2010</td>
</tr>
<tr>
<td>genetic screening to isolate genes responsible for birth defects</td>
<td>1985</td>
<td>1990</td>
</tr>
<tr>
<td>mapping of human genetic code</td>
<td>1984</td>
<td>1985</td>
</tr>
<tr>
<td>better knowledge of senescence</td>
<td>1990</td>
<td>2000</td>
</tr>
<tr>
<td>understanding of immunological processes</td>
<td>1984</td>
<td>1991</td>
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Manufacture of a wide range of pharmaceuticals together with work on gene expression and human development are already raising very difficult ethical questions about the deployment of the potential ensuing technologies.
These trends in the life sciences will produce results which will bring great challenges to society in the coming decades. The greatest of these will be how societies choose which technologies to deploy and what science to promote. The life sciences are not only posing dilemmas but also have something to offer in this respect. Our understanding of ecology suggests that we must see our planet as a whole, the concept of the self-sustaining biosphere is emergent from the life sciences. A change in agricultural practice or health care in one part of the planet can have a ripple effect through the planet. Equipping people with a science that helps them in their own locality may not be sufficient unless it is tempered with some awareness of the possible impact of any action on the surrounding region, and even the need also for whole planet management. Agriculture and public health are obvious examples of the need for a wide biological, as well as social, economic and moral understanding of issues. Policies for rural regeneration and health promotion will achieve little if they do not engage public participation. Such participation, to be effective, requires opportunities for the public to be educated in appropriate science. Local community workers in agriculture and health are likely to be key people in providing such opportunities in many areas especially where the adult population's experience of formal education is small. People such as these, that is, agricultural extension workers and paramedics, are very important elements working alongside people such as the professional agronomist, doctor and research scientist, in the growth of an endogenous science which is participatory and responsive to development needs. As far as science teaching at the school level is concerned it can make a major public contribution to harnessing science for human welfare, not least through the kind of education it provides for those who go on to work in local communities, as well as in the preparation of future research workers and professional scientists. It is very largely through the local community workers own education that it will be possible to encourage public participation in the scientific research and development process (Figure 4, page 13).

By seeing the role of science in formal education in this way it may be possible to develop attitudes that can lead to the sort of pluralism in science that Dr. Geraldo Calvacanti, Brazil's Ambassador to UNESCO (1979) writes about:

"I think we should have a richer concept of the problem of scientific and technological development, stressing the pluralistic and qualitative aspects of progress in these fields. ... Is it not possible to conceive that the diverse technological needs of developing countries, the social contexts in which they appear, the cultures they have to serve, could produce alternative scientific solutions, better adapted to the diversity of national conditions? Would it not be possible to envisage a pluralistic development of science and technology? ... . It seems evident that as long as we keep to a linear concept of scientific and technological progress, we shall sink deeper into frustration and despair. On the other hand, a world which respects and encourages diversity, which seeks not uniformity, but compatibility and integration, will have a greater chance of making Man the harmonious creature he should be".

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Where local communities are supported their is evidence that they can influence the direction of policy and research and development. In Tanzania there has been a growing interest in the use of *Crotalaria juncea* (Sunnhemp) (Figure 5, page 14) in integrated pest management and maintaining soil fertility.

When Sunnhemp is planted as a single crop it keeps the weeds down to a reasonable level for about three years. In the first year after planting Sunnhemp it often happens that no weeding at all is needed in the maize fields. In the second and third year one weeding is needed instead of two or three. Where Sunnhemp has been grown in rice fields before planting rice, only one weeding of the subsequent rice crop was required, and this only moderate. Sunnhemp also attracts certain insects and can be used in pest control, by interplanting Sunnhemp with crop plants. It was introduced in Tanzania by local initiatives in some communities, notably to help farmers suffering from weakness due to the effects of leprosy and who needed help with weeding and pest control. The potential advantages of Sunnhemp for integrated pest management and soil conservation were recognised by the small farmer who then took the initiative and pushed Sunnhemp cultivation. The Tanzanian Ministry of Agriculture's official policy is still the fertiliser programme of the F.A.O., but great interest is expressed in the possibilities of supplementing the
FIGURE 5

CROTALARIA JUNCEA

F.A.O. programme with the results of local experiments. The fostering of such of science and technology arising from local initiative and related to local resources is important in terms of human welfare and the development of endogenous science. It is also an interesting case study to explore in terms of what science a local agricultural extension worker for instance might need to deploy in attempts to help local farmers understand and critically judge in this case the potential of using Sunnhemp. To make a judgement of the effectiveness of Sunnhemp in (a) pest-control and (b) soil fertility the farmers will need to be encouraged to look quantitatively and comparatively at the practices involved. Skills of observation, inferencing and risk analyses need to be developed and related to experience in making informed judgements. The agricultural extension workers need to be skilled in the processes of science as well as its concepts if they are to help educate local farmers effectively. It follows that school science must then pay particular attention to the processes of science if it is to eventually help science to contribute to development. One would give similar case studies for health workers and others, where the processes of making judgements which have a scientific dimension are common place. What we have here then is an argument for harnessing science to the solution of everyday problems. It is possible then to describe a number of elements that need to be
taken into account when identifying and tackling issues and problems relating science to human welfare - the ideas emanating from the practice of science, the processes of science (that is ways of working in science), the interpenetration of science and technology, the social, economic and moral context of science based innovation, and human needs. These are summarised in Figure 6 below.

**FIGURE 6**

If school science education is to serve its purpose effectively it has to prepare future professional scientists, community workers, administrators, politicians, economists, and citizens, with the sort of contextual understanding of science illustrated in Figure 6. In particular the various future community workers and professional scientists will need a much wider view of science than that provided by a traditional academic curriculum and teaching approach. Science studied purely as an intellectual discipline is unlikely to equip future professional scientists and community workers with the sort of skills and attitudes that will allow them to effectively integrate science in the development process. This is true for developed and developing nations.

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The trends in the aims of science education worldwide are towards relevance - to the individual and to society - in the building of a more participatory science. Translating such aims into classroom practice is now an urgent task. William Mayer, in a paper on Biology and Agriculture prepared for the conference on Science and Technology Education and Future Human Needs (Bangalore, 1985), writes:

"When most biology courses deal with plants, students are acquainted with photosynthesis, plant systematics, reproduction, growth and development, but these are taught as if they had no relationship to the real world in which the student lives. Biology has a direct and immediate application to comprehending problems of energy, food, and human nutrition which are daily concerns for healthful living. How does one translate the biology of the classroom into the biology of field and market place? .... How should one orientate a biology course to provide application of what is learned in the classroom to what is experienced in life?"

Whenever this question has been treated seriously it has been recognised that to bring about significant change teachers need help in the provision of resources. The development of such resources has involved two contrasting approaches. One has been to take existing science courses and to seek to supplement them by developing illustrative examples of the issues and applications of science of particular relevance to the society the schools exist to serve (Figure 7 below).

FIGURE 7

Issues and Applications

The other approach has been much more radical and has sought to develop new science programmes using the issues and applications of science as the vehicles for teaching science (Figure 8, page 17).
The former approach of supplementing existing courses can be illustrated by a number of examples. In the United Kingdom the Association for Science Education, concerned to see their policy statement that the science curriculum should reflect \textit{science as a cultural activity} and \textit{science and its applications} as well as science as an \textit{intellectual discipline}, initiated in 1984 the Science and Technology in Society Project (SATIS). This resulted in the development of teaching resources in the form of units, each occupying about 75 minutes of classroom time, aimed at supplementing existing science courses. Figure 9 (page 18) gives some examples of the types of SATIS units initially developed.

These materials are being used extensively by teachers to extend their science teaching by providing follow up work after teaching a given topic. They enable teachers to widen their teaching strategies to bring social, technological and economic dimensions into existing science courses. In Venezuela the National Science Teaching Centre has produced a trial agricultural unit on "The Influence of Agricultural Activities on Soil Erosion" (CENAMEC, 1979) to supplement a modular science course. In Fiji the Basic Science course is paralleled by a Modern Studies course, produced by the Curriculum Development Unit of the Department of Education at Suva. The course units are on topics such as The Coconut, Growing Meat Chickens, and Profit from Plant Nurseries, which put the science into an applied context. In the Philippines Hernandez and Baltazar (1985) have shown how to introduce applied and issues studies into the biology programmes for the 13 - 15 age group by identifying those aspects of the existing biology syllabuses that lend themselves to extending the teaching into topics on food, nutrition and agriculture and suggesting possible teaching/learning activities. Figure 10 (page 19) illustrates some of these.
### FIGURE 9

**SCIENCE AND TECHNOLOGY IN SOCIETY UNITS**

(Association for Science Education, U.K.)

<table>
<thead>
<tr>
<th>Topic</th>
<th>Description</th>
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<tbody>
<tr>
<td>Electricity on Demand</td>
<td>Decision-making task concerning electricity generation and the use of different types of power stations</td>
</tr>
<tr>
<td>The Bigger the Better?</td>
<td>Data-analysis and discussion concerning economies of scale with particular reference to ethene manufacture</td>
</tr>
<tr>
<td>The Heart Pacemaker</td>
<td>Reading and questions concerning electronic heart pacemakers and their use in treating heart defects</td>
</tr>
<tr>
<td>Electric Vehicles</td>
<td>Reading and questions concerning the advantages and limitations of electric vehicles</td>
</tr>
<tr>
<td>Chemicals from Salt</td>
<td>Problem-solving exercises concerning the production of sodium hydroxide and chlorine by electrolysis of salt</td>
</tr>
<tr>
<td>Energy from Biomass</td>
<td>Reading and problem-solving exercises, including optional practical work, on the production of biomass energy</td>
</tr>
<tr>
<td>Robots at Work</td>
<td>Reading and questions on industrial robots and their future implications</td>
</tr>
<tr>
<td>Dam Problems</td>
<td>A role-play simulation concerning the environmental problems involved in building a large dam</td>
</tr>
<tr>
<td>Noise</td>
<td>Reading, questions and optional survey on the problem of noise pollution</td>
</tr>
<tr>
<td>The Limestone Inquiry</td>
<td>A role-play exercise concerning the quarrying of limestone</td>
</tr>
<tr>
<td>Fluoridation of Water Supplies</td>
<td>Reading and discussion concerning the artificial fluoridation of public water supplies</td>
</tr>
<tr>
<td>Recycling Aluminium</td>
<td>A home survey leading to a discussion on the question of recycling aluminium</td>
</tr>
<tr>
<td>Test-tube Babies</td>
<td>Information and discussion questions on the problem of infertility and the technique of in vitro fertilization</td>
</tr>
<tr>
<td>What's in our Food?—a look at food labels</td>
<td>Survey, analysis and discussion concerning food labelling: food additives</td>
</tr>
</tbody>
</table>
FIGURE 10
SAMPLE TOPICS ON FOOD, NUTRITION AND AGRICULTURE IN BIOLOGY
TEACHING APPROPRIATE FOR THE 13 – 15 AGE GROUP IN THE
PHILIPPINES

Hernandez and Baltazar (1985)

Topic

Micro-organisms in Plant Nutrition

Points of Entry in the Biology Syllabus:
- Soil Conservation
- Soil Ecosystem
- Cycles in the Biosphere (N. cycle)
- Nutrients (Protein) in Food
- Micro-organisms and their Activities
- Substances needed for Plant Growth

Topic

A Farm as a Modified Ecosystem

Points of Entry in the Biology Syllabus:
- Ecosystems
- Components of an Ecosystem
- Interactions in an Ecosystem
- Food Webs
- Population Densities
- Problems of Man and his Environment

Topic

Structure and Development of Farm Plants

Points of Entry in the Biology Syllabus:
- The Seed Plants: Structure and Development of Flowering Plants
- Monocotyledons and Dicotyledons

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Each of these examples have been seen essentially as enhancing existing science courses. The ideas in the Philippines example could however be easily developed into the second more radical approach, that is restructuring the science curriculum by using the social, economic and technological aspects of science as the starting points and vehicles for teaching all our science at the secondary level. An example of this in practice is a very recent one in the United Kingdom (1983) where a team, based at the University of York, have produced a three year Chemistry course leading to public examinations. This course

"...arts with materials and phenomena with which the children are familiar, introduces chemical concepts and explanations only when they arise naturally from the work on these everyday substances and situations and, allows industrial, technological, economic and social implications of chemistry to pervade the whole course: they are not merely raised at the end of a topic as time permits".

(Salters Chemistry, 1985)

The course is a modular course, Figure 11 illustrates the units in this course.

**FIGURE 11**

**UNITS IN THE SALTERS CHEMISTRY COURSE**

<table>
<thead>
<tr>
<th>Units for Age 13 - 14 years</th>
<th>14 - 15 years</th>
<th>15 - 16 units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>Agriculture</td>
<td>Electrochemistry</td>
</tr>
<tr>
<td>Drinks</td>
<td>Transport</td>
<td>Energy and Bonding</td>
</tr>
<tr>
<td>Warmth</td>
<td>Buildings</td>
<td>Energy Today and Tomorrow</td>
</tr>
<tr>
<td>Metals</td>
<td>Emulsions</td>
<td>Keeping Healthy</td>
</tr>
<tr>
<td>Clothing</td>
<td>Minerals</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plastics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Food Processing</td>
<td></td>
</tr>
</tbody>
</table>
(Members of the University of Southampton, Biology in Balanced Science (B.I.B.S.) team and the University of Leeds, Children Learning in Science (C.L.I.S.) team are participating with the University of York Salters team currently to extend this approach to embrace biology, physics and the earth sciences with chemistry in a double certificate science course.)

In Israel the Life and Agriculture Science Curriculum (Ministry of Education and Culture, Israel, 1980) treats the whole range of biology, but uses an agricultural approach and includes economics. Like the Salters Chemistry it has equivalent status, through parallel examination status, to the conventional science programmes. In both instances it was felt that such status and recognition were important if such courses were to become accepted and so influential forms of science education. In Zambia an Agricultural Science programme exists but is overshadowed by a more prestigious 'pure' science course.

All these various approaches to extending science teaching have in common a recognition that when dealing with issues and applications it is necessary to cross the conventional curriculum barriers between

(a) the separate sciences;
(b) the sciences and technology;
and (c) sciences/technology and the humanities.

Equally they all place an emphasis on teaching skills and processes seeking to help students to apply these to problem solving. A model of the processes of scientific activity was developed by the Assessment of Performance Unit in the United Kingdom, to help them in their task of identifying and measuring science skills. This model, illustrated in Figure 12 (page 22), can be very helpful when developing learning materials designed to help students engage in problem solving.

All these developments are concerned essentially to promote the contribution science education can make to human welfare. The teaching and learning strategies associated with such applied science approaches all aim at helping to educate for personal capability. Black and Harrison (1985) in discussing what is the nature of capability in the human activities we value argue that there is a common pattern in such activities. They suggest

"... that full capability for personal action calls simultaneously for both action-based qualities and the resources of knowledge, skill and experience".

The action-based qualities they describe as:

- application of personal driving qualities such as determination, enterprise, resourcefulness;
- personal innovative powers of imagination, intuition and invention;

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FIGURE 12

THE PROBLEM SOLVING CHAIN

(Assessment of Performance Unit, 1984)

- powers of observation and perception;
- willingness to make decisions based both on logic and on intuition;
- sensitivity to the needs being served, to the possible consequences, benign or harmful, of alternative solutions, to the values being pursued;
They see knowledge and both intellectual and physical skills overlapping all these. The farmer for instance not only needs action-based qualities to be successful, but also needs to know about fertilisers, pesticides, basic medical treatment and the technical requirements of machinery, plant, equipment and building. They go on to argue that the

"interaction between the processes of innovative activity and the resources being called upon is itself one of the key elements of successful human capability. It is a continuous engagement and negotiation between ideas and facts, guess work and logic, judgements and concepts, determination and skill".

School science is very much to do with what Black and Harrison call 'Resources' that is knowledge, and intellectual and physical skills. The trend in science education is to teach science in such ways that future adults will be better able to draw upon their resources of scientific knowledge, intellectual and physical skills in getting things done. Black and Harrison argue further that there are three interactive dimensions to capability which are amenable to educational development viz:

**Resources** - of knowledge, skill and experience which can be drawn upon, consciously or subconsciously when engaged in active tasks.

**Capability** - to perform, to originate, to get things done, to make and stand by decisions.

**Awareness** - perception and understanding needed for making balanced and effective value judgements.

If this is so then the skill of the science teacher will be to devise activities for students that encourage the development of capability and awareness and give opportunities for using and applying resources of knowledge and skill. Black and Harrison describe such activities as Tasks and suggest that there is a mutual interaction between Resources and Tasks chosen to develop Capability and Awareness. This relationship, illustrated in Figure 13 (page 24), is mutual, for the needs of real tasks can provide a motive for acquiring new knowledge and skills as well as consolidating those already learnt.

The results of work in many countries in recent years on children's learning in science adds to the arguments for rethinking our science teaching in the directions described above. This work is more fully described in another volume in this series (Understanding Biological Ideas, Kelly, 1987), but it is useful here to comment briefly on this work. Essentially this work on children's thinking in science has directed our attention to the ideas the children bring with them to science lessons. It has become widely accepted that children develop ideas and beliefs about the natural world long before they are formally taught science and that such ideas and beliefs need
FIGURE 13

A MODEL FOR SCIENCE EDUCATION

(Redrawn from Black and Harrison, In Place of Confusion, 1985)
to be taken into account by teachers. Learning is thus seen more and more to involve conceptual change, that is teachers have to provide pupils with opportunities to restructure their ideas. This involves creating situations where pupils are motivated sufficiently to be prepared to change. This reinforces Black and Harrison's arguments about Tasks, Resources, Capability and Awareness. It may also explain why adults after many years of school science fail to draw upon the resources of knowledge and skills implicit in science in tackling practical problems. Perhaps this is a part explanation of the situation Mayer (1985) has described thus:

"..... it must also be pointed out that a significant amount of agriculture is conducted without any knowledge of the biological principles involved. Biology offers explanations for the phenomena being experienced in farmers fields. But farming, by-and-large, does not profit from these explanations because it is largely conducted on an empirical and traditional bases using methods that have proved effective and failing to experiment to find if there is some better way to reduce labour costs and increase yields. There is a symbiosis between agriculture and biology on which neither has capitalised and from whose exercise both would profit".

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CHAPTER 2

CASE STUDIES: EXAMPLES OF WHAT HAS BEEN DONE IN

SCIENCE EDUCATION

In recent years science educators world wide have come to question several features of school science education in their attempts to improve their teaching/learning practices. In particular the following features have raised concern:

- the extent of relevance to many pupils of the contexts in which much science is taught;
- the considerable emphasis on the knowledge and content of science at the expense of the process and skills and of understanding science as a human activity;
- the lack of opportunity in school science for learning how to deploy scientific facts and concepts to solving problems.

(See Better Science: Making Relevant to Young People, S.S.C.R., 1987.)

The case studies chosen here are to illustrate teaching/learning strategies that have been developed to increase relevance and applicability of science, with the emphasis on biological science. One of the features of such approaches is that it is often necessary to include with the biology aspects of the other sciences as well as other curriculum areas. This can be achieved either through some form of integrated science course, or by co-ordinating the work of the separate science courses. In all the cases described the themes are selected as vehicles for teaching the relevance of biology through its applicability to a variety of contemporary problems - all with potential relevance to the local community. The sections are arbitrarily selected only for convenience of description, there are clearly inter-relations between them all.

Agriculture

Using agriculture as a basis for teaching science has been practised through rural science programmes in many parts of the world. A typical statement of the aims of a rural science programme is as follows:

"To enable individual pupils:

- to develop creative and aesthetic attitudes towards living things and to stimulate lasting interests;
to develop an appreciation of the significance of horticultural and agricultural practices and technologies relating to the efficient production of plants and animals for profit and pleasure;

- to develop an awareness of the way in which economic and social pressures mould agricultural practices;

- to develop a confidence in safely executing practical work involving living things, apparatus and equipment used in the rural science laboratory and in outdoor studies in farm and field, woodland and garden;

- to attain a realisation that scientific methodology has practical applicability in developing an understanding of the principles of agriculture, horticulture and forestry;

- to develop communication skills necessary for reporting in an organised manner the findings of open-ended practical investigations".

(A.S.E., 1984)

A statement of aims such as this, alongside an understanding of the role of biological systems in agricultural processes, (See Figure 14, page 28) can be a valuable curriculum tool for teachers, seeking to use agriculture as a vehicle for science teaching. I have selected two examples to illustrate teaching possibilities, both of which contain practices which seek to realise some of the above aims.

The first example is quoted fully by Jos Elstgeest in discussing Children and Agriculture (Bangalore, 1985). He argues that a child's task is to learn "to interact with the land and the things of the land" and to illustrate how this is possible with very simple materials he quotes two examples from observed practice in two schools in Tanzania. The first case involves work done by a fifth year class in Kigurunyembe in the study of soils. The students collected a number of different soils from, forest, cultivated fields, riverbank, roadside, hilltop, valley and cultivated garden. This in itself is not novel, the traditional approach would then be to analyse the soils, using simple sedimentation techniques, into sand, clay and loam and then perhaps to go on to describe to the students what crops preferred which soil. However in this case the students analysed the soils using their categories - big sand and small sand, soils with more or less of small sticks, bits of leaves, straw, different colours, each time a wet smear of soil was made on white paper. Elstgeest describes how through this the students discovered that one soil can be very different from another soil and this encouraged them to put forward the idea that there may be good soils and bad soils. They were allowed to test out their guesses by planting seeds in their different soils and keeping records of their daily growth. This did not lead to conclusive results that fitted a textbook pattern, but it did encourage enthusiasm and the development of further ideas. The students in carrying out the work, learned something of the intellectual
FIGURE 14
BIOLOGICAL SYSTEMS IN AGRICULTURE

EXAMPLE OF WHEAT PRODUCTION
skills of planning investigations, the practical skills of using a balance effectively (home made simple ones), translating their findings into a graph, measuring a variety of factors e.g. the amount and flow of water through given samples of the different soils, the speed of water uptake in different soils, percentage of air in different soils. They were able to make deductions on the comparative quality of soils. In another school Elstgeest describes how the teacher organised a series of investigations on sorting and classifying seeds, which led the students to setting up a series of experiments on germination. Again this, in itself, is hardly a novel component of a school biology programme. What is important is (a) how the teacher let the work develop from the children's questions (drawn from their own experience in the rural community) and (b) how the teacher based the work on the local environment. The teaching/learning sequence adopted was as follows:

1. Students brought in all kinds of seeds collected locally;
2. They were allowed to describe them and classify them in their own language;
3. One student brought in a large cob of maize which excited the interest of the whole class in terms of how many seeds it had - the seeds were counted;
4. The teacher presented the class with a problem: "Would all the seeds on this cob, big and small, germinate?"
5. The students prepared ten seedbeds, counted the number of seeds per bed, and prepared to water them.
6. The students forgot to water regularly and so had poor germination (the teacher allowed the students to make this mistake);
7. After repeating the experiment more carefully, they still did not get full germination - this led them to pose further questions e.g. perhaps some seeds were more susceptible to disease? They unearthed the seeds and found some rotting;
8. They changed their problem into "can we make it so that all the seeds we plant grow?" They planned the new experiment carefully, selecting what they thought to be good healthy seeds, planted their seeds and waited;
9. While the common problem described was being investigated groups of children tried experiments arising out of this activity: growing seeds without soil; influence of depth of planting; crowding of seeds.

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Elstgeest argues that

"By manipulating real living things such as seeds, plants, or insects, and by letting these respond to being placed in situations which the children themselves create and control (for instance by watering the soil, pruning the tips, turning pots upside down, making it dark) they gradually become aware that living things show a pattern in their responding behaviour. The children become conscious of the fact that by manipulating and controlling the environment, they can influence and control the response and behaviour of living things in certain ways. And is this not the basis of all agriculture?"

The two examples quoted are clearly ones which demand little in terms of practical materials, but they do allow a lot of practical experience of the living world. Local agriculture and agricultural practices can be substantial vehicles for teaching biology if approached in this way. (A possible curriculum framework for achieving this is discussed more fully in a companion volume in the series - No. 11 Agriculture and Biology Teaching, Rao and Pritchard, Unesco, 1984.)

The following example of an agricultural topic used in the teaching of science is somewhat different than the above, in that it uses second hand data and assumes a more advanced stage in the students' study of science and is a direct attempt to put science into a context. In the Science and Technology in Society Project materials (ASE, 1986 quoted in Chapter One), there are a number of units which use topics in agriculture as vehicles for teaching science in context. An interesting example concerns a trace element disease among farm animals (HILLTOP — AN AGRICULTURAL PROBLEM). The activity is presented as a data analysis problem solving exercise. It is suggested as an activity that could be incorporated into an existing science programme. The aims are:

1. To develop an understanding of trace elements in plant and animal nutrition;

2. To develop an awareness of the problems of animal disease and the economic use of land, the effect of the environment on farming and the role of scientists in helping farmers to achieve better production;

3. To develop skills in data handling and data analysis.

The students, working in groups of two or three, are given a description of a farming region in which there are five farms successful in rearing cattle, but four farms unsuccessful. The animals on the unsuccessful farms are underweight and do not grow healthily. The object of the study is to discover why the animals on some farms are not healthy. Students are asked to compare the concentration of metal ions (Figure 15, page 31) in sick and healthy
cattle and to select elements with significantly high or low concentrations in the unhealthy animals. Later the students are given data concerning stream sediments (Figure 16, page 32), together with a geological map of the area and analysis of rock samples (Figure 17, page 32).

**FIGURE 15**

**THE AVERAGE CONCENTRATION (in p.p.m.) OF VARIOUS TRACE ELEMENTS IN THE LIVERS OF HEALTHY AND UNHEALTHY ANIMALS FROM THE "HILLTOP" AREA**

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Concentration in Healthy Animals</th>
<th>Parts per million (ppm) Unhealthy Animals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromium</td>
<td>Cr</td>
<td>2.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu</td>
<td>70.0</td>
<td>16.0</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe</td>
<td>180.0</td>
<td>44.0</td>
</tr>
<tr>
<td>Lead</td>
<td>Pb</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Manganese</td>
<td>Mn</td>
<td>40.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Mercury</td>
<td>Hg</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>Mo</td>
<td>3.5</td>
<td>24.0</td>
</tr>
<tr>
<td>Nickel</td>
<td>Ni</td>
<td>4.0</td>
<td>1.3</td>
</tr>
<tr>
<td>Zinc</td>
<td>Zn</td>
<td>4.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>
FIGURE 16

CONCENTRATION OF ELEMENTS PRESENT IN THE SEDIMENTS OF THE DIFFERENT STREAM, IN PARTS PER MILLION (ppm)

<table>
<thead>
<tr>
<th>Stream</th>
<th>Cr</th>
<th>Cu</th>
<th>Fe</th>
<th>Pb</th>
<th>Mu</th>
<th>Hg</th>
<th>Mo</th>
<th>Ni</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>40</td>
<td>280</td>
<td>30</td>
<td>180</td>
<td>0.5</td>
<td>34</td>
<td>3</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>32</td>
<td>170</td>
<td>4</td>
<td>140</td>
<td>-</td>
<td>4</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>94</td>
<td>420</td>
<td>4</td>
<td>310</td>
<td>-</td>
<td>60</td>
<td>4</td>
<td>81</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>54</td>
<td>340</td>
<td>28</td>
<td>220</td>
<td>0.5</td>
<td>5</td>
<td>2</td>
<td>74</td>
</tr>
</tbody>
</table>

FIGURE 17

ANALYSIS OF ROCK SAMPLES. (VALUES IN ppm)

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Cr</th>
<th>Cu</th>
<th>Fe</th>
<th>Pb</th>
<th>Mu</th>
<th>Hg</th>
<th>Mo</th>
<th>Ni</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limestone</td>
<td>0.75</td>
<td>4.2</td>
<td>120</td>
<td>3.5</td>
<td>160</td>
<td>0.03</td>
<td>1.25</td>
<td>0.65</td>
<td>4.5</td>
</tr>
<tr>
<td>Grit</td>
<td>1.10</td>
<td>3.7</td>
<td>65</td>
<td>40</td>
<td>145</td>
<td>0.03</td>
<td>1.80</td>
<td>1.3</td>
<td>3</td>
</tr>
<tr>
<td>Mudstones</td>
<td>1.20</td>
<td>5.6</td>
<td>165</td>
<td>5</td>
<td>125</td>
<td>0.04</td>
<td>3.5</td>
<td>1.45</td>
<td>2</td>
</tr>
<tr>
<td>Shales</td>
<td>1.45</td>
<td>7.7</td>
<td>175</td>
<td>4</td>
<td>137</td>
<td>0.03</td>
<td>6.2</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Sandstones</td>
<td>1.50</td>
<td>11.5</td>
<td>200</td>
<td>5</td>
<td>157</td>
<td>0.04</td>
<td>5</td>
<td>1.8</td>
<td>6.2</td>
</tr>
</tbody>
</table>
The study leads the students to identifying Molybdenum as the cause of the sickness. However the symptoms displayed by the cattle are caused by copper deficiency. This suggests that Molybdenum in the diet is preventing the uptake of Copper. Other work has demonstrated that Molybdenum forms associations with proteins in the same way as copper. The copper is thus 'blocked' and its normal co-enzyme action is prevented so inhibiting the catalysis of reactions which are essential for metabolism in cattle.

This latter example is a good one to illustrate how more complex science can be taught in ways which show its relevance directly to problems in agriculture.

**Biotechnology**

The use of agriculture as a basis for teaching a biology that is relevant to many current issues is perhaps obvious in school science. However biotechnology may conjure up a picture of such high level and obscure science that at first sight it seems an unlikely candidate as a vehicle for teaching school science. Biotechnology finds application in a great variety of industries, including those of food, agriculture, pharmaceuticals, energy and environmental control either as an ancient craft, or as a modern science based technology. Advanced biotechnology in solving industrial and other problems (a) highlights the blurring of distinctions between science and technology and (b) brings about wider problems and issues that are of public concern. An encyclopaedic knowledge of current industrial applications of biotechnologies is not likely to be particularly valuable to future adults. However an understanding of the nature of biotechnology and the basic science of its applications is important.

There are two dimensions of biotechnology that are currently being usefully considered for school science teaching. The first relates to the long established biotechnologies such as brewing, bread making, and yoghurt making. These are essentially crafts, the technology is ancient and not, until recently science based. With our contemporary scientific understanding of the processes it is possible to enhance the associated crafts, and in this sense the inclusion of such biotechnology in school science programmes may be of direct relevance to communities - especially rural ones. The second dimension relates to the science based biotechnology such as insulin production and plant cloning. The former may involve science concepts too complex to handle fully at the school level, but such topics provide very useful vehicles for students to explore the societal affects upon, and implications of, science and technology. The latter, plant cloning, offers topics that can allow (a) conventional school science in this case plant anatomy, to be taught in a more relevant and dynamic manner and (b) opportunities for developing practical skills that can be of great advantage to a developing society. These issues have been translated into aims which policies including biotechnology in science programmes might seek to achieve.
- promoting awareness about the range of biotechnologies;
- promoting awareness about how the results of research in biology, chemistry and biotechnology are adopted by industry;
- promoting awareness of how science, technology and society interact;
- promoting scientific and technological capability.

(Better Science, ASE, 1987)

In considering how to incorporate biotechnology into science education it is worth bearing in mind the components of contemporary biotechnology that is: Fermentation technology; Enzyme technology; Genetic engineering and Plant and Animal Cell Culture. The main areas of application of biotechnology are illustrated in Figure 18, page 35).

There are a great variety of examples one could choose to illustrate the teaching of biotechnology. I have selected some which in total are reflective of (a) the range of applications of biotechnology referred to in Figure 18, and (b) the various aims referred to above.

**BIO-GAS**

Bio-gas plants, used in 46 developing countries are an integrated technology, providing both fuel and fertiliser. The fermentation of animal dung, human excreta, or crop residues in an airtight container yields a methane rich gas. This can be used to heat stoves, light lamps, run machinery, or produce electricity. The residue left by bio-gas production can be used as a fertiliser or as a component in animal feed. Sewage systems built to collect human wastes for bio-gas production also help to improve hygiene. Clearly such technology is very relevant to many rural communities. An understanding of it embraces a wide range of science concepts, it involves simple technology, and can engage students in decision making, science, technology and society, exercises. A very interesting unit of work involving bio-gas has been written as part of the Third World Science-Development Education through Science Teaching Project, (Williams, I. W., Bangor, 1982). This unit describes the basic theory behind bio-gas technology viz: Fermentation, Temperature and nutrient dimensions, Water and pH balances, and the biology of digestion. It gives examples of an operational methane gas plant (See Figure 19, page 36) and describes the role of Integrated Bio-gas system in the context of Sri Lanka - a country lacking in fossil fuels and capital. The unit includes details of how to make an experimental methane digestor using cheap materials available in a school laboratory. It would be very valuable to any teacher seeking to develop science teaching materials using bio-gas production.
FIGURE 18
THE MAIN AREA OF APPLICATION OF BIOTECHNOLOGY

1. **Fermentation Technology**

   Historically, the most important area of biotechnology viz: brewing, antibiotics etc., extensive development in progress with new products envisaged viz: polysaccharides, medically important drugs, solvents, protein enhanced foods. Novel fermenter designs to optimise productivity.

2. **Enzyme Engineering**

   To be used for the catalysis of extremely specific chemical reactions; immobilisation of enzymes; to create specific molecular converters (bio-reactors). Products formed include L-amino acids, high fructose syrup, semi-synthetic penicillins, starch and cellulose hydrolysis etc. Enzyme probes for analysis.

3. **Waste Technology**

   Long historical importance but more emphases now being made to couple these processes with the conservation and recycling of resources; foods and fertilisers, biological fuels.

4. **Environmental Technology**

   A great scope exists for the application of biotechnological concepts for solving many environmental problems - pollution control, removing toxic wastes; recovery of metals from mining wastes and low grade ores.

5. **Renewable Resources Technology**

   The use of renewable energy sources, in particular lignocellulose to generate new sources of chemical raw materials and energy - ethanol, methane and hydrogen. Total utilisation of plant and animal material.

6. **Plant and Animal Cell Culture**

   Propagation of many plants, horticultural and agricultural - orchids, strawberries, oil palms.

7. **Genetic Engineering and Breeding**

   Production of new varieties of plants and animals. Breeding resistance to disease by transfer of genes from one species to another species. Biological Control.

(Adapted from Smith, J. E., Biotechnology, Edward Arnold, 1981.)
FIGURE 19 (A)

RELATED CONSIDERATIONS OF A DIGESTER OPERATION

FIGURE 19 (B)

THE CLOSED NUTRIENT SYSTEM OF A COMPLETE DIGESTOR OPERATION
DAIRY BIOTECHNOLOGY

Dairy Biotechnology used in cheese manufacture and yoghurt making is an important technique practised worldwide. Recently techniques have been devised in India for making hard (Cheddar style) cheese from bullocks milk in order to provide a protein rich food which stores cheaply. This is an important contribution to increasing culturally acceptable higher protein foods.

A group of teachers based in Sheffield, U.K. under the auspices of the national Secondary Science Curriculum Review have developed a whole series of practical activities intended to give students experience of biotechnology. One of the foci of these activities is on Dairy Biotechnology. In this unit they suggest three activities: (1) *How Yoghurt is manufactured* - which involves the use of students' worksheets designed to give the students some insight into the manufacturing process. This is accompanied by a flow chart which encourages the students to apply their knowledge to answering practical questions concerning the techniques used e.g. Why is the milk heat treated at 90°C? Why is it then cooled to 37°C? What changes occur in the milk mix after six hours? etc. (2) *Making a Natural Yoghurt* - a short practical illustrating how simple the technique of yoghurt making can be. This provides the basis for Activity 3. (3) *Making a Nice Yoghurt* - which is an investigation of consumer preferences. The teacher can then suggest a fourth activity - Designing a New Yoghurt in which the students can explore this as a case study of the technical, commercial, social and health dimensions of the food industry in their society.

CLONING

After many years of work a successful tissue culture technique has been developed for the production of oil palms. It involves cutting a piece of tissue from the root of a selected, hardy and high yielding parent oil palm and then regenerating it in a special nutrient medium into many thousands of young palm trees, all of which will possess qualities indentical to those of their parent. Trees propagated in this manner are already bearing fruit in Malaysia, and others have been planted in other parts of the world.

This example of biotechnology in action can provide the basis for a range of teaching possibilities. It has been developed by the U.K. SSCR Group (see above) as an exercise in *Science and The Public...* This unit has four suggested activities:

1. A *discussion about Cloning* - which is prepared (a) as a role play - students acting as members of the public interviewed about their views on cloning followed by (b) a worksheet based series of questions for class discussion. This is extended then by asking the students to answer questions based on their reading of a specially prepared newsheet on the application of cloning techniques;
2. **Scientists at Work** - a look at how scientists work in a research institute with examples of the practical techniques used in plant cloning.

3. **Growers at Work** - This is an exercise which emphasises the links between scientific research and industry. It also looks at the role of profit in determining the application of science within industry. Data such as in Figure 20 (page 45) is given together with other data, and students asked questions such as: How much would a grower have to pay a Research Institute to develop a cloning technique? How much profit can be made from the sale of plantlets (whatever seems to be an appropriate variety) each year? Could the grower afford to pay the Institute in full straight away using the profits from the sale of plantlets? Would the grower have to borrow money in order to go ahead?

4. **Oil-palm Cloning - A Commercial Enterprise** - This activity takes the example of the development of oil-palm cloning by a large multi-national company and focuses on issues such as:

   (a) Third World economy problems:

   (b) The benefits to less technologically developed nations of advances in scientific research;

   (c) World trade and the role of large multi-national companies in the economies of highly technological areas of the world;

   (d) The disadvantages of foreign investment on the Third World.

**GENETIC ENGINEERING**

Clearly this is a very advanced area of biotechnology, but there are examples of it being developed in school science. The U.K. SSCR group mentioned above have developed a unit of work on Genetic Engineering and The Public using the production of Insulin as the focus. In Denmark K. Johnson of the Rungsted Statsskole (E. W. Thulstrup, 1985) has described work including practical studies on genetic engineering. In this case a group of students were asked to imagine themselves as a newly established research group working in a factory producing enzymes for industrial use. They were told that they had discovered by chance a bacterial strain that could produce a particular enzyme in large amounts. Having this strain meant that the enzyme could become commercially feasible to the factory.

The research group were given the following questions:-

- could commercial production of the enzyme be established?

- which kind of purification processes would be suitable?
- could the genetic information be characterised and integrated in a more convenient strain?
- could the factory take out a patent for the genetic information and production?

Johnson reports that the strain of bacteria had been recommended to him by professional bacteriologists as suitable for such a project.

Suitable assay methods for the enzyme and procedures for gel-making, protein separation, and DNA extraction were found in the scientific literature before the project was developed. The students were trained in the necessary techniques - cultivating bacteria, practising sterile techniques, recognising the phenotype of the strain and determining enzyme activity.

The students were organised into five teams, each working with different extraction procedures, after cultivation of large enough quantities of the bacteria for enzyme preparation. The different procedures were compared and the best adopted for further purification. Although it was not possible to transfer genetic information of the strain to others in vivo, DNA preparations were made and analysed by gel-electrophoresis. A new strain was then prepared for in-vitro transformation and mixed with the DNA preparation. Johnson reports that the results were very successful - hundreds of colonies with the expected phenotype. The students were able to answer the first three questions and the fourth was handled theoretically. Johnson argues that the students learned much

"about general biological phenomena and methods (genetics, biochemistry and biotechnology)..... they had to learn and practice - laboratory safety rules, personal safety, responsibility to other persons entering the laboratory, and waste handling. Through the practical work they learned to make critical evaluations of the information they got from different sources - and to argue intelligently about possibilities and problems of biotechnology in industrial production".

(Thulstrup, E. W., 1985)

This latter example is clearly one which requires on the part of the teacher very advanced technical knowledge and skills, as well as the availability of advanced, and often expensive, equipment. It importantly, however, raises very interesting questions about what techniques and materials can we seriously expect to engage pupils in schools with. The issues of safety are all important in this instance, because very good controls, very technically competent teachers and clearly good laboratory circumstances were available, the results, as Johnson argues, were invaluable in helping students grasp the issues of safety, personal responsibility and the use of biotechnology.
Medicine and Health

Biology has long been a vehicle for health education, and because of its importance in the preparation of future medical students, has often been oriented towards human biology. However the emphasis has tended to the academic and only recently have science courses gone beyond content concerning medicine and health, towards teaching strategies that relate the content to local and personal and community health issues.

Three very different approaches to using health issues as vehicles for science teaching may illustrate the trends in teaching human and medical aspects of biology related to the needs of different communities. The first described is an approach to nutrition education in the Philippines, the second an issues study approach in Australia, and the third a medical technology approach in the U.K.

NUTRITION

In the Philippines a nutrition education programme for an uplands community has been developed which attempts to integrate the formal school work in science into a network involving formal, informal and non-formal systems of education (Villavicencio, R. R., 1980). In 1977 the Biology Workgroup of the University of the Philippines Science Education Centre initiated a community based science and technology education project to make use of natural resources and real-life situations for the learning of science concepts in order to improve the economic and socio-cultural activities of the community. The project aimed in the long term to develop an understanding of ecological relationships in young and adult members of the community in order to help them take appropriate action to ensure a healthy and stable environment. The main aim of the project was to protect the environment. The preservation and maintenance of a healthy human environment was seen to be integral to this. Thus, health and nutrition were seen to be essential components and included as an aspect of the science and technology project.

Initially the needs and resources of the village communities - economic activities, community structure, health and nutritional status, natural resources of the community, extent of knowledge of the environment, were surveyed. This was done sensitively with small teams of researchers living in the village for three to four days each month until they were accepted. A free clinic was offered and records were kept by the resident teacher and the village leader.

An agriculture-based nutrition education programme was developed for the community. The researchers using the prevalent illnesses as starting points and hypothesising that

"if people could clearly see that:

- they could grow crops rich in nutrients needed for good health,
- the livestock farming, such as raising goats and poultry and fish cage culture could be successful in their environment, and,

- that they could be taught improved farming and good methods of food preparation,

they would accept and accommodate the programme as part of their daily lives".

(Villavincencio, R. R., 1980)

The teacher and farm technicians, together with the provision of seeds and seedlings were important elements in providing the community with resources and skills. Importantly the school science was integrated with the community development. Fish cage culture was introduced to make use of the stream that traversed the village and the initial training for fish cage culture was undertaken as a project in science by Grade V and VI pupils. A dug out pond in the school grounds was used as the fish pond. A module was written on Tilapia and carp emphasising their feeding and growth patterns as an accompanying text.

The nutrition and general health education in the school go in this way beyond simple academic knowledge to its utilisation in the community – this clearly uses science education as a component of human development.

ISSUES STUDIES

Health and medicine can involve controversial issues. Developments in biological science when applied in medicine place us in new moral dilemmas. In vitro fertilisation ('test-tube' babies), transplant surgery, the use of synthetic hormones for contraception are all issues that cause persistent public debate in communities throughout the world. Margaret Brumby working in Monash University, Australia, has developed a very interesting teaching strategy where she uses issues such as In vitro fertilisation as a means of both engaging the interest of students in complex areas of biology and so teaching concepts through such issues, and giving students opportunities to explore the social and moral dimensions of science and technology.

The aims of 'issues studies in biology' she suggests are:

1. To enable a student to develop an understanding of the impact of new developments in biological science;

2. To analyse an issue on which there is current debate, identifying the key questions and setting out the main points of controversy;

3. To consider the relationship between science, scientists and society, both now and in the future.

(Brumby, M., 1984)
A particularly interesting feature of this approach is that the students not only engage in studies of the relevant science, but also the moral and ethical issues emergent from the technical possibilities that arise from the science and very importantly a consideration of the existing legal framework. This is, for instance, illustrated by looking at the legal definitions of death and how these may relate to scientific definitions.

The topics dealt with in this work so far are:

**New Ways of Making Families:**
- Artificial Insemination by Donor (AID);
- *In Vitro* fertilisation and use of donor gametes;
- Surrogate motherhood.

**Experimenting on Living Organisms:**
- The use of animals in scientific research;
- The use of humans as subjects;
- The possible use of human foetal tissue;
- Genetic engineering and patenting forms of life.

**To Live or Let Die:**
- Abortion;
- The birth of severely disabled babies;
- Euthanasia.

**Environmental Protection:**
- Environmental change which may damage life;
- Conserving our natural heritage.

**MEDICAL TECHNOLOGY**

A module of work on medical technology for 13 - 16 year olds developed in the United Kingdom is an interesting example of how human biology can be related to both technological capability and awareness. This work involves students in technological problem-solving exercises, which require the application of scientific knowledge to technological problems e.g. How can dialysis be made quicker and more efficient? - a problem posed in a study of kidney dialysis technology. This is also interesting because the concepts necessary to illuminate the problem are not only biological, but also involve the other sciences. It is a much more real situation than the usual one which separates the biology artificially for curriculum purposes.
This material can perhaps best be illustrated by describing an extension to work on the heart - the design of a replacement heart valve. The authors suggest that the students are asked to:

"Put yourself in the position of one of the early 'medical engineers'. They then give the following instructions:

"You have the job of coming up with an idea (or lots of different ideas) for an artificial heart valve. Before you start you need to know one or two things about what will be required - the design features. These are that the valve should:

1. be small enough to fit in the space inside the heart;
2. be able to be sewn in quite quickly and easily (remember that the 'seating' of the valve will gradually heal into the heart tissue and become completely leakproof;
3. be opened and closed simply by the flow of blood;
4. have as few moving parts as possible (so it will be long lasting and won't require servicing);
5. be made of materials that will
   (a) present smooth surface to the blood
   (b) avoid rejection".

They suggest the students work in small groups to bounce ideas off each other and talk to their Craft teachers also. Clearly such an approach not only provides for a technological problem solving aspect, but also gives opportunities to raise issues of the moral, ethical and economic aspects of science and technology. In this case for instance what areas of medical technology are the most urgent to spend money on given the needs of the surrounding community.

The authors of this material comment on the use of technological problem solving exercises:-

"How this is approached will obviously vary according to the circumstances and resources of your school. In some instances pupils may actually get to design and experiment practically with simple model systems. In others they may at least be allowed the opportunity to reason out theoretical solutions to problems".

(Newcastle SSCR Group, 1987)
Conservation and Resource Management

Issues of conservation and resource management are very suitable for developing a science education reflective of human needs and intended to help individuals understand how science can contribute to sustainable development. Rugumayo (1985) in discussing environmental education argues that there are key environmental issues for which biology has a special significance - there are, in his view, conservation; food; family planning; water-related and pest vector diseases; pollution and energy. He suggests how such issues may help in developing a national environmental education programme (Figure 20, page 45).

Three topics follow as illustrations of how conservation and resource issues have been developed within science teaching programmes. They all describe strategies that could be modified to suit the circumstances of different education systems with differing resources and priorities.

CONSERVATION OF SPECIES

Zoos, game parks and conservation areas all are invaluable vehicles for teaching about the diversity of life forms and through this some of the processes of science. The BIBS project at the University of Southampton has developed a unit of work involving a field visit and follow-up school based work (Buckland, Falconer, Pritchard, 1986). This work is concerned to introduce young secondary pupils to issues of maintaining rare species of wild life. It is aimed through this to give them some understanding of (a) the variety of life-forms, (b) the needs of wild animals - particularly in relation to feeding, space and reproduction and (c) the scientific processes of observation and inferencing. The work is constructed in such a manner as to encourage the students to see these issues not only as having scientific dimensions, but also moral and aesthetic aspects. Later work develops the economic and cultural dimensions of conservation of rare species. The zoo visit is organised so that the students are first encouraged to make a personal response to the animals they are to study, to describe in their words how they feel about the animals. They work in small groups sharing their ideas. Later they are directed, using a worksheet, to observe in a more directed manner, focussing on the animals needs (Figure 21, page 46). The results of their observations are collated back at school and with use of further data, photographs and work sheets the students work focuses on making inferences from their observations. The idea here is that in making inferences students combine their previous individual experiences with immediate observations. As the previous experiences will differ, students are able to generate a range of inferences from similar observations. The technique here is to use cartoon type drawings (Figure 22, page 47) to help students understand the relationship between observations and the process of inferring.
FIGURE 20

DIAGRAM SHOWING THE PROCEDURE NECESSARY IN IDENTIFYING KEY ISSUES IN ENVIRONMENTAL EDUCATION AND HOW THESE MAY BE INTEGRATED INTO A NATIONAL ENVIRONMENTAL EDUCATION PROGRAMME.

1. Review existing literature & data
2. Inventory and ranking of major problems.
3. Case Studies
4. Cost-effective analysis of gathering information
5. Evaluation & Monitoring

1. Conservation: soil, water, vegetation cover, wildlife, recycling of materials, desertification, etc.
2. Food: production & nutrition; use, control & effect of pesticides & herbicides; ecological control of weeds & pests; maintaining a rich genetic variety.
3. Family planning: maternal and child nutrition, infant mortality, population growth and control.
5. Pollution: industrial (air, water, soil), sewage treatment & disposal, solid waste disposal.
6. Energy: conventional, alternative sources - bio-gas, processing energy from waste, etc.

for which biology has a special significance

Biology Educational Curriculum
School General
Environmental Clubs

Technical College
train technicians in environmental science

University
Ecological (environmental) studies based on key issues above

Public Participation

National Scientific Body and/or appropriate Government Ministry
FIGURE 21

WORKSHEET FOR ZOO VISIT

NAME: ..................

MARWELL ZOO VISIT

WRITE DOWN:

1. Which animal you are observing.
2. Where it lives in the wild.
3. A description of the animal for someone who has never seen it.

DRAW A plan of the enclosure, include any features that you think are important for:

A. The animals, marking on the plan the position of each animal.
B. The keepers' work.

NOW WATCH THE ANIMALS CLOSELY.

NOW WRITE DOWN:

4. How many there are.
5. What they are doing. (For example, playing, sleeping, grooming, feeding, moving, ...........)

If you were the keeper how would you look after the animals?
What did they **OBSERVE** that made them **INFER** that the rhinos are very strong animals?

Which other **INFERENCES** did they make? Which **OBSERVATION** supported it?

Think of more **INFERENCES** about rhinos.
Other work developed uses areas of the school grounds which are kept as small nature areas (Buckland and Pritchard, 1986). This work is particularly useful to develop conservation of species questions of relevance to the local community. The maintenance of the area itself provides many opportunities to enrich science programmes, but the major value is in the recording of data (qualitative and quantitative) over a long period of time. In this case the students collect data regularly as part of the maintenance (e.g. number and type of species of birds/insects etc, variety of plant life, meteorological records) and the science department acts as a local environment data centre. After some time such data is a very valuable resource for teaching. One technique that can be employed with such a nature area is to divide it into plots and in some cut the vegetation regularly, in others less frequently and in others not at all. Samples of the plots over time will reveal the development of communities with greater and lesser variety of species. Such work can lead on to questions of the likely impact of agricultural monocultures in the local area.

CONSERVATION OF GENETIC RESOURCES

This topic, while in the end concerned with species protection, may be a useful way of focussing the teaching of genetics and evolution in relation to issues of conservation and resource management. The genetic potential of life forms is enormous. Each species has a gene pool from which an extraordinary array of individuals can be selected. The application of this knowledge through genetic engineering has been referred to earlier, but work which can give students some insight into the importance of conserving genetic resources is necessary as a basis for understanding the value of genetic engineering techniques. The world's genetic resource can be illustrated with many examples, for instance the Tilapia which may soon usurp carp as the choice of the world's fish farms. In Lake Malawi at present there are 164 species of Tilapia. This fish can convert food to flesh faster than most other fish. Molluscs are first rate pollution monitors. Tojoha, long considered a desert weed produces a wax which retails to Japan for 3,000 dollars a barrel as a substitute for sperm whale oil. Cassava is a vital food crop whose disease resistance has been considerably increased since disease resistant traits were transferred from its wild cousin Manihot glasiovii. Such examples can be useful case studies for developing teaching materials which aim at teaching elementary genetics and giving students insights into issues of genetic resource conservation. Coffee is an interesting crop which can be a useful case study. Many of the coffee growing areas of the world, notably South America have coffee plantations whose origins lie in a very few number of plants. Their gene pool is therefore limited. The wild-type coffee plants are found largely in Ethiopia - the centre of origin of coffee. Coffee suffers from a number of diseases - any resistant genes will be found in the gene pool of the wild type coffee. Clearly the need for seeing conservation of genetic resources as a world problem is highlighted by such a case. Teaching material which illustrate these have been developed in Southampton University (Pritchard and Buckland, 1986).
IMPACT STUDIES

The use of impact studies has been used as a vehicle for teaching ecology in such a way as to apply it to issues of resource management. Such techniques use role play, simulation (both paper and computer based) together with laboratory oriented projects. Fairly sophisticated computer simulation exercises have become increasingly available. Two interesting examples are 'Rainbow River' and 'Golden Eagle' both produced by Cambridge University Press. The first provides data on variables related to maintaining river quality such as oxygen concentration, micro-organism concentration, vegetation, inorganic pollutants, and biotic index. The programme so provides data from a long term river study so that students can explore fresh water pollution and engage in issues studies. The second (Golden Eagle) allows students opportunities to explore the problems of managing a conservation area, and to apply their scientific knowledge to such issues.

Techniques not requiring the use of sophisticated and expensive machinery, involve instead the use of background notes and role playing. The SATIS materials already mentioned in the section on Agriculture (page 30) contain such units. An interesting set of examples for development in this respect are the unexpected impacts of dam building in some parts of Africa. The Aswan dam for instance – among the unexpected impacts was the explosion of the water based parasite disease Schistosomiasis. Such work can be developed also for small scale impact studies, for instance the development of a fish farm in a village (Buckland, 1985). This can be linked to work in the laboratory. A school pond or even aquarium would be sufficient in order to rear for example, Tilapia (Yaunde Workshop, 1985). Work such as this together with for instance the possible use of the production of bio-gas as a parallel development, and its impact on the incidence of Schistosomiasis would make meaningful, relevant and practicable impact studies for science teaching in many developing countries.
CHAPTER 3

PUTTING IDEAS INTO PRACTICE

Teaching Styles

The emergence of an applied approach to biology teaching reflects (a) the concerns for a science education that can help contribute to the development of personal capability and (b) the results of research into children learning of both the concepts and processes of science. The idea of developing personal capability has been seen as necessarily emergent out of the central purpose of school learning, that is to increase the young persons competence in taking responsibility, not least for their own learning. Through this science can make a direct contribution to the overall purpose of education by helping students to develop self-confidence in dealing with and understanding the world in which they live. All students come to school science with well established beliefs about natural phenomena, (a fuller discussion of this can be found in the volume in this series on Understanding Biological Ideas, Kelly, 1987).

The task of the science teacher is to create circumstances where such beliefs can be effectively challenged such that students may be prepared to explore scientific concepts and so restructure their understanding of the natural world. The use of situations which are real to students and which are amenable to the application of scientific ideas and procedures, is an important strategy for translating the purposes of school science into an effective model for classroom teaching. Figure 23 (page 51) is a model devised by the Secondary Science Curriculum Review (1987) in the United Kingdom, that seeks to show how one may go about implementing such a strategy.

What is clear with all the case-studies of teaching applied biology that have been quoted in Chapter 2 is that they cover a much wider variety of teaching and learning strategies than those commonly found in school science programmes. Many of these strategies are ones that may be found in use in schools, but in areas of the curriculum other than science. There are a number of characteristics of applied approaches to teaching science that distinguishes them from the more traditional teaching of science. The more important of them are:

(i) the learning sequences are more web like than linear;
(ii) teachers seek to engage the pupils in helping define the purpose and structure of the learning activities;
(iii) a consideration of cross-curricular links with other subjects is seen to be important;

- 50 -
THE INTERACTIVE CURRICULUM MODEL

Stage I
- learner
- Define the purpose
- Define the purpose
- teacher

Stage II
- Select the approach
- Brainstorming
- Mime
- Teacher demonstrations
- Problem solving
- Fieldwork
- Design and make
- Visits
- Practical work
- Discussion
- Displays
- Roleplay

Stage III
- Perform the activity
- laboratory
- workshop
- classroom
- Effects of school organisation—timetable

Stage IV
- Evaluate the outcome
- work-place
- drama studio
- environment
- residential
- Effects of resources and departmental cooperation

Learner's prior experience, skills, understandings, expectations and behaviour.
Teacher's prior experience with approaches, teaching style and preferences.
(iv) a wide variety of approaches to teaching and learning are used in all topics;

(v) the structure of a topic is determined at least as much by problems and issues of the world in which the children live as it is by the internal logic of science.

Where such approaches have been successful is where they have either arisen within the school/education system itself (e.g. SATIS - ASE, 1980) or the associated teaching/learning materials have fulfilled a need already perceived by teachers (e.g. Thulstrup, 1985). Teachers (and pupils) practised in traditional enquiry style science teaching, and satisfied with such a method, often find other structures and approaches threatening. This sense of insecurity is significantly reduced if well prepared curricular materials are available, and this is further helped by good in-service teacher-training provision. In an evaluation of the teaching bio-technology experiment in Denmark for instance (See Chapter 2 - Genetic Engineering - Thulstrup, 1985, page 38) Libner reports that both pupils and teachers found the work interesting and relevant. The project groups initial purpose had been (a) to develop teaching materials which, within a reasonably short time, would enable teachers to gain any necessary knowledge, and (b) to inspire teachers through ideas on how to organise teaching. This was in a situation where they felt that it would not, without such materials, be possible for teachers to teach biotechnology since available information was primarily meant for people with special knowledge and work. This is likely to be the case for most applied examples of biology, since in many countries teachers initial training is in pure science, and necessarily teachers have little time for experience of the working world outside the school. The case study on Nutrition Education in the Phillipines (Chapter 2 - Villavicencio, 1980, page 40) is a further interesting example of how teachers, in a very different setting to that of Denmark, may be helped in developing an understanding of the application of biology in order to infuse this into their teaching.

Using the theme Man's Intervention in the Natural World and exploring teaching this through issues such as those involved in farming; horticulture; aquaculture; pets and domesticated animals; conservation and biotechnology - the BIBS team at Southampton University (U.K.) have developed a typology for identifying the dominant elements in applied biology teaching. Figure 23 (page 53) illustrates how in structuring a topic a teacher may use such a typology to help in deciding (a) likely student interest and (b) appropriate teaching/learning approaches. In teaching a topic structured on aquaculture, for instance, it may be that locally river pollution is a problem and so the students may be interested in this as an issues aspect. A starting theme may be a pollution study, starting with a simple practical investigation to detect possible sources of pollution. It is possible to construct simple tests which are low in knowledge demands, involve some observation and inferencing skills, and which can form the means of generating an initial issues study, which would lead to a recognition of the need for more knowledge (Buckland, 1987). An ecological study may for example follow, engaging students in both knowledge and science
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process modes of thinking, and finally a technological problem-solving task designed to provide simple practical ways of resolving the pollution problem (in most cases the problem will have to be an 'invented' one, amenable to solution by the students, but derived from a real-life situation). Students would engage in a wide variety of learning strategies - some of which are illustrated in Figure 24 (page 53). A full and useful discussion of such a range of learning activities that may be used effectively in science teaching will be found in "Better Science - Approaches to Teaching and Learning" (Secondary Science Curriculum Review, Curriculum Guide 4 - Heinemann/A.S.E., London, 1987).

Resources

For many teachers any attempt at introducing applied aspects of biology into their work is difficult. Although, biology can play an important role in health care, agriculture, industry etc., and these activities are all a part of the students world outside the classroom, teachers often have little direct experience of biology being applied to such activities. Equally the resources traditionally available to science teachers, equipment, books, data, are mostly concerned with, or derived from, pure science. There will be examples of some applications, e.g. the nitrogen cycle and the importance of fertilisers, ecology and pollution issues such as pesticides in food chains. However these are often very general and not particularly useful for teachers concerned to develop more detailed applied studies, and especially studies related to the local circumstances of their students.

In developing aspects of teaching biology in the style discussed in this book the range of resources necessary for a teacher are much wider than those needed for traditional science. Equally importantly the information teachers and students need to use is more ephemeral than that of traditional science teaching. Although evidence in science is always changing as research develops, and some updating is frequently needed for school science, data concerning science related issues (e.g. pollution problems, nutrition problems etc.), changes very rapidly. There are essentially four groups of materials teachers would find helpful as 'resource information banks' in developing curricular materials with an applied dimension:

(a) **Applications of Biology** - examples of the application of biology to practical daily life relevant to the students context. Unesco publications can be very relevant here, but national science teachers associations are probably a very important means of bringing such material to the attention of teachers;

(b) **Low cost apparatus** - examples of low cost apparatus that teachers can develop to inject a more technological aspect to their science teaching e.g. simple bio-gas generators. Here again Unesco and national science teachers associations are rich sources of information.

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(c) Local Practices and Issues - details of local biology related practices and issues (e.g. in agriculture and health care) together with associated data. Here again the science teachers association may be an important vehicle for collating and disseminating information. Local colleges of agriculture, hospitals, doctors, research institutes and industrial organisations often keep records which can provide teachers with valuable raw materials of current value for lesson planning.

(d) Associated Data - data, especially local and national, concerning, for instance, the planning, legal, economic, and social aspects of science related issues. Some of this is often obscure - especially the legal and planning dimension of issues. Lawyers, Planning Officers, Chambers of Commerce, and Accountants, are all people although they may not know it who can be valuable resources. Again the science teachers associations may be effective means of assessing and disseminating such data.

In countries with established computer data bases, the development of electronic mailing systems will enormously enhance science teaching with an applied and issues dimension. However, for many, the local teachers group, supplemented with regional and national guidance, particularly through the science teachers own professional organisations, will still be the effective means of dissemination for a long time.

Of equal importance to teachers as the resources in the form of data and ideas detailed in (a) - (d) above, is the provision of opportunities to extend their experience beyond the classroom and into these aspects of daily life where biology may have a role to play. In this respect recently in some countries teachers have been given time to work in appropriate areas of commerce, industry and the social services in order to gain experience relevant to reconsidering their science teaching. Sometimes this has been an informal arrangement where after the 'work experience' it is hoped the teacher will be able to include more applied work in the school. In others it has been part of broader curriculum development, where the teachers have been expected to write curricular materials arising from their work experience (Health and Safety at Work, BIBS, 1987). In either case the teachers have not been just observers, but have been given work to do which was necessary for the commercial or industrial concerns, or social service agencies (Planning and Ecology, BIBS, 1987). These forms of 'work experience' outside school are usually for periods of about three months. Teachers engaged in this experience are then expected to disseminate ideas to fellow teachers. Shorter visits, usually a few days, followed by continued informal contact have also become common practice, with the advantage that it is possible to give many more teachers experience out of school in this way. This approach is also being explored as a component in pre-service teacher training (Buckland and Pritchard ICP, 1985) in the United Kingdom (See ICP Project, Universities of Bath and Southampton).
In all these situations what seems to develop in the reciprocal goodwill between teachers and the community, so that people working in many spheres of life are prepared to help contribute both directly and indirectly to school science education. This latter situation is one which can cultivate all the necessary resources for schools to redirect their science teaching to meeting human needs.

**Assessment and Evaluation**

Implicit in many of the teaching styles in the case studies quoted are two forms of assessment procedures, formative and summative assessment. In attempting to engage pupils in helping to define the purpose and structure of learning activities, (See the earlier discussion on teaching styles in this chapter), teachers need to use formative assessment procedures.

Formative assessment has been described as "a means by which the teacher and pupil can find out what a pupil has or has not managed to learn, and is therefore a guide to subsequent action" (Black and Dockrell, 1980). The interactive curriculum model (Figure 23, page 51) described earlier involves formative assessment techniques in developing stages I, II, III and IV. The instrument also referred to earlier for selecting interest and relevant teaching/learning strategies (Figure 24, page 53) is based on particular formative assessment techniques currently being developed for applied biology teaching by the Southampton University BIBS team (Buckland and Pritchard, 1987). A fuller discussion of techniques of formative assessment will be found in the volume in this series on Understanding Biological Ideas (Kelly, 1987).

Summative Assessment is essentially that which records a student's achievement for certification purposes - this often now involves not only final course examination papers, but also continuous assessment. A lot of effort is currently being given to the development of graded assessment procedures - all these are criterion referenced systems as opposed to norm referenced systems. They lend themselves particularly well to assessing achievement resulting from the teaching strategies discussed earlier.

Currently most applied approaches to science teaching use a mixture of formative and summative assessment together with profiling and records of achievement. A very useful discussion of a variety of assessment techniques and records of achievement will be found in 'Better Science: Assessing Progress' (Heinemann/ASE, 1987). One of the interesting and important aspects of current developments in profiling and records of achievement is the engagement of the student in making comments on their own strengths and weaknesses.

Clearly whatever strategies are adopted for assessment purposes the range of objectives to be assessed when teaching through an applied approach is very wide, at one end simple manipulative skills, through measuring conceptual understanding, and the intellectual procedures of science, to the students ability to discuss the economic, social and technological contexts of the biology
they have been taught. In the United Kingdom a working party on Assessment Grade Criteria for Biology, for the new national secondary examinations at age 16 years (General Certificate of Secondary Education) has suggested that for the purposes of grade assessment three domains should be identified:

Domain A: Knowledge with understanding

Domain B: Handling Information and Solving Problems

Domain C: Experimental Skills and Investigations

and they suggest that each of these domains provides opportunities to be placed in technological, social, economic and environmental contexts (Pritchard and Buckland, BIBS, 1986). The following is an illustration of an assessment of applied science teaching (from the SATIS project, U.K.) and it shows how these three domains are reflected in the assessment materials. (Figure 25, page 58)
Q.1

Typhus is a serious disease. The symptoms of typhus are severe fever, muscle pains and a rash. If it is not treated, typhus can be fatal.

Typhus is caused by a microorganism called a rickettsia. This microorganism is spread by human parasites such as lice and fleas, which pass the microorganism into the blood when they bite. These parasites are themselves carried by rats. Typhus can spread particularly quickly when people are living in very crowded conditions and in dirty surroundings. Typhus outbreaks were very common in concentration camps in the Second World War. During and after the War the insecticide DDT was used very effectively to prevent typhus outbreaks among refugees and soldiers.

(a) Explain why DDT is effective in controlling typhus.

(b) Name one other disease that can be controlled effectively using DDT.

(c) Suggest a reason why typhus spreads rapidly when people live in very crowded conditions.

(d) Suggest a reason why typhus spreads rapidly when people live in dirty surroundings.

In the 1960's, DDT was banned from use in many countries for environmental reasons. It was found that the insecticide was responsible for the death of many species of animals, particularly frogs and birds.

(e) Explain how DDT can get into the bodies of animals such as frogs and birds even if they have not been treated with the insecticide.

(f) Birds or prey are often particularly badly affected by DDT poisoning. Suggest a reason why.

Although DDT has been banned in many countries, there are still many other insecticides in use.

(g) Apart from controlling disease, what other major uses are there for insecticides?

(h) No insecticide can be completely safe. Even the safest insecticide is bound to cause some environmental problems. Do you think all insecticides should be banned from use? Explain your answer.
Q.2

This question is about a chemical called metaldehyde - META for short. META is a white solid. It contains, carbon, hydrogen and oxygen. Its formula is \( \text{C}_8\text{H}_{16}\text{O}_4 \).

META has two important uses:

1. For killing slugs. Some species of slugs are pests because they eat food crops. META can be used to poison these slugs.

2. As a solid fuel for camping stoves. META burns steadily with a clean flame.

(a) What substances will be formed when META burns in a plentiful supply of air?

(b) Write a balanced equation for the reaction in (a).

(c) Suppose you were supplied with a piece of META and a piece of fire-lighter, each weighing 5 grams. Describe simple experiments you could do to find out which gave out more heat when it burned.

(d) Give two pieces of further information you would want before you used META to poison slugs in your own garden.

(e) Suppose a chemical company discovers a new chemical for killing pests. Give three tests the company would need to carry out on the chemical before it could be used by the public.

Q.3

A dairy farm at Church Weston in Somerset is suffering from a cattle disease called 'staggers'. Scientists believe the disease is caused by a shortage of certain trace elements in the animals' diet.

To investigate the problem further, scientists analyzed the trace elements present in the livers of healthy and unhealthy animals. Their results are shown in this table. The figures show the concentration of each element in the livers, in parts per million (P.P.M.).

<table>
<thead>
<tr>
<th>Trace Elements</th>
<th>Iron</th>
<th>Nickel</th>
<th>Copper</th>
<th>Zinc</th>
<th>Chromium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy Animals</td>
<td>180.0</td>
<td>4.0</td>
<td>70.0</td>
<td>4.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Unhealthy Animals</td>
<td>212.5</td>
<td>3.4</td>
<td>18.0</td>
<td>5.4</td>
<td>1.1</td>
</tr>
</tbody>
</table>
(a) What is meant by a 'trace element'?

(b) Using the figures in the table, suggest which element is most likely to be responsible for the disease. Give a reason for your answer.

(c) What other tests would you do to try and confirm your answer to (b)?

(d) Explain why a shortage of a particular element in the soil can lead to a shortage of the same element in an animal's body.

(e) What steps could the farmer at Church Weston take to try and stop the disease?

(f) Iron is an important trace element. Name one important use of iron in mammals.

(g) What disease in humans results from a shortage of iron in the diet?
BIBLIOGRAPHY

The aim of this list is to direct the reader to references used in the text and also to sources that are rich in further references, so that bibliographies, resources and curriculum materials appropriate to the reader's own needs may be identified.


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